COCO-2: A Model to Assess the Economic Impact of an Accident

N A Higgins[1], C Jones[2], M Munday[2], H Balmforth[3], W Holmes[3], S Pfuderer[4], L Mountford[4], M Harvey[1] and T Charnock[1]

[1]HPA Centre for Radiation Chemical and Environmental Hazards, Chilton, Didcot OX11 0RQ
[2]Welsh Economic Research Unit, University of Cardiff CF10 3EU
[3]Health and Safety Laboratory, Buxton SK17 9JN
[4]Department of Food and Rural Affairs, Agricultural Economics Unit, London SW1 A2EY

ABSTRACT

COCO-2 is a model for assessing the potential economic costs likely to arise off-site following an accident at a nuclear reactor. COCO-2 builds on work presented in the model COCO-1 developed in 1991 by considering economic effects in more detail, and by including more sources of loss. Of particular note are: the consideration of the directly affected local economy, indirect losses that stem from the directly affected businesses, losses due to changes in tourism consumption, integration with the large body of work on recovery after an accident and a more systematic approach to health costs. The work, where possible, is based on official data sources for reasons of traceability, maintenance and ease of future development. This report describes the methodology and discusses the results of an example calculation. Guidance on how the base economic data can be updated in the future is also provided. A file of supporting data is available for download from the HPA website.

This report was partly funded by the Health and Safety Executive under contract NS/X/364.

Approval: October 2008
Publication: November 2008
£40.00
ISBN 978-0-85951-628-0

This work was undertaken under the Environmental Assessment Department's Quality Management System, which has been approved by Lloyd's Register Quality Assurance to the Quality Management Standards ISO 9001:2000 and TickIT Guide Issue 5, certificate number 956546.

Report version 1

CONTENTS

1 INTRODUCTION

An accident at a nuclear licensed site that results in the release of radioactivity beyond the site boundary will, in addition to any direct health and environmental consequences, produce direct and indirect effects on the economy of the surrounding area. In the unlikely event that the accident results in a major release of radioactive material to the environment, the economic consequences could be widespread and severe. To account fully for the consequences of an accident when considering the design or modification of plants, the economic consequences must be assessed and used to support the case for the inclusion of safety systems and design features intended to limit or mitigate the consequences. In 1991, the National Radiological Protection Board (NRPB), in collaboration with Forschungszentrum Karlsruhe (FZK)[*] for the application to German conditions, developed the model COCO-1 (Haywood et al, 1991) to assess the economic consequences of accidents.

The current work, in recognition of changes and developments that have occurred since 1991, is concerned with the replacement of COCO-1 with a more comprehensive model that includes additional features and a more detailed representation of economic interactions. COCO-2, by accounting more fully for the economic consequences of an accident, provides a robust and up to date planning aid. The work was jointly funded by the Health Protection Agency (HPA) and the Health and Safety Executive (HSE) and is a collaborative effort between the HPA, the Welsh Economy Research Unit (WERU), the Health and Safety Laboratory (HSL) and Department of Food and Rural Affairs, Agricultural Economics Unit, London (Defra). Assistance was also received from NERA Economic Consulting, the University of East Anglia and Newcastle University on value of life issues.

The COCO-2 model is composed of the methodology described in Sections 2-10 of this report with data to support the implementation of the model provided in an accompanying file[†]. The data sources are described in Section 11 and the results of an example calculation are discussed in Section 12 with further developments and conclusions in Sections 13 and 14. For convenience, a glossary of economic terms has also been provided. The majority of the data in the accompanying file are provided on a regular grid at 1 km resolution for England, Scotland and Wales in a form suitable for use with a geographic information system[‡]. The contents of the file and the production of data on a grid are described in Appendix B.

[*] Formerly Kernforschungzentrum Karlsruhe

[†] The compressed file in ZIP format is available for download, together with a copy of this report, from the HPA website.

[‡]Data are provided as ESRI map data and database files see http://www.esri.com for more information.

1.1 Background

It was recognised, when the COCO-1 model was published, that some potentially important consequences were either excluded entirely from the model or only included in a very simple manner. In particular, it was recognised that a substantial potential component of the cost consequences of an accident were losses that are, by their nature, difficult to value. It was not possible, at that time, to develop a model that fully incorporated such costs (for a brief review of existing models see OECD (2000)). However, since COCO-1 was released progress has been made, both in the availability of data for economic modelling and in the modelling of accident consequences. Developments in emergency planning and the sharing of insights during the exercising of emergency plans have further highlighted the potential importance of factors not included in COCO-1. It is for this reason that the revised model, COCO-2, has a more detailed description of loss mechanisms than was considered in COCO-1, including additional impacts related to the effect of the accident on tourism consumption and lost quality of life following any health effects arising from the accident. The change in approach introduced by COCO-2 results in a model with greater economic refinement than its predecessor, achieved in large measure by explicitly considering the role of companies and the economic consequences for them of an accident affecting their business. Care has been taken to base COCO-2 on data from official sources to facilitate the update of COCO-2 when new data become available.

1.2 Structure and content of COCO-2

The COCO-1 report briefly discussed the Regional Input-Output modelling system (RIMS) of Cartwright et al (1981) which provided a method of estimating the regional impact of changes to the economy (see Appendix A). This approach (the use of an Input-Output framework as originally developed by Leontief (1941)) was thought inappropriate for general accident applications at the time and was not used. However, the economic modelling of accidents and disasters has been developed in the intervening period, mostly in response to earthquake and hurricane damage; see for example the papers by: Cochrane (1974, 1995, 1999), Wilson (1982) Kawashima et al (1991), Boisvert (1992), Gordan and Richardson (1996), Cole (1997), Rose et al (1997), Rose and Benavides (1998), Okuyama et al (1999). Although these models have not been developed to consider the specific consequences of a nuclear accident, they have been introduced by the Federal Emergency Management Agency (FEMA) in the USA into their hazard assessment methodology and software, HAZUS. This methodology considers earthquakes, hurricanes and floods (Cochrane, 1999) within an Input-Output framework. Further developments by Okuyama and Lim (2002) are improving the dynamic responsiveness of such modelling and there are many related models that include, for example, the welfare effects of fiscal policy changes on transport including consideration of congestion, air pollution and accidents (Mayeres, 1998). COCO-2 employs similar Input-Output techniques to represent the effect of lost production in an affected region*. This includes estimates of the national loss to the manufacturing, services (including tourism) and agricultural production sectors and in addition, specific tourism losses at a regional level. The opportunity has also been taken to ensure that COCO-2 is able to use the more extensive information on countermeasures that has become available with the publication of the UK Recovery Handbook (HPA-RPD, 2005) and importantly to consider a 'willingness to pay / quality of life' based valuation of health effects.

The model is restricted to off-site consequences, in accordance with the general approach of the Nuclear Installations Inspectorate (NII) for determining whether existing or proposed safety features constitute what is ALARP. However, the model, while not costing damage to the accident site, does cost lost electricity output†. The model makes use of site-specific information within a generic framework, but where specific features not accounted for in this way have the potential to influence the costs of accidents significantly, guidance is given on how to modify the model to account for these.

The model estimates the national loss from the disruption of people's lives through evacuation and relocation, the disruption of business, restrictions placed on agriculture, the cost of radiation induced health effects, the cost of countermeasures put in place to reduce the consequences of the accident and, as stated above, the economic losses from reduced tourism to the region primarily affected. However, it is important to note that the calculated loss from regional tourism cannot be added to the estimated national loss and is included only as a guide to the potential regional impact of the accident on this economic sector. The regions considered are the government office regions of England, together with the nations of Wales and Scotland.

A nuclear accident will produce dislocations in the local, and potentially in the national, economy as the lives of people and the functioning of local businesses are disrupted. It may also cause a real or perceived deterioration of the local environment and incur additional health costs. For planning and safety case development the potential consequences of an accident are generally explored using an Accident Consequence Assessment code (ACA) and COCO-2 is intended to be used as one part of an ACA code or as an additional step following the modelling of an accident using an ACA code. Based on the predictions of the ACA code COCO-2 will then provide a method of estimating the cost of an accident in a simple but robust way.

2 SOURCES OF ECONOMIC LOSS

Following a nuclear accident with off-site consequences, radioactive material will affect the local environment and potentially contaminate areas further afield. The population

*Except for the treatment of tourism losses COCO-2 is not a regional model, ie, one in which the economic flows into and out of a region are modelled explicitly, as there are specific difficulties in the UK in creating such a model due to the lack of coherent regional data sets for the whole country.

† In addition, the loss of the site as a customer for contractors, suppliers and service providers is also considered.

near to the site of the release may need to be evacuated or other countermeasures applied and local business and community activities may be disrupted. The model proposed to represent these effects has several components illustrated schematically in Figure 1.

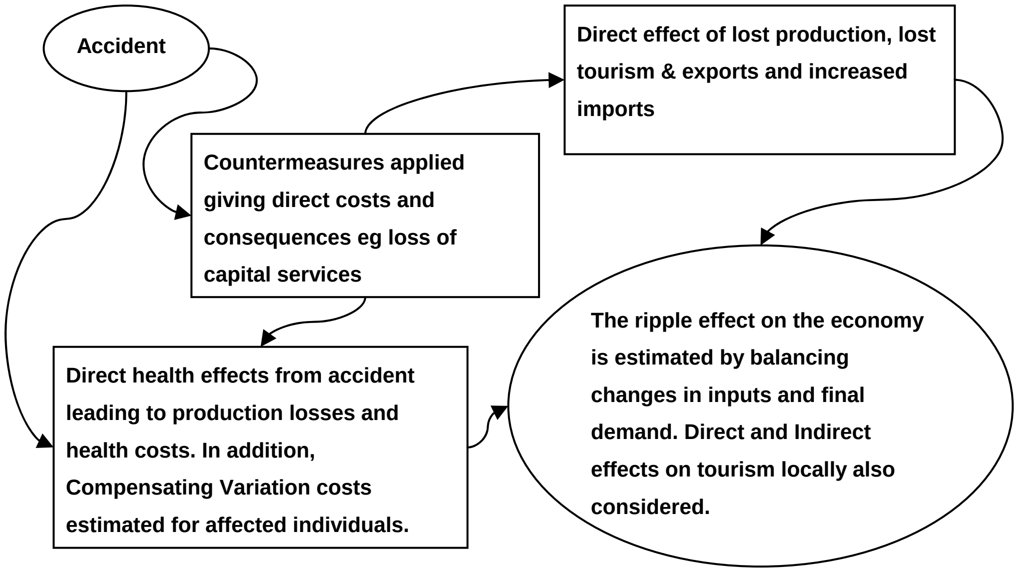

Figure 1 Schematic representation of how the direct effects of an accident give rise to a range of economic effects.

The costs contributing to the various terms are discussed in more detail in the sections below. However, before embarking on a discussion of the particular terms, it should be noted that several features of the approach of COCO-2 differ from the COCO-1 formulation. One of the main departures is the introduction of a mechanism for handling the 'ripple through' effect of final demand or production changes on the economy. This mechanism accounts for the loss of demand from directly affected businesses on the rest of the economy, an affect that varies with respect to the different types of economic activity undertaken and the size of businesses affected. The COCO-1 model previously assigned the economic activity of an area to the population of the area and did not distinguish between different types of economic activity. COCO-2, by having improved spatial discrimination, recognises that population and industry are not necessarily co-located and that people living in the affected area may not all work in local industries. To do this and, consequently, allow ripple or indirect effects to be estimated, COCO-2 requires information on the spatial distribution of Gross Value Added (GVA) to be supplied to represent the benefit of local businesses to the economy[*]. COCO-2 therefore demands much more information than COCO-1, and information that varies spatially. However, this only makes economic modelling consistent with the other modelling approaches used, for example, in accident consequence assessment (ACA) which conventionally uses information on the spatial distribution of people and food production.

[*]GVA is a measure of the contribution to GDP made by an individual producer, industry or sector. The gross value added generated by any unit engaged in production activity can be calculated as the residual of the units' total output less intermediate consumption. GVA is the compensation of employees, gross operating surplus, and taxes less subsidies on production.

Another departure from the approach applied in the COCO-1 model is the explicit recognition of the potential importance of tourism consumption and any losses from this sector to the local economy (see Section 5).

As indicated above the costs incurred following an accident can be thought of as a mix of direct and indirect effects that come into play over various time scales. Consider a sequence of events in a hypothetical accident, which contaminates the environment, and potentially affects people, animals, crops and buildings*. Initially, short-term countermeasures are introduced to mitigate the effect of any release on those potentially affected. Following the end of the release and the plant being made safe the short-term countermeasures will be lifted and longer-term actions initiated, if required. If there was no requirement for longer-term countermeasures, it is likely that the costs to the economy would be constrained. The costs would consist of the costs of the countermeasures and their impacts on the local economy together with any health costs incurred. There may also be less predicable effects due to a loss of tourist income. However, it is likely that the local people and economy of the area would quickly return to near normal. Alternatively, the introduction of longer-term countermeasures would indicate and introduce a much greater level of disruption with potentially significant dislocation of the local economy. In this case, industries might be affected for long periods and people may be forced to commute over long distances and / or change their jobs.

Table 1 introduces a broad scheme for classifying accident losses, which illustrates the many categories that must be considered if an assessment of the full cost of an accident is to be attempted.

TABLE 1 CLASSIFICATION OF ACCIDENT LOSSES

Type of loss	Direct	Indirect
Tangible (market values)	Costs that are closely related to the accident and can be valued via the market, eg, damage or contamination of infrastructure, buildings and contents, vehicles, boats, human capital cost of illness, lost production, emergency response and relief, clean-up costs.	Costs that are not closely related to the accident but can be valued via the market, eg, loss of production due to ripple effect, and any decline in tourism in the wider area.
Intangible (non-market values)	Costs that are closely related to the accident and are not valued in the market, eg, death and injury (excluding human capital), loss of items of cultural significance and personal memorabilia.	Costs that are not closely related to the accident and are not valued in the market, eg, inconvenience and disruption, especially to schooling and social life. Stress induced ill health and mortality. Perception of area (affects tourism).

Adapted from Smith et al (1995, p 21).

The economic effects of the accident, excluding those related to the site itself, are broken down into the two major categories of direct and indirect. The direct consequences of the accident on business, as demonstrated in Appendix A, are likely to

* Countermeasures may be taken before a release occurs, which while having the important benefit of reducing health consequences may also increase the losses of business, which are closed for longer.

be greater than the indirect in most circumstances[*]. One feature that should be noted is that indirect costs can arise as a necessary consequence of a direct effect (the economic linkage of customer and suppliers) or because of perceived risks. The latter loss, even allowing for a risk-averse response, should be captured by the costs of countermeasures put in place to mitigate the risk from radiation and allow normal living to be resumed[†].

The intangible and indirect costs are likely to be the most difficult to assess and in some circumstances the most significant. However, although the direct and tangible losses following an accident will be comparatively easy to categorise in comparison, the estimated costs incurred will depend on the recovery measures put in place.

Not all losses fit conveniently into the scheme, eg, tourism losses may be largely indirect and tangible but predominately determined by the indirect and intangible loss of perceived value in the directly affected and neighbouring areas after the accident. The most visible consequence of a strongly risk-averse response in the general population will be on elective activities that can equally well take place elsewhere. Thus, tourism to the general area could be affected to a degree that is difficult to estimate if the area is perceived as dangerous or at least unwholesome. This is discussed more fully in Section 5.

COCO-1 almost exclusively focused on accounting for the direct and tangible costs identified in Table 1 while COCO-2 considers, in addition to those costs, the tangible indirect costs of the accident and the direct but intangible health related costs. It does not attempt however, to value other intangible losses and in particular the indirect losses stemming from inconvenience and the adverse perception of the area[‡]. As discussed further in Section 13.3, this would require a social psychological survey of an analogous event to infer the likely level of heightened stress in the affected population and any changes in their behaviour, as well as an economic survey to determine an appropriate level of Compensating Variation while still leaving the perception of potential visitors unknown.

The following sections discuss the modelling of the losses illustrated in Table 1 beginning with direct tangible and intangible losses in Section 3, and then considering tangible and intangible indirect losses in Section 4. The loss mechanisms of Sections 3 and 4 apply to the business, agriculture and tourism sectors, and in Sections 8 and 9 they are formulated into expressions for the calculation of losses in these sectors.

[*] There may be effects on confidence in the economy or perceptions of the wholesomeness of the environment, which could amplify the indirect effects of an accident. These would be difficult to predict and account for and are likely to be only partly related to the size of the event and more strongly tied to how well the aftermath is managed. These effects are therefore not included in COCO-2. This is discussed further with respect to tourism losses in Section 5.

[†] However, if the perceived risks greatly exceed the quantifiable risks to health, the economic effect cannot be readily assessed. The perceived risk may manifest itself in increases in stress and depression, which could further compound health effects as found in studies of those affected by Chernobyl but valuing this sort of consequence is beyond the scope of COCO-2.

[‡] For example, COCO-2 does not consider the environmental economics measures of the existence or bequest value of a good.

However, the approach for estimating direct and indirect tourism losses is further elaborated in Section 5, with agriculture discussed in Section 6. The approach to costing both the net productive loss and Willingness To Pay (WTP) aspects of health effects is discussed in Section 7 and formulated into loss expressions in Section 10.

3 DIRECT LOSSES

The direct losses arising from an accident are related to the effects on people and businesses directly affected by the released radiation or the countermeasures applied to mitigate the effects on the population. Table 2 lists direct economic effects that might be expected after an accident and whether and how they are considered by COCO-2.

The types of cost listed in Table 2 are thought to cover most major categories that are likely to have a long-term impact but the examples are not necessarily exhaustive. In addition to health costs, Table 2 lists three broad categories of direct cost. Firstly, that arising from the business or industry being closed or the sales of its products restricted for a particular length of time. Secondly, the cost of restricting access to particular areas by moving people to protect them in the short or longer term, and thirdly, the cost of countermeasures introduced to minimise the disruption to peoples' lives and economic activity in the affected area.

The estimated direct business disruption cost modelled by COCO-2 is based on the simple assumption that the application of countermeasures such as sheltering, evacuation and relocation will temporarily stop production at the affected factories. If the annual GVA of the business is known, the amount lost during the period of closure or disruption can then be easily estimated. It is assumed that value is generated uniformly throughout the year, which is a reasonable assumption in most cases although if information were available on seasonal effects for particular industries and areas this could be used in the estimation of losses[*]. The analysis uses current official data manipulated by WERU into an appropriate form, which means that COCO-2 estimates can be updated as new releases of the datasets become available. Section 11 gives details of the manipulations and data sources used to derive the GVA data used by COCO-2.

[*] Seasonality for activities other than agriculture and tourism may not have a significant effect on GVA as firms can accelerate production after a close down period to make up lost ground, particularly where they have slack capacity (which they may have to support a seasonal response).

Table 2 Direct losses[1]

Source	Effect[2]	COCO-2	Category
Emergency service costs	Police, Fire and Ambulance services Local government and voluntary services Military aid	Emergency service costs should be costed as countermeasures or included with the costing of other countermeasures although they are not specifically considered by COCO-2[3].	Emergency Countermeasures
Evacuation and short term relocation of population	Loss of asset services	COCO-2 estimates transportation costs and the lost value of housing services	Emergency Countermeasures
Individual and population exposure to radiation	Short and long-term health effects	COCO-2 provides a mechanism for costing the morbidity and mortality that arise from the accident as a combination of the direct net productive loss, individual WTP and the cost of treatment.	Health
Contamination of farm land, crops, animals and their products	Restrictions on the sale of food and livestock	COCO-2 provides estimates of output and GVA losses from lost sales.	Production and / or sales restricted
	Access restrictions to affected areas for workers and inhabitants	COCO-2 does not consider the direct but intangible loss from restricted access to unproductive land.	Access restricted
	Access restrictions to affected areas for visitors or those passing through	Local tourism losses account for visitor losses however, the costs of transit restrictions are not considered by COCO-2.	Access restricted
	Countermeasures applied to land and livestock	Appropriate countermeasures costs for use in COCO-2 are provided by HPA-RPD (2005). Additional costs for the disposal of agricultural wastes are provided in Appendix C.	Recovery countermeasures
External contamination of dwellings	Decontamination costs of gardens and exteriors	Appropriate countermeasures costs for use in COCO-2 are provided by HPA-RPD (2005).	Recovery countermeasures
	Disposal costs of waste water, vegetation, etc	Appropriate countermeasures costs for use in COCO-2 are provided by HPA-RPD (2005).	Recovery countermeasures
	Access restrictions	COCO-2 does not consider the direct but intangible loss from restricted access but the lost use of assets is considered as part of the costs of evacuation and relocation.	Access restricted
Internal contamination of dwellings	Costs of decontaminating houses	Appropriate countermeasures costs for use in COCO-2 are provided by HPA-RPD (2005).	Recovery countermeasures
	Value of goods lost and disposal costs	Appropriate disposal costs for use in COCO-2 are provided by HPA-RPD (2005). COCO-2 provides a minimum cost estimate for the temporary and permanent loss of domestic goods. However, this does not include any consideration for the intangible value of particular items of sentimental value.	Recovery countermeasures
Relocation of Population	Permanent relocation costs	COCO-2 estimates the capital loss of dwellings and if appropriate other capital assets.	Capital loss
External contamination of commercial / industrial units	Decontamination costs	Appropriate countermeasures costs for use in COCO-2 are provided by HPA-RPD (2005).	Recovery countermeasures
	Business disruption cost	This is represented by COCO-2 as the loss incurred while businesses are temporarily closed.	Production and / or sales restricted
Internal contamination of commercial / industrial units	Cost of decontaminating premises	Appropriate countermeasures costs for use in COCO-2 are provided by HPA-RPD (2005).	Recovery countermeasures
	Cost of contaminated stock	This is not considered by COCO-2.	
	Business disruption cost	COCO-2 accounts for this loss by assuming that businesses are closed while decontamination is being carried out.	Production and / or sales restricted
Relocation of Businesses	Permanent relocation costs	COCO-2 estimates the capital loss of the building and if appropriate the capital assets.	Capital loss

[1]These are exclusively direct tangible losses with the exception of the WTP health cost see Section 13.3.

[2]The full cost incurred in carrying out countermeasures should be used because, in general, the work of applying the countermeasure is of no economic benefit. However, where some benefit occurs, eg, some agricultural countermeasures increase soil fertility or provide an alternative crop the overall loss should be considered, ie, the cost of the countermeasure and the difference between the expected GVA without an accident and the GVA realised after the countermeasure has been applied. COCO-2 only supplies information for the crops discussed in Appendix C and listed, as part of the information supplied on the CD, in Appendix B. For economic information on other crops, eg, non-food crops, the reference sources of Section 11 and Appendix C should be consulted in the first instance.

[3]It could be argued that, as an emergency service, there is no marginal cost associated with using fire brigade staff.

Within the category of restrictions placed on production and sales it is assumed that a simple interruption to production is appropriate for manufacturing and service industries where, unlike agriculture, no product specific restrictions apply and economic output is generated from a confined area so that it is reasonable for the whole enterprise to be affected. Tourism related businesses, eg, hotels, fit within this category and any losses they experience will automatically form part of the national loss estimate. However, in addition to national estimates COCO-2 provides a regional estimate of losses in tourism related industries. The modelling of the regional tourism loss is considered in Section 5. Agricultural losses are product specific and may not involve the whole enterprise. The calculation of the direct loss is therefore considered separately in Section 6. Following the calculation of the direct loss for any sector of the economy the indirect loss due to disruption is estimated using the common approach of applying an appropriate input output multiplier.

3.1 Countermeasure Costs

The COCO-2 methodology does not provide detailed costings for the full range of countermeasures possible. Guidance on estimating the full panoply of direct costs arising from the application of a particular combination of post-emergency phase countermeasures is given in the UK Recovery Handbook (HPA-RPD, 2005). The choice of countermeasure or combination of countermeasures to be applied in particular circumstances depends on many factors such as the time since the deposition, the practicality and effectiveness of the countermeasure and what other countermeasures have been or are to be applied, as well as the cost. These considerations, which have been discussed in detail in the UK Recovery Handbook, are outside the scope of COCO-2.

The cost estimates given in the UK Recovery Handbook were developed to help in the selection of recovery options and not as component terms in an economic model. However, the estimated total cost information provided is appropriate for use in COCO-2 and has the advantage of coming from an extensive and consistent data set that is part of a maintained manual. Thus, when implementing the COCO-2 model within an ACA code it is anticipated that generic countermeasures with costs consistent with those of the UK Recovery Handbook would be appropriate. The derivation of appropriate generic costs is a modelling issue beyond the scope of COCO-2.

The information currently available from the UK Recovery Handbook provides guidance on calculating some of the direct costs of countermeasures. Thus, data are available which will allow the costs of carrying out a particular decontamination procedure to be estimated. The UK Recovery Handbook provides many alternative methods of decontaminating or returning to use buildings, land and animals (information is also available on decontaminating valuable artefacts). Decision trees are provided that allow the many factors (such as the effectiveness of particular techniques at removing contamination or reducing doses in comparison to costs, public perception and wastes arising) to be considered. Although the economic consequences of selecting particular options will be of interest to decision makers deciding what techniques to apply, it is not appropriate for COCO-2 to attempt this sort of formulation. COCO-2 is not intended for use by decision-makers after an accident but as part of the safety case submission by those proposing changes to existing facilities or the creation of new facilities.

COCO-2 is a prospective model designed to work with probabilistic (or deterministic) accident models. These models can only supply a broad indication of the levels of contamination that might arise following a particular accident and it would therefore be inappropriate to attempt detailed predictions. In addition, application of COCO-2 within an ACA environment requires the use of a simple countermeasure scheme (consistent with the UK Recovery Handbook or more complex modelling) that allows decisions on the choice of countermeasure to be more or less automatically determined by the consequences of the release, and the particulars of the affected environment.

The UK Recovery Handbook, as a generic reference, considers the component surfaces of an environment and provides cost estimates for decontamination per unit area. To combine these estimates with the other cost terms considered by COCO-2 requires the extent of treated surfaces to be estimated or assumed, eg, in the form of representative environments (see Appendix B and Appendix E).

4 INDIRECT LOSSES

Indirect losses are more difficult to value than direct losses but estimates are provided for those that are a tangible consequence of the disruption to businesses directly affected. However, the tangible effects on people indirectly affected are not considered by COCO-2. Such effects would include disruptions to travel and local services such as schooling. The even more difficult to value intangible indirect effects such as a perceived loss of value due to the despoiling of the environment are also not considered. However, although difficult to value such losses may be significant and their existence should be borne in mind when the results of a COCO-2 analysis are considered. This is discussed further in Section 13. Table 3 provides a summary of the indirect losses considered by COCO-2, ie, those generally associated with the disruption to the supply and sale of goods caused by the effects of the accident rippling through the economy.

TABLE 3 CLASSIFICATION OF INDIRECT TANGIBLE LOSSES[1]

Loss category	Examples	Comment
Disruption of business	Manufacturing, Agriculture	This is modelled by COCO-2 though the use of an Input-Output multiplier.
	Retail, distribution, office	
	Leisure services	
Disruption of public services	Libraries, schools and hospitals	Many public services, eg, libraries and schools, are only weakly coupled to the productive economy and therefore the loss of service if these facilities are closed is not specifically considered.
Disruption of networks	Communication links, eg, road and rail transport, telephone, computer control systems, and power distribution	This feature, which is important following physical damage in an earthquake or flood, is not specifically considered in COCO-2. However, this sector will be as affected as any other will be by reduced demand from directly affected businesses, which is included in COCO-2. Any significant effects arising from unaffected parties having communication difficulties is thought unlikely although there may be increased travel costs and delays for people and businesses in surrounding areas (see Section 8.3.2). Further work is required to assess the consequences of disrupting critical road and rail links, see Section 13.
Disruption of households	Reassurance monitoring	Any monitoring required in areas thought unaffected by the accident should be treated as a direct countermeasure cost.
Loss of Tourism	Diversion of tourists destined for the region to other regions and countries	The indirect economic loss stemming from the direct regional loss is accounted using a multiplier, although this cannot be used in an estimate of national losses; see Section 5.
	Diversion of tourists outside the region to other regions and countries	As indicated in Table 1 although a tangible effect it is likely to have an intangible origin and is not considered by COCO-2.

[1]*Adapted from* Thompson & Handmer (1996, p 58).

Indirect losses affect businesses because of the direct effect of the accident on their customers and suppliers. For example, the building trade locally may be depressed as people and companies choose to delay decisions to build or renovate. Similarly, there may be no alternative outlet other than the directly affected companies for goods produced encompassing anything from specialist components to sandwiches*. A specific model has been developed to consider regional tourism losses, which is discussed in Section 5. However, the approach employed is similar to the Direct and Indirect loss modelling for the general economy discussed below. The main feature not accounted for is the trade effect of having an affected business. In particular, there may be image sensitive products that fare badly if even indirectly associated with radioactive contamination.

The indirect loss stemming from a direct effect to particular sectors of the economy in a particular location can be estimated using an Input-Output model. This is a static economic model designed to depict the mutual interdependence among the different parts of an economy. Input-Output modelling has been widely used and referenced in

*The increase in 'just-in-time' manufacturing may make certain industries particularly vulnerable to an interruption to their supply chain. This may have a serious effect on the purchasing industry if alternative supplies are not easily available and it may hinder the recovery of affected companies as their customers form new supplier relationships. However, in general, alternative supplies will be available and COCO-2 need only consider downstream multipliers. This is discussed further in Section 6.

the economic literature since its introduction by Leontief (1941). The model describes the economy as a system of interdependent activities that act on one another directly and indirectly. Thus, an Input-Output model describes how one industry uses the outputs of other industries as inputs, and how its own outputs are in turn used by other companies as inputs. An Input-Output model is a systematic deconstruction of the economy that describes the flow of goods and services necessary to produce finished products (goods and services).

An Input-Output model can be used to derive internally consistent multi-sector projections of economic trends and detailed quantitative assessments of both the direct and indirect (secondary, etc) effects. Input-Output models are widely used to assess the total (direct plus higher-order) economic gains and losses caused by sudden changes in demand for a region's products. Input-Output modelling traces the flow of goods and services among industries and from industries to households, government, investment and exports. These trade flows indicate how much of each industry's output is comprised of regional suppliers' products, as well as inputs of labour, capital, imported goods and the services of government. The resultant matrix can be manipulated in several ways to reveal the economy's interconnectedness, not only through direct links but through transactions at several removes. The net result, from the perspective of COCO-2, is a set of multipliers that can be applied to the GVA of directly affected industries to determine the indirect economic consequences.

The technique is open to several criticisms: Input-Output models tend to be static one-period models, which are essentially descriptive, and therefore are not very effective for inferring probable policy effects in the future; the models are insensitive to price changes, technological improvements (changing production coefficients), and the potential for input substitution at any given point in time*. The latter feature means, more simply, that alternative suppliers are generally easy to find whereas customers are more difficult. COCO-2 assumes that a loss results from a lack of customers (see Section 6.1). However, even with these limitations, Input-Output techniques are a valuable guide to the measurement of indirect losses and are widely used to represent the effect of sudden changes to an economy, for example, when modelling the effects of a tax or legislative change on an economy.

COCO-2, by using an input-output model, will tend to maximise the impact on business of a sudden loss of demand. A more advanced Computable General Equilibrium Model would be, for example, able to take account of the buffering effects of producing for stock. However, such models are computationally expensive and very data hungry, requiring information such as stock levels and the ability of industries to substitute between alternative stocks. At the current time, such a model is both impractical and inappropriate for COCO-2, as even if the data were available the gains are unlikely to outweigh the increased complexity and difficulty of use.

For COCO-2 WERU has used the UK regional economic accounts for 2003 (amended using data on UK productivity gains to estimate approximate 2004 value added) to

* There is a logical necessity for changes in demand to affect the supply of goods and services but the converse does not follow.

derive regionally adjusted GVA information. This information can then be combined with the latest production coefficients produced by the Office of National Statistics (ONS, 2002), which describe the Input-Output relationship of economic activities in the UK economy to establish a set of simple Type 1 multipliers for COCO-2[*]. These allow the indirect effects caused by a loss of demand from the directly affected businesses to be calculated. WERU has also extended the methodology by introducing an attenuation function that accounts for the reduction in the indirect effect as the area directly affected increases. This latter effect follows from the fact that local trading relationships between businesses cease to be relevant when the interacting firms have both been directly affected[†]. The size of the affected area therefore determines the strength of the multipliers for particular industries. The multiplier determining the size of the indirect effects is therefore attenuated progressively until ultimately (hypothetically) it would reduce to zero if an incident affected the whole of the UK and everything was directly affected.

The scheme developed for COCO-2 takes account of the lost output and demand from directly affected industries. However, it does not include the effect of a loss of supply to industries elsewhere in the economy. Generally, the disruption caused to industries purchasing goods will be less as they can easily source their purchases from elsewhere but in some cases, this may be difficult[‡]. COCO-2 will require further development if it is thought likely that this capability will be a general requirement.

The disruption of public services, networks and households identified as indirect sources of loss in Table 3 have a more limited ability to affect the cost of an accident. For example, disruption of households does not include the direct effects of evacuation or relocation. It is more focussed on the inconvenience of shops that are not open or contractor’s vehicles taking part in decontamination work elsewhere adding to congestion and making travel more difficult. Similarly, the disruption of networks is a potentially serious consequence of many types of accident, eg, fires, floods and explosions. However, there will be essentially no tangible physical damage caused by radioactive contamination following a reactor accident and many network operations will therefore be able to continue unaffected particularly if they are automatic (see Section 13.2).

[*] If only the productive industries are assumed endogenous then the model is referred to as ‘Type I’. However, if local households are assumed to be an endogenous component of the economy that sells labour and buys locally produced goods and services then the formulation can be extended to include the household sector and the model is then of Type II. See Appendix A for more details.

[†] The situation becomes more complex when businesses are able to resume trading at different times.

[‡] For example, the loss of electrical capacity following a reactor accident will be made up by production from elsewhere distributed through the national grid. The replacement of supply may be more difficult after an accident at a specialist chemical facility.

5 TOURISM

One of the new features of the COCO-2 model is that an explicit, if simple, estimate is now made of the economic consequences of a reduction in tourism after an accident. It was observed after the Foot and Mouth Disease (FMD) epidemic hit the UK in 2001, that the loss of tourist income from overseas and the diversion of the internal tourist market to destinations in other countries, or at least to unaffected regions in the UK, were more damaging than the direct agricultural losses suffered (Blake et al, 2001).

Direct tangible losses from tourism and day visitors, ie, those that are a direct result of restrictions placed on people and locations can be easily assessed[*]. Only a limited number of hotels, guesthouses and tourist attractions from beaches to theatres will be directly affected by any countermeasures imposed following an accident. The attractions may be assessed for contamination or actually require decontamination treatments to be applied or the land nearby may be restricted due to levels of contamination, etc, but these effects are likely to be very localised or represent the consequences of a very extreme event. This direct effect will have ripple effects through the regional economy, which can also be assessed and a multiplier for the indirect contribution derived. In addition to this direct tangible effect on the regional economy, individuals may suffer a loss from forgone tourism, which could be accounted for by a level of CV[†]. However, tourism more than most other activities can be deferred or transferred to another location and the ease of doing this is likely to minimise the size of any CV that might be considered. This aspect is therefore not considered further in COCO-2.

The consequential economic costs from the directly tangible effects are likely to be small. However, the indirect tangible effects, which are difficult to predict, have the potential to be large. Tourism is an elective activity, and depends on the confidence of the public. The intense media interest that would follow a nuclear accident or to a lesser extent any other major industrial calamity would mean that the affected area would become negatively associated in the public mind with the accident. It is also likely that the further away the news audience is the more generic the association will become. This is consistent with the observed reduction in overseas tourists to London in the aftermath of the FMD outbreak. It is also likely that the larger the accident the larger the amplifying effect of publicity would be on the tourism industry.

Unfortunately, it is difficult, if not impossible, to predict how an accident will be reported nationally and internationally. If the authorities are portrayed as effective and efficient, the consequences seem contained and there are other competing news events in the world, the international media will quickly move on to a new story and the impact on

[*]Following internationally agreed guidelines, ‘tourism’ includes that element of day visits that are outside the ‘usual environment’; see OECD et al (2001) for more detail.

[†]Individuals will suffer a loss if they cannot take their planned holiday however this may be quite small if they are easily able to choose an acceptable alternative. A measure of the loss incurred is given by the Compensating Variation, the monetary equivalent of the difference in value between their original intentions and the alternative taken. A representative value could be obtained directly by survey before an accident or potentially by using revealed preference methods.

inward tourism might be minimal. There would remain a large local tourism impact leading to a regional loss, not all of which would be displaced to other UK locations. However, if there was a news angle suggesting incompetence or cover up, the consequences were on a large scale or there was little alternative news of the same import, then the effects could be potentially very large. Tourism is a major component of both regional economies and the national economy and the ripple effect of a major decline in tourist income could be very significant.

The economic consequences that would follow from a large reduction in tourism could be assessed if an estimate could be made of the likely reduction and redistribution in tourist numbers regionally and nationally. Work has been reported in the literature on estimating the tourist income expected if the crisis had not occurred so that a more reliable estimate can be made of the tourist income subsequently lost. However, there are no known predictions of the change in demand likely from a particular crisis. This is essentially a question concerning the behaviour of groups of people where the economics of the decision is unlikely to be an important consideration. An estimate of the effect is therefore beyond the scope of COCO-2[*].

COCO-2 has restricted its attention to estimating the tangible direct and consequent indirect effects on the local economy[†]. As tourist activity is likely to be displaced to other locations within the UK, the net loss to the UK economy cannot be assessed. The loss given should therefore not be added to the national loss figure derived in the main part of the model, which in any event includes some accounting for the loss of tourist related activities. The estimates are therefore primarily of interest to policymakers at the local and regional level where disruption to tourism activity may have significant economic consequences. In judging these estimates, it should be remembered that the limited scope of their derivation means that they are underestimates, but that it is not possible to quantify the scale of the underestimate at the current time.

5.1 Business dependence

The relative dependence of local industries such as restaurants and bars, on the spending of visitors and residents will vary spatially to a degree that cannot be accommodated by the model given the limitations of the available data. Thus, for example, in a small area with a relatively large number of pubs and takeaways serving locals, there could be an over estimate of the Tourism Gross Value Added (TGVA) generated in the area. However, given the relative concentration of all TGVA generating activities, this is not considered a significant problem (see Section 11.1).

In addition to the variation in spending between locals and visitors there may also be a systematic spatial variation in the levels of productivity between areas. The method

[*] A joint Defra/DCMS project estimated the net cost of FMD to have amounted to 0.2% of GDP. The loss was mitigated by a transfer of tourism spending from rural to urban areas or to other purchases. http://archive.cabinetoffice.gov.uk/fmd/fmd_report/documents/D-GovtPublications/Government%20Publications.html.

[†] The multiplier effects of a loss of demand from directly affected businesses.

employed could therefore tend to under estimate the TGVA in such areas. This is neglected by COCO-2, which allocates tourism value added according to Full Time Equivalent (FTE) employment in an analogous way to GVA estimates for the general economy (see Section 11).

6 AGRICULTURE

The assessment of losses to the agricultural sector is an important part of the COCO-2 model. Although the contribution of agriculture to the national economy is small, it is an important economic sector in particular regions of the UK, especially more remote rural areas. Nuclear power stations are often located in these remote rural locations, where agriculture and tourism are the main economic activities. In the recent past, losses related to the outbreak of BSE and the FMD epidemic have illustrated the importance of assessing the economic consequences of accidents on the agricultural sector and placing the results in a wider context. It was found, for example, that for the FMD epidemic tourism losses were the dominant loss locally although nationally the two losses were of broadly similar magnitude.*

Actions taken to minimise the doses to people from food or to restore or change the type of agricultural production in an area following an accident may have major economic effects beyond the immediately affected farms or activities directly related to agriculture. For example, agriculture in radiologically unaffected areas nearby may be adversely affected if downstream customers stop buying products grown near the restricted areas. In addition, within the directly affected area, revised farming practices might alter the landscape in the longer term, which could have consequences for the attractiveness of an area to tourists and locals that are difficult to predict.

One problem that makes estimating the economic effects of agricultural losses particularly complex is the impact of the Common Agricultural Policy (CAP) on agricultural markets. The recent reform of the CAP introduced the Single Payment Scheme (SPS) under which payments are no longer tied to production. This removed some of the market distortions although the change is not yet universal with production support continuing in the UK for some minor arable crops, beef cattle in Scotland and for other agricultural commodities in other parts of the EU†.

The values used in the model discussed below exclude direct subsidies paid to farmers. Subsidies are transfer payments and should not be included in the calculation of costs to the economy as a whole. However, some market interventions of the Common Agricultural Policy, such as quotas for sugar and milk, the operation of intervention systems or set-aside, will have an impact on domestic markets.

* A joint Defra/DCMS project reported the cost of FMD to have amounted to 0.2% of GDP. http://archive.cabinetoffice.gov.uk/fmd/fmd_report/documents/D-GovtPublications/Government%20Publications.html

† Direct payments, at least in England, are limited to the energy crops, protein crops and nuts.

The fact that there are government interventions that distort the market is not only true for agriculture but also for other sectors such as energy and transport and tariffs exist for many non-agricultural products. The approach generally, and the one adopted for COCO-2, is to use market prices despite these government interventions and their impact on the market.

6.1 Direct losses

A direct agricultural loss is likely to occur when, following an accident, restrictions are placed on the sale of agricultural products that exceed EU limits on the permitted radionuclide concentration in food sold for human or animal consumption (see Section 9). In distinction to other products or services where GVA is lost, for example, due to the temporary closure of a factory, it is the agricultural crops that are primarily affected and not the production process. Crops intercept radioactive material being transported in the atmosphere or take up some part of the material deposited on the ground through their roots*. Similarly, animals ingest material directly deposited on grass or taken up through the roots of grass and fodder crops. Some of that ingested activity will in turn be transferred to the meat and milk of the animals. Accident consequence models are available to estimate the amount of production that will exceed the EU limits, whether that occurs immediately, through direct deposition as a contaminant cloud passes over the crop, or later (eg, harvest) as radionuclides are taken up from the soil by plants and animals (Brown and Simmonds, 1995).

In practice, the modelling of the deposition and transfer processes involved is likely to require various assumptions and approximations to be made. However, for the purposes of COCO-2 it can be assumed that an estimate can be obtained of the amount of food that will exceed EU criteria as a function of time. Generally, the model estimates likely to be available will use generic food categories, and for this reason, the cost estimates provided by COCO-2 are based on the food categories listed in Table 4. These generic food categories are assembled from the detailed agricultural survey carried out by Defra in June each year. The costs associated with these categories, together with a discussion of their derivation and the source data used, are given in Appendix C. If required the COCO-2 agricultural methodology of Section 9 could be adapted to apply to a different combination of food categories using costs derived from the source data of Appendix C.

*The same ideas could be applied to chemicals but the modelling of transfers is not as well developed.

Table 4 Generic food categories considered in COCO-2

Food Category[1]	Comment[2]
Milk	The farm gate price for raw milk used by COCO-2 does not generally depend on the end use. A loss at the processing stage, eg, in the production of cheese, yoghurt, etc, would only occur if adequate alternative supplies were not available and is not considered by COCO-2[3].
Beef meat Sheep meat	In some circumstances, liver may be restricted when the meat is not restricted. However, liver is a small component of a carcass in terms of both the mass and value of the product. Given the experience of abattoirs in removing specified material, as a precaution against the spread of variant CJD, the exclusion of liver should not cause significant difficulties. Thus, COCO-2 does not consider losses arising from restrictions on the sale of liver[4].
Cereals	Although there are separate prices for feed and milling wheat, malting barley and feed barley, etc, figures from the aggregate agricultural accounts are used to give a representative value. Regional price variations induced by changes in the mix or quality of production are dominated by price variations year on year. Thus, for practical and data availability reasons, a single annual value averaged over several years and representing all regions is therefore used[5].
Potatoes	
Sugar beet	Not likely to be a major dose pathway and therefore not generally considered from a radiation protection perspective but an economically important crop in particular regions and covering a greater area than the UK potatoes crop[6].
Leafy green vegetables[7]	An aggregate category is used, as it is not generally appropriate to attempt to estimate the amount of radioactivity in each particular type of green vegetable. This is consistent with the economic information available for different vegetables. However, the methods applied to individual crops can be used if data are available and it is thought appropriate.
Legumes	Only legumes for human consumption are considered.
Root vegetables	This includes bulbs such as onions and plays a role similar to the leafy green vegetable category, but excludes potatoes, which are costed separately.
Fruit	Soft and hard fruits are treated separately.

[1]Fresh water fish farms and hatcheries are not explicitly considered under agriculture because the small spatial extent of a facility and consequences of any transferred water borne contamination is adequately represented by the approach followed to estimate the losses from conventional industry, ie, that the whole facility is closed for a period.

[2]The assumption made in COCO-2 is that national economic losses occur during the first 2 years (or less) of restrictions. Restrictions that are likely to extend beyond 2 years will not result in any additional loss to the general economy as it is assumed that sufficient time has elapsed for any affected production to be sourced from elsewhere following an appropriate adjustment of the general economy, see Section 6.2.

[3]Thus, the loss of specialist products from farm scale businesses where substitution is inappropriate will not be accounted for.

[4]The economic loss neglected will be less than the likely variation in animal prices.

[5]It is not always clear beforehand whether grain will go for food or feed purposes, with the choice being highly weather dependent. COCO-2 does not consider the consequences of grain originally destined for food, instead being used as feed. Work by the AFCWG suggests that buying contaminated feed when clean feed is available would not be acceptable (HPA-RPD, 2005 (agricultural appendix 2B)). Any PRA model implementing COCO-2 is expected to estimate of the amount of cereals subject to sale restrictions.

[6]Sugar beet is used as animal feed as well as for the production of sugar.

[7]A few minor foods such as rhubarb will not be well represented by this category but these are unlikely to be economically or radiologically important.

For a given accident scenario an estimate can be made of the amount of annual production of each of the above types likely to be lost. Unlike the majority of losses that might occur if other sectors are affected the amount lost is likely to be strongly dependent on the season. An accident occurring in the late spring has larger consequences for food production systems than one occurring in the late autumn. In economic terms, an accident that takes place shortly before harvest requires the inputs committed throughout the year to be accounted for, while for an accident shortly after harvest relatively few inputs will have been committed to the next harvest. COCO-2 provides both seasonally adjusted and annually averaged costs. Section 9 describes how COCO-2 calculates seasonal agricultural losses with examples given in Appendix C.

Before considering the effect of seasonal adjustments, a mechanism is required to convert the hectares of food lost into an appropriate economic loss. In particular, the economic loss calculated using COCO-2 must fit with the scheme already proposed for other sectors of the economy, ie, a multiplier approach derived from the 1995 analytical Input-Output tables (ONS, 2002) using the Standard Industry Classification (SIC) codes to identify the affected industries (see Appendix A)*. The Input-Output table contains information on the relation between agriculture and other parts of the economy where, for agriculture, indirect losses are composed of losses to farm suppliers such as seed producers or agrichemical companies.

As discussed in Section 4 the modelling assumption made by COCO-2 for all sectors of the economy is that, barring exceptional cases, alternative sources of supply can be found but that alternative customers are much more difficult to find. However, the delayed delivery of crops may result in a cost for the supplier who would be required to meet contractual orders by buying alternative supplies. This cost may be significant if supplies are constrained, eg, organic production. However, this may be true of many other products and COCO-2 does not attempt to model short-term price changes or downstream losses to food processors. Thus, indirect losses stemming from a direct agricultural loss are calculated in the standard way using an Input-Output multiplier where the direct loss is calculated using the procedure described in Section 9.

The agriculture losses that might arise after an accident are difficult to assess because of the large number of countermeasures that might be implemented. For example, milk in a relatively large area near an accident site may have restrictions placed on its sale but this will only apply to milk derived from cows on contaminated pasture. A farmer could resume milk production quite quickly if the cows were brought indoors and supplied with feed from elsewhere. This would add to the cost of production but have only a limited indirect effect, eg, there would be additional slurry waste to dispose of and it may take two weeks to accustom the animals to the new feeding regime and restore yields (HPA-RPD, 2005). The decision to use clean feed for animals will depend on the time of year and the likely duration of any restrictions as well as the likely cost and availability of clean feed. However, the product may still not be acceptable to processors and the public because it is from an area where restrictions are in force.

From a COCO-2 perspective, it is assumed that lost milk production can be calculated using an accident consequence model and that if countermeasures such as supplying clean feed are adopted they are appropriately costed. This would mean, for example, that not only is the cost of feed considered but also the costs of waste disposal from having cows indoors.

The effect of restrictions remaining in place for an extended period, such as several years, also needs to be considered. If production ceased the GVA lost could be recouped by production elsewhere in the country within a short period, eg, by the third

* The SIC is an internationally agreed classification of the economy in output sectors.

year. This could occur through the release of land from set aside or the build up of milk production elsewhere*. However, if, for example, the use of clean feed allowed milk production to continue, a choice must be made as to how the continued higher cost of this production should be modelled. If this countermeasure were only required for a short period, there would be no need for replacement production to be developed elsewhere but if it was likely to be required for longer then its use would affect the development of alternative (cheaper) production†.

Generally, it may be expected that the output of the agricultural economy could fully recover within 2 years to allow production to resume at pre-accident levels in the third year through changes in the pattern of production nationally and locally, see Section 6.2. This is the assumption adopted for COCO-2.

Countermeasures are introduced after an accident to protect human health and ensure a speedy return to normal life (although not necessarily the same life as before the accident). Any decision to continue with the application of countermeasures beyond 2 years will be the result of complex considerations that may not be primarily economic. For example, if there is no alternative economic activity for the area, continued financial support for countermeasures may be thought appropriate. However, countermeasures then cease to be a one-off-cost for economic restoration but a new and continuing transfer payment to particular groups in the economy. The economy has recovered but there is a change to the social contract with a slight adjustment to the pattern of transfer payments. As noted in Section 1.2 COCO-2 is not a regional model and is unable to represent continuing localised losses when the economy as a whole has recovered. Limitations of the approach with respect to loss and intervention are discussed further in Section 6.2.

* This argument is based on the assumption that land is available that is not used for production when the incident occurs. This is theoretically the case due to the requirement under the CAP to set-aside land. However to alleviate some of the world-wide shortages of cereal supply, the EU Agricultural Council has set a 0% rate for set-aside in 2008. The commission has proposed ending the system of set-aside under the 2008 'Health Check' of the reformed CAP and the government has supported the Commission's proposal to end the system of compulsory set-aside in the arable sector. http://www.defra.gov.uk/farm/policy/capreform/pdf/caphealthcheck-govresponse.pdf. However, in addition to land that was previously set-aside at the compulsory rate of 8% there is also land that is left fallow (at June 2006 it amounted to 150 thousand ha compared to 513 thousand ha of set-aside). It is likely that if set-aside were to be abolished that some land would go back into production but the area of fallow land would probably also increase. These fallow areas could come into production if the market situation changed, ie, if the supply of crops fell due to some areas being taken out of production. Thus, some displacement of production could still take place though not to the same degree.

† This point is not specifically related to the particular conditions of milk production, although there is a milk quota in the UK it will not prevent the development of alternative sources of production as it can be traded and has not been binding for several years and so is unlikely to have a significant distorting effect on the market.

6.2 Intervention and loss

To estimate the cost of accidents the COCO-2 model makes several simplifying assumptions about the economy, which make it impractical to consider structural change. The Input-Output approach adopted by COCO-2 allows perturbational changes to the economy to be modelled but assumes that the underlying relationships remain fixed. The model does not consider employment, labour mobility or, of particular importance for agriculture, the environmental and social consequences of production changes. Thus, from a COCO-2 perspective one of two alternatives prevails. Either the cost to the economy of continuing to support particular countermeasures beyond 2 years is a trivial and declining cost and therefore not considered, or, given that 2 years is sufficient time for alternative sources of production to become available from elsewhere, new uses are found for the affected land and the net cost to the UK economy is negligible[*]. The affected land could be set-aside or rezoned for non-agricultural use. However, new agricultural activities on the affected land might be only slightly different from pre-accident uses. For example, beef cattle could be bred, which are then sold on for fattening to unaffected areas, (thus allowing activity levels in the meat to fall below restricted levels[†]) or crops could be produced that are not destined for the food chain such as biofuels. To support the case that the agricultural recovery can be rapid it should be noted that much smaller economies with a correspondingly very much larger agricultural sector have recovered from major natural disasters within a year, eg, the 1998 floods in Bangladesh were hydrologically a once in fifty year event. However, agricultural GDP rose in the following year by more than the government pre-flood forecast growth (Benson and Clay, 2004). In the UK the most significant recent agricultural crisis was the 2001 FMD outbreak but as stated in VIDA (2003) a report of the Veterinary Laboratory Agency (VLA) 'In 2003 recovery from the 2001 Foot and Mouth Disease outbreak was effectively completed with dairy and beef farming having adjusted to the post movement restrictions'.

The imposition of restrictions on agricultural products may induce a change to the supply of goods with little or no change in the pattern of demand or a switch to alternative foods. In either event, this is likely to promote imports and a loss of UK GVA. The scale of this change may be dependent on how the imposed restrictions are viewed by the public. Any material being marketed would be considered safe by the authorities, ie, any residual contamination would be at a level less than the European Council Food Intervention Levels (CFIL) agreed within the EU (see Table 5). The COCO-2 model provides estimates of the costs of accidents and, while conservative assumptions are appropriate, it is thought unreasonable that safety case expenditure should be influenced by discretionary actions not based on risk or requirements. Hence, a loss of

[*] Structural change may modify the mix of products imported and exported. For example, if milk were restricted following an accident it may be possible to increase production in unaffected areas particularly as the overall herd size in the UK has declined substantially over recent decades (~60% larger in 1950) as yields have increased. This could be accompanied by market adjustments such as replacing some of the ~16% of UK fresh milk used in milk powder production with imports.

[†] A FEPA order restricts the movement of animals but consents may be given to allow finishing elsewhere, eg, this currently applies in areas affected by contamination resulting from the accident at Chernobyl.

consumer confidence in agricultural production from unaffected areas is not considered further. This is similar to the position adopted for tourism where only direct and indirectly attributable losses stemming from tangible effects are considered.

TABLE 5 Selected CFIL categories for foods, (Bq kg^{-1})[1]

Radionuclides	Dairy produce	Other foods
Isotopes of strontium	125	750
Isotopes of iodine	500	2000
Alpha-emitting isotopes of plutonium and transplutonium elements	20	80
All other radionuclides of half-life greater than 10 days	1000	1250

[1]CEC (1987)

As discussed previously, in addition to the loss of primary production, there will be increased costs to support the production of derived products, eg, yoghurt, as milk is sourced from elsewhere and transported further, although this is likely to be much less important than a loss of demand. COCO-2 considers the up-stream consequences of a loss of demand by estimating indirect effects, which for agriculture is of the order of ~90% of the direct effects. The generally very much weaker downstream indirect effects due to the loss of supplier are likely to be less than this*. However, it is beyond the capability of COCO-2 to give a precise estimate of this loss.

COCO-2 requires an estimate of the amount of agricultural production that is prevented from being sold for a period, consistent with the cost information supplied for the generic food categories of Appendix C. Given this, COCO-2 will provide an estimate of the cost to the UK economy of the lost production. Equations are given in Section 9 that indicate how the direct effect of the losses can be estimated. The loss depends on the way agricultural products are cropped and the costs are therefore presented in terms of the cropping regime used. The combination of seasonality and cropping regime makes the process of estimating the loss from agricultural restrictions more complex than that for losses from other sectors of the economy. Associated intervention costs such as the cost of waste disposal or the cost of any countermeasures used, eg, to allow production to be resumed more quickly should be included as part of the overall assessment of cost. COCO-2 provides information on the cost of agricultural waste disposal in Appendix C and countermeasure costs are available in HPA-RPD (2005).

7 HEALTH EFFECTS

The loss to the UK economy from any health effects arising from an accidental release of radioactivity is, like other losses, composed of a mixture of costs representative of the divisions introduced in Table 1. Thus, there is the direct tangible loss of production and consumption of those taken ill, the cost of care, the direct but intangible costs

* Production does not create demand but demand creates production.

associated with the value of life and morbidity, the indirect costs stemming from lost production and consumption and the loss of voluntary contributions to society such as the care of relatives and work in the community. The calculation of health costs is complex and the component terms of the above cost framework for estimating the economic consequences of the health effects arising from an accident are discussed below. However, not all costs can be adequately modelled and in deciding which costs to include in estimating the value of fatalities and injuries, two key criteria are considered: transferability/applicability and significance in terms of overall cost.

In line with the approach taken in COCO-1, COCO-2 considers the direct loss of labour from the people who are ill[*]. This quantity, in conjunction with the cost of care, has been taken in the past to represent the total cost of ill health. This loss of services from human capital is a stark and limited view of the loss suffered when someone is ill or dies. It also suffers from a number of methodological problems and both aspects are discussed in more detail in Section 7.1.1.

COCO-2 also considers the cost of treatment, which like other countermeasures should be fully accounted for, as the need for treatment would not have arisen without the accident. It should be noted that only a small fraction of the health costs that occur following a severe nuclear accident are likely to arise from deterministic effects[†]. The majority of any treatment costs are likely to be for cancers occurring at some time and distance from the event. These cancers cannot be uniquely attributed to the accident or to a particular region. Indeed, trying to assign them to a region would not be practical and would probably be misleading. It should also be noted that different cancers have different treatment costs and outcomes. Although this is not considered in detail by COCO-2 (see Section 10.3) it should be kept under review (see Section 13.1), as it will become easier to produce statistics that relate disease, cost and outcome as the electronic patient records and 'payment by results' programmes of the NHS develop.

The direct but intangible cost of the loss related to the Value of Statistical Life (VOSL), or Value of Preventable Fatality (VPF) as it is more commonly termed in the UK is also considered. In COCO-2 this represents the statistical average Compensating Variation (CV) required to match the personal losses inflicted on those suffering radiation induced morbidity or death[‡]. Conceptually this is the most difficult component to value, with continuing debate on the methodology and the valuations proposed in the literature (see Jones-Lee et al (2007)). It is nevertheless likely to be the dominant component of the loss and is discussed more fully in the sections below.

The loss of voluntary work from those taken ill and the costs to employers of replacement staff are briefly considered but, like the indirect effects of lost production and consumption, are not pursued further.

---

[*] Strictly, in line with the opening paragraph, it is the net loss that is important, as people are both consumers and producers.

[†] Deterministic effects are also called harmful tissue reactions.

[‡]The VPF is typically defined as the CV for a *gain* in the form of a reduction in the risk of suffering a loss.

Before proceeding to discuss the above terms in more detail, it is important to note that by introducing a CV into the health cost model, COCO-2 will achieve a better representation of the loss. However, it is not assumed by the model that the welfare loss is realised as a financial loss to the economy, ie, that transfer payments will be made. This estimate is included to achieve a measure of the loss appropriate for policy and planning decisions.

7.1 Valuing life

To some people the idea of placing a monetary value on the lives lost and injuries sustained in an accident may seem inappropriate. However, an accurate estimate of the cost of a potential accident is a necessary input to policy-makers' decisions about the appropriate level of risk reduction and hazard mitigation expenditure. The more inclusive these cost estimates are of intangible factors like death and injury, the better the opportunities for more informed decision-making.

Excluding values for death and injury may effectively equate to assigning zero values. Therefore, the inclusion of these costs, even if they are lower bound estimates, represents an improvement in identifying more accurately the full costs of an accident. Studies on the cost of transport accidents have found that the values placed on life and injury tend to be a substantial component of total costs (DfT 2002, BTE, 2000, p 19).

There are generally two approaches favoured by economists for estimating the value of a statistical life: Human Capital (HC) and Willingness to Pay (WTP). Before describing each approach, it is useful to clarify what is meant by 'value of statistical life' and whose life is being valued.

7.1.1 Value of statistical life

Most people would probably consider that their own lives and those of loved ones are priceless. They may extend this view to the life of others although on a progressively more abstract basis as those considered become more remote. There are many examples where large amounts of money have been spent to save a single life (for example, a person stranded at sea)*. There are also many examples in everyday life where the implicit values placed on life are much lower. The amount of funding allocated to activities that save lives or prevent injuries, such as hospitals and emergency services, reflects implicit decisions made about the price society is willing to pay to save lives. The critical distinction is whose life is being valued, as people asked directly to value life naturally come up with a value that reflects their own lives and the lives of individuals close to them. When a 'value of life' is being developed for use in public policy decision-making, it is not any particular person's life that is valued, but that of a

* The estimates presented in the press of the rescue of a lone sailor often exaggerate the cost, ie, the salaries of Navy, air force, coast guard personnel, etc, are being paid anyway and although the fuel used is extra, there are benefits in for example gaining bad weather flying experience that might not be justified in ordinary training.

'statistical' individual*. Strictly, it is not the life that is valued but the reduction in the risk of death, which is then re-expressed as a value of life. As might be anticipated, the funds allocated to saving statistical lives are typically much less than the amount that might be spent to save identified lives.

Ascertaining how much people are willing to pay is fraught with difficulties as the problem being addressed is usually to find out how much people would be prepared to pay to make a small change to a low probability of death from a particular cause, eg, by introducing barriers and traffic lights to reduce road accidents at particular junctions.

The methodological discussion below is largely drawn from BTE (2000, pp 19-23), for more detailed information, refer to BTCE (1992), BTCE (1996) or BTE (1998).

7.1.2 The human capital approach

The human capital approach characterises people as a labour source and input to the production process. This approach argues that the value to society of preventing a death or injury arises from the saving in potential output or productive capacity. It is an *ex ante* accounting approach that uses the discounted present value of a victim's potential future earnings as a proxy for the cost of premature death or permanent injury. The human capital approach can also be used to value non-paid work in the form of service to family and community. A non-economic loss can also be incorporated to represent pain, suffering and lost quality of life. The use of a simple HC method in isolation has essentially been abandoned in favour of individual preference methods as discussed in Section 7.1.3. This approach was used reluctantly in COCO-1 and more generally in the UK until ~1988†. However, an essentially arbitrary allowance was generally added to reflect "pain, grief and suffering" corresponding to about 30% of the overall value of preventing a fatality although with no theoretical or ethical grounding other than as a gesture towards treating people as more than just productive capital equipment‡.

7.1.3 The willingness to pay approach

The willingness to pay approach estimates the value of life in terms of the amounts that individuals are prepared to pay to reduce risks to their lives (or amounts accepted as compensation for bearing increased risk). The approach uses people's preferences (either stated or revealed) to ascertain the value they place on reducing risk to life and reflects the value of intangible elements such as quality of life and joy of living. BTE (1998) provides a detailed and comprehensive review of the theory and practice of

---

*In the loss of a statistical life, n individuals are exposed to an independent risk of death of 1/n for each individual. This should not be confused with the loss of an anonymous life, which involves the certain death of one, as yet, unidentified individual in a given population. The *expected* number of fatalities is one in both cases, but the two probability distributions of lives lost are very different. The VPF is essentially the aggregate willingness to pay for the prevention of one *statistical* fatality.

† The Department for Transport (DfT) stopped using the human capital approach for valuing risks in 1988, to use a value based on the WTP approach.

‡ COCO-1 provided separate HC and subjective valuations.

willingness to pay methods. The use of WTP methods is discussed further in Section 7.3, which considers the relationship between WTP and the measures of benefit used in health economics. Alternatively, Cookson (2003) provides a sceptical view of the applicability of WTP in health economics.

7.2 A comparison of approaches to valuing life

The HC and WTP approaches are different in concept and, in terms of the 'value of life' produce different results. WTP methods more naturally include the measure of intangible losses associated with death and injury, whereas the human capital approach typically only measures direct and indirect tangible losses. However, the approaches are not mutually exclusive, indeed WTP methods generally include direct and indirect tangible and intangible elements and thus include terms representative of the more dated HC approach[*]. As a result, it is important to recognise that in some cases, adding the results of the HC and WTP approaches would be reasonable, but in others, this may involve double counting. Both approaches are imperfect in estimating the economic value of life (Kuchler and Golan, 1999). Table 6 provides a summarised version of the arguments for and against the use of the two approaches.

[*] It is difficult to get respondents to asses fairly the associated social costs and it is therefore simpler to include these separately.

TABLE 6 COMPARISON OF APPROACHES TO VALUING HUMAN LIFE

Advantages	Disadvantages
Human Capital	
The data are reliable and readily available.	Some lives may be valued higher than other lives due to labour market imperfections, such as wage discrimination. If simplistically applied, the very young and old are undervalued.
It provides consistent and transparent results.	It overestimates productivity costs in an economy with less than full employment.
It is simple to use.	It does not reflect a key reason for investment in safety, ie, the aversion to death and injury rather than income protection.
	It ignores the loss of 'joy of life', while values for pain, suffering and grief are often arbitrary.
	There are actuarial uncertainties with regard to life expectancy and earnings.
	The selection of the appropriate discount rate is controversial.
Willingness to Pay	
The approach is comprehensive.	People have difficulty understanding and valuing small risks (generally less than 1 in 10 000).
It incorporates subjective welfare costs.	Individual perceptions of risk may differ.
It reflects individual preferences.	Willingness to pay does not necessarily imply ability to pay.
	Differences exist between people's expenditure patterns/actions and their real preferences.
	Aggregating individuals' willingness to pay may not produce the social willingness to pay, as individuals may ignore external social costs. However, there is now a substantial literature on altruism and individuals' expression of their preferences in the role as "citizens" (OECD, 2005).
	There is a risk of considering an anonymous life instead of the more difficult to apply concept of a statistical life.
	There are methodological difficulties from, eg, inaccurate responses, and the strategic behaviour of interviewees when responding to surveys.
	Equity is generally imposed on the approach as opposed to being an inherent feature see for example Treasury (2005, p. 26). For further discussion on equity and WTP, see Smith et al (1999).
	There is a discrepancy in results obtained using willingness to pay and willingness to accept approaches.
	The value obtained will change with income and variations in safety. However, any respectable attempt to obtain empirical estimates of individual willingness to pay for reductions in the risk of death or injury will make considerable efforts to ensure that, so far as possible, respondents *do* take account of the ability to pay, see for example Viscusi and Aldy (2003) who discuss the income elasticity of the VOSL.

As the willingness to pay approach includes elements that the human capital approach has difficulty in costing, the former will generally give higher values than the latter. This is particularly the case for fatalities. Estimates of WTP vary markedly in value across the world: for example see Viscusi and Aldy (2003) for a review of the VOSL predominately in the United States, Canada and the UK. The wide variation in WTP estimates of the value of statistical lives is, in part, because the value depends on circumstances and individual preferences in avoiding or accepting physical risk. For example, different attitudes towards risk mean that how a person dies affects the values derived. People's perceptions and attitudes toward risk can vary widely over different types of natural hazards. Some individuals may be willing to pay more to avoid drowning in a flood than burning in a bush fire. Slovic et al (1980) found that, in the nuclear context, the perceived risk was much greater than the actual risk, despite a perception of having the lowest annual number of fatalities compared to the other risk contexts studied (this may have changed following Chernobyl). This discrepancy was assigned to the perceived potential for disaster. Slovic et al (1982, 1984) found that accidents also sent signals about the possibility and nature of future accidents, and asserted that, for nuclear accidents, these secondary impacts may be the most important because the public perception of nuclear accidents is of poorly understood risks with potentially catastrophic impacts. Because of these differences in risk perception, the WTP method may produce different values for the same reduction in risk from different hazards.

Recent studies commissioned by the HSE (Burton et al, 2001; Chilton et al, 2007) suggest that for causes resulting in instant or near-instant death (such as road or rail accidents), there are clear indications of differing degrees of ‘dread’ (with, for example, rail deaths being considerably more dreaded than road deaths). However, these ‘dread’ effects are largely offset by ‘baseline’ risk effects (with the baseline risk for death in a rail accident being only a fraction of that for death in a road accident), so that a ‘common’ VPF may well be appropriate for all such causes. By contrast, in the case of causes that result in protracted periods of pain and suffering prior to death (such as cancer) some additional amount (or ‘dread’ weighting) may be considered appropriate. This is discussed by Jones-Lee et al (2007) who conclude that, consistent with the conventional health economics view, no dread weighting should be applied. They noted from the study of Chilton et al (2007) that considerations of blame and responsibility were an important influence on people’s judgement about the priority to be attached to the reduction of different hazards, and thought as a consequence that for nuclear accidents the issues of blame and ‘cancer’ would dominate other considerations. The former is associated with political and management issues and should remain distinct from the particular valuation of health impacts. The latter issue, namely death from ‘cancer’, does not *per se* support a higher weighting unless that weighting is viewed as a crude proxy for the period of morbidity likely to precede death. As morbidity is specifically considered, a higher weighting for cancer deaths would be an unnecessary and unreliable complication. This view has been adopted in COCO-2.

7.3 Contingent Valuation and the QALY

Contingent valuation, ie, the process of asking people directly how much they would be willing to pay for a good or service or how much they are willing to accept to give it up, is central to the theory of welfare economics as, consequentially, is the view that people seek to maximise their welfare through the choices they make. Any spending decisions can thus be seen as a balance between options offering different welfare gains. This leads naturally to cost benefit analysis as the general theoretical framework for decision-making where gains and costs across all areas stemming from a particular choice are traded against alternatives. However, health economics employs Cost Effectiveness Analysis (CEA), which does not fit easily (or at all) within a welfarist model. Essentially, while welfarists believe that healthcare should be judged by its contribution to overall welfare (the weighted sum of individual utilities), which includes goods other than health the supporters of a CEA perspective seek to maximise health gains to the exclusion of other considerations. Thus, the change in health state and not the change in individual utility is the important consideration.

COCO-2 estimates the economic cost of a nuclear accident given a particular scenario and when used as part of a PRA study will provide information to support the assessment of the safety case of any proposed change. As a procedure for assessing the overall cost from component losses associated with business and agriculture as well as health, COCO-2 fits within a CBA / welfarist framework rather than that of CEA.

An alternative perspective is offered by the use of the Quality Adjusted Life Year (QALY) when valuing health detriments (DH, 2004). QALYs are health economic constructs allowing the relative merits of alternative treatments to be judged through cost effectiveness analysis. A range of scales exist which value the relative health detriment of a particular state, based on a multidimensional scale characterising mobility, self-care, the ability to perform usual activities, pain/discomfort and anxiety/depression[*]. A QALY represents the resulting weighted score with (1) representing a year in perfect health and (0) death. A monetised QALY represents the QALY score multiplied by a Value of a Life Year (VOLY) where the latter is the monetary worth of a year of perfect health. A CEA comparison between treatment options offering different QALY improvements at different costs can then occur. The National Institute for Health and Clinical Excellence (NICE) associates a QALY with a single, age independent, VOLY of approximately £30,000. The advantage of a QALY measure for COCO-2 is that a large body of work on health states is potentially available to use in the assessment of the health consequences of an accident (however see Baker et al, 2003). This would allow the health costs used by COCO-2 to be more easily maintained and possibly developed.

Unfortunately the WTP and QALY conventions cannot be easily reconciled by, for example, assuming that the value of a life year (VOLY) for an individual is given by the WTP value of a preventable fatality (VPF) divided by the remaining life expectancy. A VOLY calculated in this simple way for a constant VPF for someone with eight years of remaining life expectancy, will be five times as large as the VOLY for someone with forty years of life expectancy. 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 with eight years of life expectancy is one fifth of the VPF for a forty year-old[†].

As discussed in Gyrd-Hansen (2005), although there may be potentially insuperable theoretical problems in attempting to establish a generic relationship between QALYs and WTP values there may be pragmatic advantages in doing so for particular circumstances. The relationship between QALYs, WTP and the value of a statistical life is a topic of on going research. An example of current research is given in Appendix D, which discusses how a method of addressing this problem specifically developed for COCO-2 by Jones-Lee et al (2007), should be applied. The context and more complex

[*] The above is an example of the EuroQol scale. Several scales can be used to measure the QALY of a particular health state see for example Nord et al (1992).

[†] Either, in essence, there is one value for a statistical life or there is a single value for an arbitrary year of life.

issues associated with the work summarised in Appendix D are discussed in Jones-Lee et al (2007).

7.4 Health cost framework

In summary, the health costs considered by COCO-2 are the following. COCO-2 accounts for productivity losses (a Human Capital term discussed in more detail in Section 7.4.1), the cost of medical treatment (discussed in Section 7.4.2), and as discussed in Sections 7.2 and 7.3 the WTP to avert a fatality and, through the use of a QALY approach, the cost of a limited period of morbidity.

7.4.1 Value of labour

When a person is killed, their potential labour output and consumption over what could reasonably have been expected to be the remainder of their life is lost. If they are injured or permanently disabled the output loss is until they recover or find appropriate alternative work. This loss occurs at three levels - the workplace, the household and the community. The net value of these losses may well be a significant proportion of the total cost of fatalities and injuries. The value of labour lost in the workplace depends on how much working life a person could have reasonably expected to have remaining at the time of death or injury and the worth of their labour to the workplace. Estimating a value for the labour lost in terms of the contribution to the home (for example, child minding) and the community (including voluntary assistance to schools, sporting and community groups) is more difficult but important. Although unpaid, this work is important to the quality of life for individuals, families and the wider community. In addition, some proportion of this work may consequently have to be taken up by public agencies or charities, eg, care of elderly dependents. This is discussed further in Section 13.3.

The workplaces of accident victims suffer additional losses related to the loss of a staff member. Productivity will decline for a time and other staff may have to work overtime or temporary staff may have to be employed to fill the gap. When a fatality or serious injury occurs, the workplace will also face recruitment and training costs. The National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation estimated the extent of these costs for fatalities (3 months' wages), severe injuries (4 months' wages) and minor injuries (2 days' wages)*. In the absence of alternative data, this information could be used in COCO-2. However, it is to be expected that even for a large nuclear accident the majority of health effects will occur some years after the accident and not necessarily to employees of the companies that were originally affected by the release or any countermeasures imposed. Thus, although it is theoretically possible to calculate the number of accident induced cancers expected in a future working-age cohort so that this contribution to the costs could be limited to that sub-group, from a COCO-2 perspective, this component of the costs of illness for the

* Severe injuries are more disruptive than fatalities as the recruitment of replacement staff is likely to be delayed.

working population will be a small fraction of their total costs. It will be an even smaller fraction of the cost for the whole population affected, as most cancers will occur in population cohorts beyond working age. Thus, the tangible but indirect costs of staff replacement on business are not considered in COCO-2.

7.4.2 Medical costs

The medical cost of an accident to the local or national economy is the additional cost of providing the various services required, eg, the use of ambulance, hospital in-patient, outpatient and casualty/emergency services, general practitioners, specialists and allied health services such as radiography and physiotherapy. The additional cost of medical treatment is ether reflected in extended treatment times and through them a reduction in economic efficiency and lower quality of life, as the greater demands require care to be rationed, or as increases in taxes or government borrowing. In theory, an estimate of the marginal cost of medical services should assess the difference between the prospective requirements of the population with and without the accident[*].

Where possible, COCO-2 has used information on the appropriate medical pathways to assess the likely total cost of treating an illness. Within the NHS, information is available on the costs of spells in hospital and episodes under a particular consultant. However, cost information on care for a single patient that is composed of several distinct and important stages is not yet collated although there is work underway on the development of treatment pathways. A treatment pathway is a guide to the likely route through the healthcare system of patients with a particular disease accounting, for example, for the probability of some patients to need different follow up treatments (see Section 10).

8 MODEL APPLICATION: INHABITED AREAS

The previous sections have assembled the general ideas and arguments of COCO-2; this section and Sections 9 and 10 will present the general formulation of the model based on those arguments and the more detailed discussion of the appendices. In particular, this section will consider the losses from industry excluding agriculture and the losses of people excluding health related losses. The data required to evaluate the formulae presented in this section are provided either in Section 11 (Tables 21, 23 and 24) or in the accompanying file as described in Section B7.

To estimate the direct economic effects on people and industry of an accident, COCO-2 needs to be supplied with information on the areas affected and the length of time any restrictions are in force. The number of people affected is an important determinant of the economic impact. For example, the number of people moved and taken to reception centres will partially determine the costs associated with evacuation. In addition to the

[*] Note no consideration is given to the saving of future health costs due to people dying prematurely from a radiation-induced cancer.

number of people affected, the initial locations of those people when countermeasures are implemented are also important because a COCO-2 economic impact assessment can differentiate between residential areas and industrial estates.

It is assumed that in any application of COCO-2 the affected area can be matched against relevant features on the ground, such as industrial estates, schools, houses, etc. Data are provided in the accompanying file on the economics of each small area of the country together with supporting information that will help in the assessment of loss. The information included covers such things as the area of roads, gardens, green space, types of dwelling and types of industrial property and is discussed in full in Appendix B. It is recommended that local survey information is used to improve the representation of buildings in a particular area, if it is thought that any gaps or inaccuracies in the supplementary data provided in the accompanying file are likely to affect the estimated cost of countermeasures significantly.

COCO-2 does not consider a proximity effect on businesses in nearby areas, which, although not directly affected, nevertheless lose custom if the nearby population has been advised to shelter or has been evacuated. This is similar to an indirect loss, which is accounted for, but would require the consideration of Type 2 multipliers (see Appendix A). This is discussed further in Section 13.2. COCO-2 assumes that there is no loss of demand from any evacuated population and that the loss due to the proximity of sheltering in neighbouring areas will be small, as only a fraction of the customer base of any peripheral business will come from an affected area.

The losses considered in COCO-2, which stem from the restrictions placed on people and their places of habitation following an accident, are shown in Table 7, which also lists the appropriate equations to use when evaluating the costs that arise from the implementation of restrictions and countermeasures during the different phases of an accident. The equations and their derivation are discussed in the subsequent sub-sections.

Following the discussion of Section 8.1 on why some supporting countermeasures commonly associated with those of Table 7 are not costed, the common sources of loss applicable to the countermeasures of Table 7 are presented, ie, costs stemming from the closure of businesses. Additional specific losses and points to bear in mind when applying these common terms are then presented.

It should be noted that the production losses of Table 7 accumulate in proportion to the length of the disruption while the other costs related to, eg, accommodation or capital loss are triggered by particular actions. Thus, from a COCO-2 perspective short-term countermeasures are those that trigger a limited set of costs, ie, all costs except capital losses whereas long-term countermeasures may require all cost components to be evaluated. Thus, it is for the ACA code to determine that an extended period of evacuation or temporary relocation must become permanent if it is to extend beyond a given duration. The only exception to this is the COCO-2 assumption that economic recovery will occur within 2 years of the accident and therefore that temporary relocation will have ceased with the population either returning or being permanently relocated.

TABLE 7 Population based countermeasure losses considered[1]

Action	Losses	Equations	Comment
Sheltering	Cost of lost GVA and TGVA	The direct business loss can be calculated using Equation 8.2 and direct plus indirect business loss using Equation 8.3. The direct regional tourism loss can be calculated using Equation 8.4 and the direct plus indirect tourism loss calculated using Equation 8.5.	Implementation costs are assumed negligible in comparison to the direct and indirect GVA losses.
Evacuation	Cost of population movement	This is calculated using Equation 8.6.	
	Cost of temporary accommodation and temporary lost use of domestic assets	Short-term accommodation costs are calculated using Equation 8.7 and the temporary loss of use of domestic assets by Equation 8.10.	The loss of use of domestic assets may be small for a short period of evacuation and only relevant when considering temporary relocation. However, if convenient it can always be included. It should be clearly stated when using COCO-2 if potential cost components are omitted.
	Cost of lost GVA and TGVA	The direct business loss can be calculated using Equation 8.2 and direct plus indirect business loss using Equation 8.3. The direct regional tourism loss can be calculated using Equation 8.4 and the direct plus indirect tourism loss calculated using Equation 8.5.	If sheltering occurs initially, the total loss will be given by the appropriate formulae evaluated over the period of disruption.
Relocation	Cost of population movement	This is calculated using half of the estimate given by Equation 8.6.	There is no return journey and transport costs are therefore reduced by a factor of 2. This may be in addition to the cost of evacuation. It should be clearly stated when using COCO-2 if potential cost components are omitted.
	Cost of temporary accommodation and temporary loss of domestic assets	Short-term accommodation costs are calculated using Equation 8.7 and the temporary loss of use of domestic assets by Equation 8.10.	
	Permanent loss of housing and domestic assets	The permanent loss of housing is calculated using Equation 8.9 and the permanent loss of household assets is calculated by Equation 8.11.	Not all losses need accrue in all circumstances, eg, if relocation is occurring because of the long-term risk of radiation exposure from the external environment but where possessions inside houses do not pose a risk and may be removed. It should be clearly stated when using COCO-2 what cost components are excluded.
	Cost of lost GVA and TGVA	The direct business loss can be calculated using Equation 8.2 and direct plus indirect business loss using Equation 8.3. The direct regional tourism loss can be calculated using Equation 8.4 and the direct plus indirect tourism loss calculated using Equation 8.5.	The ACA modelling may assume that under some circumstances the population may return from evacuation before subsequent relocation. This should be treated as a continuous period of disruption so that the total loss is given by the appropriate formulae evaluated over the entire period of disruption.
	Loss of industrial buildings and assets	The lost capital value of industrial, commercial and retail buildings is calculated using Equation 8.12 and the loss of the internal assets is calculated using Equation 8.13.	Not all losses need accrue in all circumstances, eg, the building may be lost but the internal assets recovered or the building and fixed assets lost while the transport assets are unaffected. It should be clearly stated when using COCO-2 what cost components are excluded.

[1]Further countermeasures may be applied to reduce the length of time restrictions are in force and or the area over which they apply. This is likely to reduce the losses accruing from the countermeasures listed but requires the cost of the additional countermeasures to be included when estimating the total cost. The cost of iodine prophylaxis is not considered see Section 8.1.

8.1 Supporting countermeasures

The short-term countermeasure actions commonly envisaged following an accident are those of sheltering, stable iodine prophylaxis and evacuation. However, as indicated in Table 7 the cost of providing iodine prophylaxis is not considered by COCO-2. In the event of radioactive iodine being released the local population may be advised to take potassium iodate (KI) tablets as a prophylactic countermeasure either before, during or, if necessary, a short time after the dispersing plume of radioactive material has passed by. The majority of the cost involved in providing KI tablets is incurred when new tablets are procured and old tablets replaced at the end of their shelf life. This cost, like the costs of maintaining and rehearsing the emergency plan, is not consequential on there being an accident and is outside the scope of COCO-2.

Similarly, as well as not considering the cost of purchasing tablets, the cost of distributing KI tablets on the day, either as the main supply or as replacements for those that have mislaid their supply, is not considered in COCO-2. The default assumption in COCO-2 is that any KI distribution costs will be negligible in comparison to other costs and potentially quite variable depending on how, when and where they are distributed. There may be a size of accident where additional tablets are required, the costs and dislocations of the emergency phase dominate the costs, and the distribution costs of the tablets are significant[*]. If such a situation is considered, the full cost of any additional distribution should be included.

A similar argument to the above can be applied to reassurance monitoring which is not specifically costed within COCO-2. Although it may not be explicitly considered as a general countermeasure before people return home following evacuation, and shops, factories and schools reopen, it is likely that reassurance monitoring will take place. This will establish that there is no untoward risk if the population return, and that the distribution of residual radioactivity and the potential radiological consequences of the accident have been assessed. If it transpires that there are areas where people should remain excluded, or where decontamination should occur, then these procedures can be initiated and, if necessary, the affected population kept out for a few more days.

From a COCO-2 perspective, the dominant cost associated with reassurance monitoring is likely to be the continuing accrual of business, industrial and accommodation losses due to the delay in resuming work or letting those evacuated return home. This should be accounted for in the times supplied to COCO-2 indicating how long countermeasures are in force in any particular area. However, if the cost of undertaking monitoring is thought likely to be significant then it should be accounted for in full in the same way as any other countermeasure.

[*] It is thought unlikely that distribution costs for tablets will be a significant fraction of business and agricultural losses.

8.2 Production losses

The COCO-2 model assumes GVA to be lost for the period a business is closed and that this will occur if the workforce is required to shelter, evacuate or relocate. It is assumed that businesses are not bankrupted and the workforce made redundant but, instead, that a business is disrupted and takes time to recover. The affected businesses may resume operations in the same area or relocate[*]. In the former case, they will be able to resume operations once restrictions are lifted and in the latter case, they may be operational much sooner but with the additional expense of leasing new premises. The recovery time of business in an area is, with some constraint on the total time, assumed equal to the time taken to lift countermeasure restrictions in the area. For example, a complex facility, eg, a chemical plant, may take a long time to decontaminate due to the complexity of the facility, but there is also less opportunity to relocate. The business facing closure for an extended period would review its options and the decision arrived at would depend on the market for its product, the age of the plant and the cost of new facilities, etc. The details of such a decision are beyond the scope of COCO-2 which makes the assumption that the worldwide supply and demand for the products of the plant are in approximate balance and therefore the existing plant is likely to resume operation.

The direct economic loss of businesses in an area is assumed proportional to the length of time the businesses are out of action, which is in turn determined by the time taken to lift the countermeasures that halted production and carry out any checks deemed necessary. The implicit assumption of this approximation, relating time to loss, is that GVA is uniformly produced throughout the year. Although this will not be true in many cases, it is a convenient assumption and unlikely to cause a gross distortion of the estimated costs (the exceptions to this are agriculture, which has well defined seasonal outputs and is discussed in Section 9 and tourism, which is discussed in Section 8.2.1[†]). It is further assumed for simplicity that a business is either working or not working. In practice, there may be considerable scope for businesses to maintain a reduced level of output while such things as monitoring and decontamination take place.

An annual GVA estimate for 2004 has been generated for every 1 km grid cell in England, Scotland and Wales or more precisely an annual GVA per Standard Industry Classification (SIC)[‡] per km^2 (see Section 11). It is assumed that GVA is generated uniformly within each element and therefore the loss of GVA within an element is directly proportional to the area within the element subject to the countermeasure.

In addition to the lost GVA the cost of any countermeasures applied should be fully costed, see (HPA-RPD, 2005), including the cost of disposing of any waste generated.

---

[*] If a business were to be bankrupted it is assumed that an equivalent business would be created elsewhere in the country.

[†] If some local industries were highly seasonal, the tourism formulation of Equation 8.7 could be co-opted to apply with the replacement of TGVA by GVA_{SIC} and the provision of values for the seasonal adjustment factors.

[‡] The SIC is an internationally agreed classification of the economy in output sectors.

The loss of GVA can be estimated by calculating the GVA within a series of countermeasure contours. Firstly, it is assumed that GVA is lost in areas where restrictions such as sheltering, evacuation or relocation are advised. Although the advice to shelter may be lifted some hours after being initiated it will be assumed for the purposes of COCO-2 that the need to ventilate premises, carry out monitoring and allow workers to reassure or be reassured about relatives and friends will mean that, as a minimum, one days' production will be lost. Similarly, if sheltering for between 1 and 2 days, 2 days' production will be lost. Secondly, production will be lost in areas where evacuation or relocation takes place although in these cases there will be additional sources of loss (see Section 8.3).

To calculate the business and industry loss the areas subject to restrictions should be matched with GVA information supplied in the accompanying COCO-2 file. Figure 2 illustrates how elemental areas subject to countermeasures (A_i) can be related to the underlying economics grid for the area. As stated previously it is assumed that GVA is uniformly distributed across each 1 km grid cell and the loss of GVA within each 1km cell is therefore directly proportional to the area of the cell covered by countermeasure elements A_i.

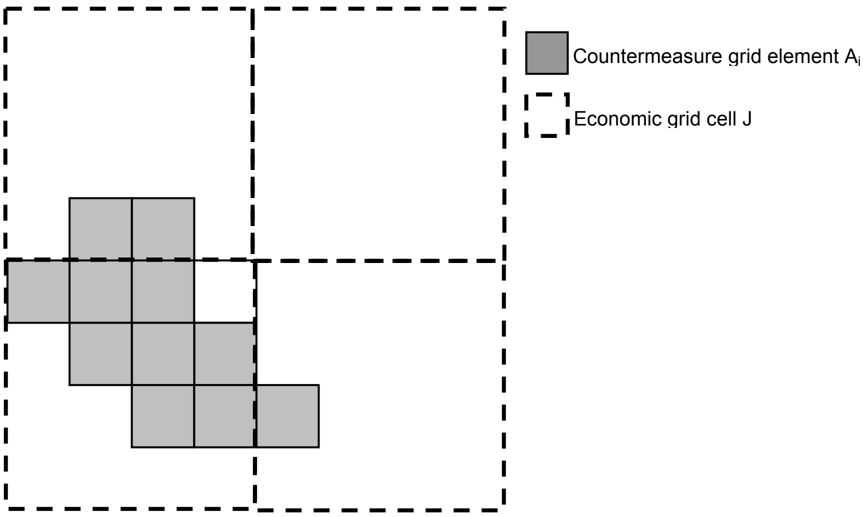

Figure 2 Example representation of countermeasure area matched to GVA grids

Thus, from Figure 2 the loss of GVA from directly affected businesses (DL_{GVA}) may be estimated using Equation 8.1:

$$DL_{GVA} = \frac{1}{365} \sum_{J} \sum_{i} \sum_{SIC} GVAD_{SIC,J} \times \Delta T_{SIC,i} \times A_i \qquad (8.1)$$

where $GVAD_{SIC,J}$ is the GVA density per SIC code for cell J and A_i is a countermeasure element where a countermeasure is in force for a period of $\Delta T_{SIC,I}$ days. The time an area is affected will depend on the scenario being considered by the ACA code, eg, it could be represented by a 1 day sheltering time or a combined sheltering and evacuation time.

Equation 8.1 is generalised in Equation 8.2 to remove the dependence of the result on the hypothetical countermeasure elements:

$$DL_{GVA} = \frac{1}{365} \iint\limits_{\forall \Delta T > 0} \sum_{SIC} GVAD_{SIC}(x,y) \times \Delta T_{SIC}(x,y)\,dx\,dy \qquad (8.2)$$

where GVAD is supplied in the accompanying file as a piecewise smooth function of the co-ordinate location x, y and the integral is calculated over all areas where the short-term countermeasures of sheltering or evacuation are applied, ie, where industry is shut for a period $\Delta T(x, y) > 0$ days. The derivation of GVAD used in Equations 8.1 and 8.2 and supplied in the accompanying file is explained in detail in Section 11 (see for example Equation 11.1).

The length of time businesses are closed is not related to their SIC code except in exceptional cases of industrial processes that, when shut down quickly, take time to restart*. COCO-2 does not provide information on industry specific closure periods although these may be used if available. Other than the supplied GVA information, all other quantities are specific to the accident and COCO-2 expects these to be supplied by external models.

To account for indirect effects (see Section 4 and Appendix A) the direct loss estimated using Equation 8.2 should be multiplied by the appropriate SIC dependent factor to give the aggregate direct and indirect loss of Equation 8.3:

$$TL_{GVA} = \frac{1}{365} \iint\limits_{\forall \Delta T > 0} \sum_{SIC} GVAD_{SIC}(x,y) \times M_{SIC} \times \Delta T_{SIC}(x,y)\,dx\,dy \qquad (8.3)$$

where TL_{GVA} is the total loss due to the closure of businesses for a period ΔT, M_{SIC} is the industry dependent multiplier of Table 21 (see Section 11.2.1) and all other terms are as defined in Equation 8.2. If the accident is very large it may be appropriate to attenuate the difference between Equations 8.3 and 8.2 to avoid double counting using the function discussed in Section 11.2.3.

* Exceptionally, a business might also be closed for longer if the products of the business were restricted, for example, if a fish farm were closed following the application of an order under the Food and Environmental Protection Act (FEPA) (see Table 4 Section 6.1).

8.2.1 Tourism losses

Tourism losses are calculated in essentially the same way as business losses except that a single aggregate measure, TGVA, is used to measure the lost GVA from all tourist related enterprises. Thus, as in Equation 8.2 the direct loss is proportional to the time businesses are closed. However, in addition, national seasonal adjustment factors are provided to enable seasonal effects on tourism losses to be estimated. Thus, Equation 8.2 becomes Equation 8.4 where DL_{TGVA} is the direct loss in the tourist sector and TGVAD is the TGVA density as a function of location x, y. The qf are the seasonal adjustment factors where S_i is the season, P the number of seasons*, T_s the time in days from the beginning of the year when restrictions are first applied, ΔT the duration of the restrictions and Rem is the remainder function†. If no distinctions are made between seasons, the term within the braces reduces to ΔT and Equation 8.4 becomes identical in form to Equation 8.2.

The industry sectors that contribute to TGVA are given in Section 11.2.2 together with national seasonal adjustment factors (Table 23) and the TGVA values in £ million per square kilometre are supplied in the accompanying file.

$$DL_{TGVA} = \iint_{\forall \Delta T > 0} \frac{TGVAD(x,y)}{365} \left\{ \sum_{n=0}^{N-1} qf(S_{i+n}) \left[\frac{365 - \mathrm{Rem}(T_s \times P, 365)(1-\theta(n))}{P} \right] \theta(N) + qf(S_{i+N}) \left[\Delta T - \sum_{n=0}^{N-1} \left[\frac{365 - \mathrm{Rem}(T_s \times P, 365)(1-\theta(n))}{P} \right] \theta(N) \right] \right\} dx dy \quad (8.4)$$

where $S_{i+P} = S_i, \quad T_s \in \{1, ...365\}, \quad i = 1 + INT\left[\frac{T_s \times P}{365}\right],$

$$N = INT\left[\frac{P(\mathrm{Rem}(T_s \times P, 365) + \Delta T)}{365}\right], \quad \theta(x) = \begin{cases} 1 \; if \; x > 0 \\ 0 \; if \; x \le 0 \end{cases}$$

and $\sum_{i=1}^{i=P} qf(S_i) = 1.$

The national seasonal adjustment factors provided can be replaced with specific local information if the national factors are not thought to capture the local variation in tourism activity with the season. If seasonal adjustment factors are used, COCO-2 will require the start day of the restrictions in addition to the duration of any restrictions to be supplied.

The indirect contribution to tourism losses is slightly simpler than for industry in general because of the use of a single term representing TGVA and a single multiplier for that

* The number of seasons represents the number of equal partitions of a year. This could be spring, summer, winter and autumn or for computational convenience some other division such as a biannual division.

† The remainder r of a number L when divided by m rem(L,m) is such that L =n.m+r where L, n, m and r are integers and r<m.

term (see Table 21 in Section 11.2.1). Thus, the total tourism loss TL_{TGVA} is given by Equation 8.5:

$$TL_{TGVA} = M \times DL_{TGVA} \tag{8.5}$$

where M is the tourism multiplier given in Table 21. For an accident that affects a large amount of the local government region, it may be appropriate to consider attenuating the indirect loss using the function of Section 11.2.3.

8.3 Short-term countermeasures

COCO-2 assumes that the losses discussed in Section 8.2 and, in particular, Equations 8.2, 8.3, 8.4 and 8.5 can account for the economic consequences of sheltering. In terms of economic effects, sheltering will interrupt business activities but the interruption may be insufficient to cause detectable disruption to the wider economy beyond that arising from the loss of the primary facility, as it is likely only to continue for a short period. Thus, for practical purposes the contribution of indirect effects to the loss can be omitted if sheltering is the only countermeasure applied*. Administrative costs associated with the imposition of sheltering are not specifically considered, as these are unlikely to be significant. However, if specific and significant countermeasure costs associated with sheltering are identified these should be added to the cost of sheltering estimated by COCO-2.

The cost of evacuation is composed of several terms. In addition to the costs arising from the closure of businesses (the production and tourism losses of Equations 8.2, 8.3, 8.4 and 8.5) the people to be evacuated must be transported from their houses, offices, farms, hospitals, schools, etc, to one or more new locations and then if necessary provided with overnight accommodation. The numbers to be transported will vary considerably depending on the nature of the areas affected and the timing of any moves. If evacuation is advised and residential properties are affected it is likely that a considerable number of people will self-evacuate. If large offices or factories are affected it is more likely that there will be an orderly evacuation in communal transport and this is almost certainly the case if schools, residential care homes or hospitals are affected. An orderly evacuation will give people the opportunity to be checked out and reassured or sent for treatment. It will also allow separated groups to be reunited, eg, parents and children. The duration of any evacuation is likely to fall into one of three classes: short term, of intermediate duration or for a longer time that could easily be transformed into permanent relocation.

* However, it should be borne in mind that input-output models are static representations of an economy and therefore the temporal variation of multipliers is not explicitly considered by COCO-2. The stoppage of output for even for a single day will result in some indirect effects but to determine how rapidly indirect effects are likely to achieve their full effect would require much more complicated modelling which is currently both inappropriate and impractical (see Section 4).

A specific decision will be made to relocate the population and therefore for the sake of definiteness evacuation is assumed to mean that those affected will return. If those evacuated are not to be returned but are to be considered relocated the estimated transport cost of Section 8.3.1 should be adjusted accordingly, see Section 8.4.

The costs incurred in evacuating a group of people will therefore be composed of the cost of transporting them to a reception centre and either maintaining them there for a short period or transferring them on to appropriate temporary accommodation[*]. The exact sequence of events may differ but the overall cost is likely to be broadly equivalent. The transport and accommodation costs are discussed below in Sections 8.3.1 and 8.3.2 respectively. It should be noted that there are at least two populations involved in any evacuation, the resident and non-resident populations, (composed of workers, schoolchildren and visitors to the area). Although both will be moved initially, those that are non-resident are likely to be able to leave for their own homes following their processing at a reception centre. COCO-2 assumes that evacuation transport costs are determined by the numbers moved.

Residents that work or go to school outside the affected area, but who live within it, may also attend reception centres. COCO-2 will capture the accommodation cost associated with this group as costs are based on the number of houses within the affected area. COCO-2 assumes that they will be able to continue working or attending school by commuting from their temporary accommodation but does not cost the CV associated with disrupted travel plans.

8.3.1 Evacuation transport cost

The cost of transporting people will depend on who is being transported. In most cases, it will simply be the cost of a coach seat but for some people ambulances and attendants will be required. Local demographic information specifically gathered or from the National Population Database (NPD) of the HSL (see Appendix B) could be used to estimate the additional costs potentially incurred if it is required to evacuate the elderly and infirm or those with special needs.

The cost of evacuation C_T is, with some slight generalisation, of the same form as previously considered in COCO-1, where m_i is the number of trips of type i (eg, coach or ambulance) required, C_i is the cost per km and d_i is the distance of travelled. The number of trips required is given by the number of people n_i in a particular category requiring transport divided by the capacity of the typical vehicle V_i. The formulation includes an allowance for an extra journey of a partially filled vehicle if required[†]. The required calculation is given by Equation 8.6.

[*] Some fraction of them may self-evacuate and although that cost may be less, it is likely to be of the same order and is therefore not specifically considered. Self-evacuation will ease the transport burden but may create additional administrative costs, eg, reconciling the numbers of children collected by parents with those evacuated as a group and providing support for those seeking medical reassurance at destinations remote from the accident.

[†] The remainder r of a number L when divided by m rem(L,m) is such that L =n.m+r where L, n, m and r are integers and r<m.

$$C_T = 2\sum_i C_i m_i d_i$$

$$\text{where } m_i = INT\left(\frac{n_i}{V_i}\right) + \theta(\text{rem}(n_i, V_i)) \qquad (8.6)$$

$$\text{and } \begin{cases} \theta(x) = 1 \ \forall \ x > 0 \\ \theta(x) = 0 \ \forall \ x \le 0 \end{cases}$$

The cost per journey will depend on how far the evacuated population is being moved which will in turn depend on the accident and the provisions of the emergency plan. However, as the population is expected to return from evacuation after a comparatively short period and it will be logistically simpler if fewer coaches are required it is not expected that the distances involved will be great[*]. The costs incurred by those self-evacuating are unlikely to be greater than that of standard coach transport and, for simplicity, it is therefore assumed that for the assessment of transport costs self-evacuation can be neglected. Transport costs are only likely to make a small contribution to the overall economic effects of an accident and a simple estimation of the likely cost will therefore suffice. However, if arrangements already exist for a particular area, having been specifically developed or proposed for emergency planning purposes, it is appropriate that this specific information is used. This will allow potential destinations to be considered, eg, the nearest unaffected large town is likely to be better able to cope with an influx of tens or hundreds of people. COCO-2 provides the following default values:

- The majority of buses and coaches have 36 or more seats and therefore the default capacity V_i is conservatively assumed to be 36. The operating cost C_i of a bus or coach per km is £1.20 (Scottish Executive, 2006)[†].
- The average cost of a transport ambulance journey is £48 per patient with the assumption of 5 patients per ambulance (Curtis and Netten, 2006)[‡]. The cost per km C_i and travelled distance d_i used in Equation 8.6 should be replaced with a cost per journey CJ_i.

In addition to the above default information, COCO-2 expects to be supplied with the number of people of each category evacuated (n_i) and the whole journey distance d_i for those travelling by coach.

[*] Note in estimating the distance travelled when evacuating or returning people coaches will generally travel one-leg of the journey empty and this should be included in the costing if appropriate by doubling the above result as shown in the example results of Section 12.

[†] This is the 2004/05 cost but for reference the 05/06 cost (Scottish Executive, 2007) is £1.29.

[‡] This is the 20004/05 cost based on Hospital and Community Health Services (HCHS) inflation indices (Curtis and Netten, 2006). For reference the quoted 2005/06 cost using the same indices is £50.

8.3.2 Short term accommodation cost

For those that do not self-evacuate to stay with relatives, etc, their most likely immediate location will be the reception centres set up under the emergency plan. People are not expected to be away for their homes and offices for very long and although the facilities of the reception centres, eg, municipal buildings, will be limited, they are likely to be adequate for some hours. Due to lack of data, COCO-2 only calculates the direct tangible cost of accommodation. In addition, because of the stress and inconvenience of being evacuated there will be a direct intangible component contributing to the loss suffered by those moved. This could be estimated together with the tangible loss by assessing the required CV (see Section 13.3). However, information on the expected CV is not readily available and the use of proxy measures such as compensation payments is fraught with difficulty as these may be assessed using many criteria and contain punitive elements that simply represent a transfer payment and not a loss to the economy through any reduction in welfare[*].

Independent of the need to accommodate people, facilities will be required to house their pets. If the owners were to be away for two or three days, animals could become distressed and potentially die. To calculate this cost, information would be required on the level of pet ownership and the likely cost of housing these animals. However, this cost is not assessed in COCO-2.

There will be an economic loss from the reduced GVA contribution of the public buildings no longer able to operate normally. However, associating a loss of GVA with the use of public buildings is difficult, as public administration will normally only contribute indirectly to the generation of economic activity[†]. In addition, although the temporary accommodation people are moved into is no longer being used for its proper purpose, eg, there may be a loss of sport centre services or hotel usage by visitors, the exact arrangements would depend on the particular circumstances of the accident and the available local facilities. However, the house prices in the area affected provides an alternative method of estimating the economic cost using imputed rents[‡].

The simplest way of estimating the loss to the economy of people maintained away from home for a few days, whether in a reception centre or hotel, is to consider the loss in the value derived from their house. Their asset provides them with accommodation, the value of which is equivalent to the rent they would otherwise pay less the maintenance component of that rent[§]. The maintenance component can be equated to the depreciation of the building where the building is an appropriate fraction of the cost of the property, ie, one that excludes the cost of the land.

---

[*] A transfer payment is a payment that is not associated with a productive output or service.

[†] Reception centres will be located in areas that are not directly affected by the accident. Unless their locations are known, there will be additional uncertainty introduced into any calculation of the loss of GVA due to their use as reception centres.

[‡] A similar approach was used in COCO-1.

[§] Maintenance preserves the asset value so that it can be sold without loss. Thus, money not spent on maintenance will be available to spend on return or a fraction of the asset value will have been converted to cash. However, the asset had no use value during any evacuation period and that is the accommodation loss.

Several potential approaches have been considered, for example Guðnason (2003) estimated the lifetime of a property and from that the value that must be gained from the use of the property each year, while student rents were used as a surrogate measure by the ONS project to develop a Household Satellite Account (HHSA) (Holloway et al, 2002). However, for COCO-2 a more direct and transparent calculation is made based on the net return from private rental property, which, according to information from the Association of Residential Letting Agents (a trade body for landlords)[*], was approximately 4.7% in 2004. COCO-2 uses this number in conjunction with an estimate of the value of the housing stock in the area to derive an overall imputed rental loss from the evacuated houses. The advantage of this measure is that it is directly relevant, stable[†], and readily available, without the need to estimate an average property lifetime or a real interest rate as required by the Guðnason (2003) approach. Note, in this formulation, that the number of houses evacuated is used to measure the loss from unused assets without reference to the number of individuals moved.

Thus, in COCO-2, the cost of short-term accommodation A_s is given by Equation 8.7, where ΔT is the time in days that people are away from their homes (RZ represents the areas where people are permanently removed and is discussed in Section 8.4.2) and the annual imputed rent IR is 4.7% of the value of the evacuated stock.

$$A_s = \frac{1}{365} \iint_{\substack{\forall \Delta T > 0 \\ (x,y) \notin RZ}} IRD(x,y) \times \Delta T(x,y)\, dx\, dy \qquad (8.7)$$

The Imputed Rental Density (IRD) is supplied in the accompanying file as the Imputed Rent (IR) in £ millions per square kilometre of Great Britain. It was derived from data supplied by the Land Registry for England and Wales, and by the Scottish Executive and HBOS plc[‡] for Scotland. The methodology for England and Wales was to use the supplied data on the value of housing sales in the categories of detached, semi-detached, terraced, and flats available at Medium Super Output Area (MSOA) resolution, which is an aggregate of a small number of Output Area (OA) census boundaries[§]. The data have gaps where houses of a particular type have not been sold in that area and although 2004 price data are used, the house numbers used are from the 2001 Census. The missing prices are estimated using the average percentage difference in price between categories of house and estimating the missing value from the next nearest house type, eg, estimating the price of detached houses from the semi-detached houses sold in the area multiplied by the average price differential. The net result is information on the average daily cost of keeping people out of their homes distributed geographically, which was then apportioned to values on a 1 km grid. The gridding of data is discussed in Appendix B. The methodology for Scotland was necessarily more approximate and complex, due to the limitations of the data, and is explained in full in Appendix B.

[*] http://www.arla.co.uk/index.htm

[†] At least over a few years, the rental return value used was an approximate average over the four quarters of 2004 - which was rounded up to 4.7% - from 4.68%

[‡] http://www.hbosplc.com/home/home.asp

[§] The MSOA represent areas with a mean population of 7200 people.

Communal dwellings that are commercial businesses, such as retirement homes, will lose GVA if closed and are thus automatically included with the other business categories in Equation (8.3). It would be double counting to include a loss of capital service as well unless the business re-established itself in new premises while still having to pay for the old. The costs and consequences of such actions are not considered in COCO-2.

There is no implication in this process that people would be accommodated differently just that the loss to the economy is related to the lost use of assets of a particular total value. There are uncertainties due to the need to use housing numbers that are slightly older than the price information, which in turn is not a random sample of the stock in the area, but the subset of those sold. The uncertainty in the Scottish data is likely to be larger due to the approximations involved. The numbers provided for England and Wales, and particularly for Scotland, are therefore indicative. If a more detailed assessment were required for any particular area the value of houses in the area affected could be estimated by purchasing a small amount of base information from the National Registers of Scotland or the Land Registry for England and Wales at limited cost.

If people are likely to be excluded for some time, then consideration should be given to longer-term costs including further capital service losses and ultimately the costs of lost capital, see Section 8.4.

8.4 Long-term and permanent relocation costs

A substantial countermeasure that may be applied is the relocation of the resident population of an area to protect them from the risk of elevated exposure in the long term. If this occurs, it may be possible, in some circumstances, for some manufacturing to continue within the affected area. However, for the purposes of COCO-2, it is assumed that if the population of an area is relocated then the manufacturing facilities within that area will be shut.

The variety of possible relocation scenarios are not of direct interest to COCO-2 except to the extent that they need to be accommodated by the model framework, eg, the costs of transporting people given in Section 8.3.1 can be adapted to fit any appropriate scenario. In addition to the short term losses discussed in Section 8.3 that arise when people are removed from their homes, there is, in principle, a cost to those employed outside the affected area that are required to change their daily travel plans. However, this group would be difficult to identify and, in any event, the CV required is likely to be a small factor in comparison to other costs and is not considered further by COCO-2. Note the model does not consider employment changes as a result of the accident and the induced effects that might arise from some people losing income while others gain (see Appendix A and Section 13.2).

The time taken for the economy to recover is generally assumed short[*] although local impacts may continue for some time. COCO-2 assumes that the economy will recover within two years and there is therefore no need to consider discounting[†].

8.4.1 Restoration costs

After a severe accident, it is likely that substantial remedial actions will be required to allow the affected community and region to resume a normal economic life. As part of a restoration and mitigation process, affected areas may be subject to decontamination measures. These are designed to remove deposited radioactivity from surfaces or at least to reduce the doses received. A great deal of work has recently been done on characterising the merits and effectiveness of the many different techniques that can be applied (HPA-RPD, 2005). The cost information gathered on these techniques is generally suitable for COCO-2. Thus, using this information the COCO-2 methodology is able to calculate the economic consequences of applying a particular sequence of countermeasures, chosen for a mixture of radiological protection and practical reasons. Although essential to the application of COCO-2 within a PRA model the criteria and rules to be applied to decide on the use of decontamination techniques are not considered part of the COCO-2 methodology. Thus, COCO-2 requires the cost of any countermeasures applied at any particular location and, as decontamination countermeasures are likely to generate waste, the cost of disposing of any waste generated (HPA-RPD, 2005). COCO-2 also requires the duration of any restrictions (ie, sheltering, evacuation, relocation) whether or not decontamination techniques are applied.

8.4.2 Long-term accommodation costs

Accommodation costs have been discussed under the heading of evacuation in Section 8.3.2 and the approach followed there will apply in the longer term with the additional consideration that housing deemed unusable for an extended period will be written off and the people permanently relocated. Some people may choose to move away from the area but if this is not deemed necessary by the authorities, the vacated house will be sold and any loss to the seller due to stigma will be a gain to the purchaser. Such transfer payments are not considered further in COCO-2. However, if people are excluded for an extended period the imputed rent based on the property values in the affected area should be adjusted to account for the expected changes in house prices that would have occurred without the accident. The accommodation cost of permanent resettlement A_p is given by Equation (8.8) where $\hat{A}_s$, the short term relocation cost, is of the same form as Equation (8.7) but for those households subject to permanent relocation, and $\hat{H}_p$ is the value of the lost capital asset, ie, the value of the houses less the value of the land.

[*] Following Buncefield a back office services company (Northgate Information Services) was fully functioning within days from alternative premises. http://www.information-age.com

[†] Second year losses can be discounted but the uncertainty in the loss estimated over two years is likely to be much greater than the difference between the total undiscounted and discounted costs.

$$A_p = \hat{A}_s + \hat{H}_p \tag{8.8}$$

It is assumed that ownership of the lost assets will be transferred to local or central government, which will eventually release the land for development when the level of contamination has reduced sufficiently for this to occur. Land values are not provided on a regular grid in the accompanying file. However, regional data, which will provide an indicative price per hectare, are freely available from the Valuation Office Agency (VOA) website* (see Table 8). At the resolution of the VOA data, it is likely that a single value will be sufficient to represent the residential land value in the affected area. COCO-2 assumes that any work carried out shortly after an accident to, eg, prevent the spread of radioactivity from abandoned properties, secure the site, or even to demolish abandoned buildings for disposal, will be fully costed (see HPA-RPD, 2005). It is further assumed that the cost of any ongoing work, for example to prevent access to the abandoned buildings while they pose a risk, will be negligible and is not considered further by COCO-2.

TABLE 8 Value of land for residential development as at January 2004[1]

Region	Small Sites £s per ha	Bulk Land £s per ha	Sites for flats or maisonettes £s per ha
North East	1,590,000	1,490,000	1,820,000
North West	1,740,000	1,700,000	2,090,000
Merseyside	1,250,000	1,120,000	1,340,000
Yorkshire and the Humber	1,650,000	1,640,000	1,950,000
East Midlands	1,950,000	1,800,000	1,950,000
West Midlands	1,950,000	1,870,000	1,850,000
Eastern	2,830,000	3,280,000	3,600,000
South East	2,930,000	2,770,000	3,350,000
South West	2,260,000	2,030,000	2,430,000
Wales	1,360,000	1,320,000	1,400,000
Inner London	8,900,000	6,995,000	9,700,000
Outer London	5,790,000	5,530,000	6,780,000
Scotland	1,340,000	1,410,000	2,590,000
Northern Ireland	1,163,000	1,154,000	1,346,000

[1] http://www.voa.gov.uk/publications/property_market_report/pmr-jan-07/residential.htm

The presence of restricted areas and abandoned properties may blight neighbouring areas where no restrictions are imposed. However, the loss of value is uncertain and difficult to assess, as it will depend on how the restrictions are implemented and perceived (see Guntermann, 1995 and Walker, 2000). It can also be argued that the loss from blight is the result of a perceived risk where the actual risk is insufficient for the authorities to take action and, in line with the argument applied to potential tourism losses from similar perceived effects, should not be considered further. This loss is

* http://www.voa.gov.uk/publications/property_market_report/pmr-jan-07/residential.htm

therefore not considered further in COCO-2 but discussed as an area for further work in Section 13.3.

If permanent relocation is to occur, it is likely that this decision would be made at an early stage and the short-term relocation cost $\hat{A}_s$ will therefore only accrue for a limited period after which time it is assumed that the legal transfer process will be completed and those affected will be able to buy or rent property. However, COCO-2 does not attempt to model the housing market and therefore makes no allowance for the ease or difficulty of finding alternative accommodation. This should only be a problem if the numbers affected are large (see Section 13.2)*.

Thus, expanding Equation 8.8, COCO-2 estimates the loss from permanent relocation using the formula of Equation 8.9:

$$A_p = \iint_{(x,y)\in RZ} \left\{ \frac{IRD(x,y)\times\Delta T(x,y)}{365} + H_p(x,y) - vl(x,y) \right\} dx\,dy \quad \forall \Delta T \le 730 \qquad (8.9)$$

where the relocation zones (RZ) are the collection of areas where the population are not returned to their homes, ΔT is the time in days this group is in temporary accommodation, H_p is the house price per square kilometre, vl is the value of land per square kilometre (see Table 8) and IRD the imputed rental density introduced in Section 8.3.2. COCO-2 supplies IRD and H_p in the accompanying file but expects ΔT and the RZ areas to be supplied.

8.4.3 Lost capital services

Capital services represent the benefits gained from invested capital and in the context of an accident represent the infrastructure affected by the release. In particular, they represent the houses and factories contaminated and in need of decontamination. However, the capital assets of business exist to support the production of GVA and the loss incurred because business assets are unused is already accounted for through the estimated loss of GVA discussed in Section 8.2. The loss of capital services from empty housing stock has already been discussed in Section 8.3.2 and this section therefore focuses on the cost of lost capital services in household goods and follows the discussion given in the experimental Household Satellite Account (HHSA) from National statistics (Holloway et al*,* 2002).

Within the context of COCO-2, serious contamination within buildings is less likely than contamination of exterior surfaces and the loss of goods from such an event is therefore only likely to be a problem when severe or unusual accidents occur. In the latter category, the Goiania accident, briefly discussed in Appendix E, resulted in a large number of possessions being disposed off, some of which were of sentimental value. COCO-2 does not attempt to assess a suitable CV for the loss of objects of sentimental

* A large number of potential cash buyers of houses would provide a stimulus to the market.

value, which in the terminology of Table 1 are direct losses of intangible value. However, the UK recovery Handbook (HPA-RPD, 2005) does provide information on the decontamination of household possessions and precious objects in the event that that might be required.

COCO-2 provides the option to assume that if an affected population is permanently relocated they may, depending on the circumstances, be able to take their possessions with them. In this case, there will be no loss of capital service from the goods owned by those relocating. However, if people are moved out of their houses for a short period, eg, a week or a month, until the affected area has been decontaminated then it is thought unlikely that they would be able to take a substantial number of possessions with them and there will be a small loss.

A similar argument to that previously employed to estimate the loss of derived value from the housing stock when people are removed from their homes while decontamination occurs is used to value the lost use of assets. The HHSA proposes that to measure the contribution of household capital to household production, an estimate is required of the value of the services they provide. There is no market information giving rental prices or stock prices of household goods and therefore data on expenditure from the National Accounts is used in conjunction with a perpetual inventory model (PIM) to estimate the value of capital consumption, as a proxy for the value of capital services. The assumption is that goods are regularly replaced and the benefit gained from the services provided each year equals the yearly loss in value of the goods. Thus, consumption of fixed capital is measured as the decline, during an accounting period, of the current replacement value of the assets used because of deterioration, obsolescence and accidental damage.

Household capital is classed as those items that are described as durables, eg, white goods. Semi-durables (household textiles, glass and crystal-ware, cutlery, kitchen utensils, small tools, etc) may last for many years indeed as long as or longer than some durables, but are generally of less value. The HHSA represents these items as intermediate consumption, as it is impossible to know when they are likely to be replaced particularly as this may occur for reasons of changing fashion and taste.

The National Accounts are insufficiently detailed to develop a perpetual inventory model for HHSA purposes. This is because goods with very different service lives are classified together. Therefore, to disaggregate the National Accounts data to construct the HHSA, the National Accounts classification was split and market research information on the value of purchases of specific white goods compared with detailed data from the Family Expenditure Survey (FES).

8.4.4 Household asset loss

The data required for the PIM are constant price expenditure at the appropriate level of detail together with the required average asset lives. Items that are more technical are also required: such as a depreciation formula for the assets, deflators, to allow the capital consumption to be reflated to current prices, and a mortality function, which describes how assets are retired around their average lifetime.

The HHSA includes a discussion on motor cars but the inclusion of cars as a major component of consumer durable loss is problematic as an unknown but potentially large number of those who have left the area may have self-evacuated, ie, they have taken their car with them. Thus, in estimating the capital service loss incurred before the population returns, it is likely that if motor cars are included, costs will be overestimated. However, if some of the population were not able to return and the resulting capital losses are considered, then, if goods within houses are being treated as capital losses, it is reasonable to assume that cars will also be capital losses. Essentially this is not an economics issue but a countermeasure modelling problem and beyond the scope of COCO-2. However, COCO-2 provides the appropriate component costs to allow any combination to be modelled.

The average life lengths for new and second-hand cars and for motorcycles were obtained from the DVLA – these are different from the life length of business vehicles used in the National Accounts, because different patterns of usage are assumed for households and businesses. In addition, the COICOP* series for motor cars includes dealers' margins on second-hand car sales and estimates of cars in kind, both of which, for the purposes of estimating the capital stock and consumption, must be excluded.

Information on asset service life lengths of white goods has been collected by the E-SCOPE† study (Cooper and Mayers, 2000), investigating the purchase, use and disposal of household appliances in the UK. Estimates of average life lengths for furnishings, carpets and bicycles have been taken from the Eurostat working paper (Varjonen J et al, 1999).

The value of consumer durable services lost due to householders temporarily moving to new accommodation can be estimated from the household consumption of capital from the HHSA provided for the whole country multiplied by the fraction of houses relocated with respect to the total housing stock and the fraction of a year the occupants are removed. This figure could be adjusted to account for the differences in wealth in different regions if required. Table 9 shows the annual capital consumption estimated in the HHSA project by ONS. Note the consumer durables considered are those that are assumed to contribute to the generation of household GVA.

*COICOP is the Classification of Individual Consumption According to Purpose (United Nations statistical methodology).

† E-SCOPE Electronics industry – Social Considerations of Product End-of-Life.

TABLE 9 Household capital consumption by asset type from HHSA (2000) (£ million)

COICOP class	Asset type	Asset life (years)	Capital	Capital consumption[1]	Capital[2] (2004)	Capital (2004) consumption[2]
05.1.1	Furniture	[3]15	54,538	7,162	60,906	7,998
05.1.2	Carpets	[3]10	12,719	3,075	14,204	3,434
05.3.1	Cookers	[4]12	4,549	638	5,080	712
	Microwaves	[4]7	705	169	787	189
	Fridges & freezers	[4]11	4,209	643	4,700	718
	Dishwashers	[4]9	881	164	984	183
	Washing machines & driers	[4]9	4,051	753	4524	841
	Showers, fires, vacuum cleaners, etc	[4]8	4,285	895	4,785	1000
05.5.1	Tools	[3]7	1,124	288	1,255	322
07.1.1	New cars	[5]13	83,186	14,198	92,899	15,856
	Second hand cars	[5]11	38,612	5,931	43,120	6,624
07.1.2	Motorcycles	[5]10	3,541	544	3,954	608
07.1.3	Bicycles	[3]9	3,428	558	3,828	623
	Total H_C		215,828	35,018	241,028	39,107
	Total less cars and motorcycles H_{CE}		90,489	14,345	101054	16,020

[1]HHSA PIM estimates.

[2]Value adjusted by a GDP deflator of (1.12) from the deflator series provided by HM Treasury on 28 March 2007.

[3] From a Eurostat working paper (Varjonen et al, 1999).

[5]DVLA cars in kind and dealers' margins on second hand cars have been excluded.

[4]From the E-Scope Study by Cooper and Mayers (2000).

The assumption is made that the market is at steady state and new appliances are bought to replace old appliances. However, as the number of households in the country is increasing as a function of time due to changing lifestyles with more people living alone that assumption will tend to over estimate the value of the loss. COCO-2 makes the further assumption that all households have the same basic complement of appliances. If data were available, this could be adjusted not only regionally but also socio-economically possibly through some proxy measure such as house type or the mosaic classification*.

If the population were to be temporarily relocated for more than a year, the second year loss would accumulate at the same rate, as linear depreciation is assumed†. However, as this loss is only applicable to temporary relocation, it is unlikely to last as long as a year. Nevertheless, the value lost through temporary relocation is given for a maximum of 2 years by Equation 8.10:

$$H_{CS} = H_{CE} \frac{n \times \Delta T}{365 \times N} \quad \forall \Delta T \leq 730 \qquad (8.10)$$

* http://www.business-strategies.co.uk/

†Consistent with other second year losses considered by COCO-2 no discounting is applied. As previously stated the uncertainty in the estimated loss is likely to be greater than the expected difference between the discounted and undiscounted second year loss.

where ΔT is the number of days those relocated are away from their homes, n is the number of dwellings affected and N is the total number of dwellings in the country. Information on dwellings from the 2001 census is provided in the accompanying file and discussed in Section B7. Thus, the loss of household capital services from consumer durables H_{CS} is given by the total annual household capital expenditure of Table 9 less the value of motor cars and motor cycles (H_{CE}), times the faction of the year (in days) that the population is removed and the fraction of the total housing stock affected[*]. Note the modelling for cars in the HHSA is from 1986 and therefore should be used with caution if at all.

In the unlikely event of all household goods being lost Table 9 will provide a minimum estimate of that loss H_{CL} by taking the total capital value of household goods H_C and multiplying it by the ratio of houses affected (n) to the total number of houses (N) as shown in Equation 8.11.

$$H_{CL} = H_C \frac{n}{N} \tag{8.11}$$

In this case, it would be appropriate to include the loss of cars and motorcycles, as they will be at least at the same risk of substantial contamination as the goods inside houses. Equation 8.11 is likely to underestimate the loss as only a limited selection of household products is included. There is a shortage of information on the value of household possessions but estimates by Royal Sun alliance in 2003[†] suggests that the total value of the contents in UK homes is £756 billion with an average value for a typical household of £41,914. This estimate is approximately three times that of H_C given in Table 9 without accounting for the exclusion of motor cars from the total. This problem is discussed further in Section 13.

8.4.5 Business asset loss

Similar arguments should apply to the lost services of business capital assets and interdicted land. In the latter case, land could be re-zoned and the loss would arise from the change of use. This is mostly likely to occur as an agricultural countermeasure and land is therefore discussed in Section 9.

The most likely loss of business capital will occur if business premises are abandoned for some period while they are decontaminated. The GVA loss discussed in Section 8.2 assumes that a component of the turnover is used to service the capital requirements of the business. However, if a business relocates to new premises so that it can resume production more quickly it will incur new capital costs from the rental of new premises without necessarily relinquishing the old costs. Unfortunately, as discussed in Section 8.2 it is not known exactly what proportion of businesses will relocate and on

[*] The assumption is made that cars and motor cycles were taken by those temporarily removed.
[†] http://www.rsagroup.com/rsa/pages/media/morethanmediacentre press release October 2003

what time scale. However, although moving will impose costs it is likely that a business will only do this to minimise its overall losses and therefore not considering this aspect of the problem is conservative.

If, following a very severe accident all the businesses in an area are forced to relocate because it is considered impractical to decontaminate, the capital loss of the buildings can be estimated as the property value of the vacated premises. COCO-2 estimates this loss from the ratio of the rental value to rental yield for the type of property. Rental information is available at MSOA resolution from the Valuation Office Agency (VOA) via the DCLG and ONS for England & Wales*. Regional yield information is also available from the VOA for industrial, warehousing and retail premises although the latter data is likely to over estimate the contribution of large retail units. Information on office yields is more difficult to locate but data on equivalent yields published by the independent property databank (IPD)† an umbrella organisation that collects information on behalf of major property companies has been used to derive the necessary yield data (Smith, 2006). An equivalent yield takes into account periods when buildings are unoccupied but this obscures the capital calculation and the approach adopted was to use the ratio of equivalent yields for industry and office properties from IPD to generate an effective office yield based on the VOA industry yield. The IPD database is primarily focussed on larger and more valuable properties, which may bias the estimate although the use of a ratio of IPD yields as a correction to VOA data should help to minimise the effect. Thus, as shown in Equation 8.12, the lost capital value of commercial and industrial buildings CI_C can be calculated by multiplying the total capital value per square kilometre in the affected zones by the area of the affected industry zones AZ determined by the countermeasures in force‡:

$$CL_c = \iint_{(x,y)\in AZ} CD(x,y)dxdy \qquad (8.12)$$

where CD is the capital density given by the sum of industrial, warehouse, retail and office capital values in £ millions per km^2. COCO-2 expects information on the extent of the AZ to be supplied.

If, following a severe accident, industrial and commercial buildings are vacated, there is a possibility that the contents may also be lost. There is no direct measure of the capital assets associated with particular industries or activities collected as a national statistic. However, the quantity of interest is estimated at a national scale by ONS using a Perpetual Inventory Model (PIM) (Giffen et al, 2005), which has been the subject of a recent review to make its predictions more robust (West and Clifton-Fearnside, 1999).

* Aggregated information of this type is not available for Scotland.

† http://www.ipd.com/

‡ AZ is the affected industry zone, which is the zone industry is excluded from. It may be coincident with the relocation zone RZ where people no longer live but does not need to be.

The assumption made in COCO-2 is that although property values change with location the value of plant and machinery will not and national data can be used. This may not be strictly true as manufacturing plants in more depressed areas may retire their machinery later but if this occurs, it is likely to be a minor effect. The main differences between regions are the size of the local economy and the change in the dominant business sector. The approach adopted is therefore to apportion capital estimates derived by the ONS in the ratio of local GVA to national GVA for that sector of the economy, ie, it is assumed that capital exists to support the production of GVA. This is consistent with the COCO-2 assumptions on productivity used to derive the GVA estimates and discussed in Section 11.1.

At the national level a more aggregated SIC division is employed but this is not expected to cause particular problems. The lost capital value is therefore given by Equation 8.13 where PMR_{SIC} and TER_{SIC} are the ratios of capital in plant and machinery and transport equipment in a sector to the GVA generated by the sector respectively.

$$C_{PM} = \iint_{(x,y)\in AZ} \sum_{SIC} GVAD_{SIC}(x,y) \times \left(PMR_{SIC} + TER_{SIC}\right) dxdy \qquad (8.13)$$

Transport equipment is included in Equation (8.13) as a separate item because it may not be within the affected zone AZ at the time of the accident. However, COCO-2 does not consider this issue further. The values of PMR and TER for 2004 are given in Table 24 of Section 11.3.

9 MODEL APPLICATION: AGRICULTURE

One of the features of agricultural losses, which differ from losses in other sectors of the economy (where production may be affected but not the product), is the connection between the product and the duration of any restrictions imposed. The general assumption of COCO-2 is that factory production is continuous and uniform and therefore the closure of a factory for a period will result in a loss proportional to the length of time that the factory is closed. In agriculture, restrictions vary with the product and potentially with where that product is produced within a single enterprise. In addition, the GVA from restricted products is not necessarily generated uniformly throughout the year and, in distinction with industrial production, variable inputs are more likely to be lost following the imposition of restrictions on the sale of food. The economic consequences of agricultural restrictions are therefore measured in terms of the Output and GVA losses incurred, where Output measures the sum of GVA and variable input costs. The values of Output and GVA used have been provided by Defra. The data sources and assumptions made to estimate these values are discussed in

Appendix C*. COCO-2 does not provide the underlying agricultural production data but appropriate data are available, eg, data may be licensed from EDINA†.

The cost of applying countermeasures to crops and animals including any breeding stock affected should be added to any estimate of the loss incurred. This might be minimal, for example, if a restricted crop had only recently been sown and it was decided to plough the crop in, or more substantial if, eg, it were appropriate to harvest and compost the crop. Whatever stage production has reached there are likely to be a variety of countermeasure options available and these and their associated costs are discussed in detail in HPA-RPD (2005) and briefly, together with disposal costs, in Appendix C. However, apart from countermeasure costs it is assumed that, where practical, no further inputs, eg, the application of fungicide treatments, will be made to crops that cannot be sold. Note if a countermeasure were applied that reduced the uptake of radioactive material sufficiently for some crops or animals to be sold, there would be no loss of output for this fraction of the production and the only additional cost for this production would be the cost of the countermeasure applied.

COCO-2 provides model estimates for agricultural losses arising from restrictions placed on a periodic production process (eg, cereals) or restrictions placed on a continuous production process such as, for example, milk. Section 9.1 describes the model appropriate to periodic production and Section 9.2 describes the model appropriate to continuous production with the subsequent two sub-sections describing the variations required when considering the continuous production of animal products. Section 9.3 provides an expression that allows the indirect loss contribution to be included in the loss estimate while an example application of the models of Sections 9.1 and 9.2 to specific crops is elaborated in Appendix C. Before deriving the appropriate formulae Table 10 provides a convenient summary of the small number of parameter values required to evaluate the agricultural loss equations described in the following sub-sections.

---

* Default costs for other sectors are quoted for 2004; however, agricultural output and GVA values have been averaged over the years 2003 - 2005 to remove seasonal fluctuations.

† EDINA national data centre Edinburgh (www.edina.ac.uk)

Table 10 Output and GVA per hectare and for crops modelled as periodically produced the annual average seasonal adjustment factor <QF>

	Cereals	Potatoes	Sugar Beet	Root vegetables	Green vegetables	Legumes	Orchard Fruit	Soft Fruit
Output per hectare (£)[1]	512	3,787	1,769	10,280	8,161	1,399	5,741	22,440
GVA per hectare (£)[2]	259	2,476	1,012	3,627	3,059	524	3,087	11,508
<QF>[3]	0.56	0.44	0.74	-	-	0.26	0.23	0.23
	Cattle	Cow milk	Sheep					
Output per animal £[1]	279	1,015	39					
GVA per animal £[2]	49	544	22					
<QF>[3]	-	-	0.63					

[1] The value averaged over three years, see Table C2.

[2] The value averaged over three years, see Table C3.

[3] The values are estimated using Equation 9.2 and the assumption that the probability of an accident occurring is independent of the season of the year as described in Appendix C. The values shown are the recommended values from Tables C5, C7, C9, C11, C13, C15 and C17 with the estimate where appropriate based on the harvest year, see Appendix C.

9.1 Periodic production and seasonal costs

As stated in Section 9 above inputs such as seed, sprays, fertiliser, etc, vary with the season so that production costs do not accrue uniformly over the year. The simplest way of incorporating this effect is to use a seasonal multiplier that represents the fraction of the final output value of the crop accrued before the accident. Any restrictions predicted to be in force at harvest, will then only result in the loss of a fraction of the full output value of the crop, as determined by the multiplier applicable at the time of the accident, ie, it is assumed that, where practical, variable inputs will cease if the crop cannot be sold at harvest.

The GVA realised from the sale of a crop will always be lost if the sale is restricted for a sufficient period, regardless of whether any variable inputs have been used. This is consistent with the situation for restrictions that extend to a subsequent harvest when only the GVA value will be lost.

Thus for crops that are only harvested once a year, eg, cereals, the loss in the first year is given by Equation 9.1:

$$DL_{GVA} = F \times (QF(s) \times (Output - GVA) + GVA) \qquad (9.1)$$

where DL_{GVA} is the direct loss in £ from not being able to sell the crop, F is the hectares of food restricted from sale because it exceeds or will exceed the criteria at harvest, QF(s) is a dimensionless loss fraction for the season the accident occurs and the Output and GVA are in units of £ per hectare*. If appropriate, the expected seasonal independent loss can be calculated by replacing the seasonal loss fraction by its weighted average:

$$\langle QF \rangle = \sum_s QF(s)p_s \qquad (9.2)$$

where p_s, is the probability of an accident occurring in any particular season.

For restrictions predicted to be in force at harvest in the second year, it is assumed that the affected crop will not be planted again and there will therefore be no loss of the second year variable inputs, reducing the second year loss to that given by Equation 9.3†.

$$DL_{GVA} = F \times GVA \qquad (9.3)$$

Appendix C provides estimates of QF(s) and ‹QF› for a selection of crops with the latter evaluated under the assumption that all seasonal probabilities are identical‡.

9.2 Restriction costs for continuous production

If the agricultural product is continuously produced, it is assumed that seasonal inputs will be broadly constant throughout the year and any losses are independent of the season the accident occurs. The assumption of continuous production can be applied to both crops and animal products with slightly different formulations in each case.

9.2.1 Crops

The simplest assumption that can be made is that an amount of the annual output proportional to the restriction period is lost in the first year and if restrictions extend into the second year, the amount of GVA proportional to the second year restriction period is lost. However, these assumptions are not very satisfactory as they implicitly assume that the product will take a year to grow and that inputs continue to be made to crops with no sale value on harvest. A more realistic model of the loss will require the assumption of an average time from planting to harvest. Strictly, this average time will subsume many factors that depend on the particular crop and for crops that are actually planted throughout the year, the particular planting season. For example, winter planted crops may take longed to mature than those planted in the spring. Nevertheless, if a representative growth period is selected and if fallow periods are neglected, then assuming that inputs are supplied continuously, the output loss following restrictions that

* A year can be divided biannually into just ‘summer’ and ‘winter’ seasons if required.

† This assumes that any inputs already bought for the next season can be kept or sold on.

‡ The units of the output and GVA values should be consistent with those for the amount of food restricted ie if required the values of Tables C2 and C3 can be converted to £ per kg provided that the conversion factor is applied consistently to the amount of crop affected.

last for less than the growth period can be represented by Equation 9.4[*] (see Appendix C):

$$DL_{GVA} = \frac{F\Delta T}{365}\left[\frac{2GP + 1 - \Delta T}{2GP}(output - GVA) + GVA\right] \tag{9.4}$$

where F is the area in hectares with restrictions lasting for a given time ΔT in days and where the crops have an average growth period of GP days such that $\Delta T \leq GP$[†].

If the restrictions are predicted to last longer than the growth period, the additional losses will be proportional to the GVA to give the total loss shown in Equation 9.5 (see Appendix C for the derivation):

$$DL_{GVA} = \frac{F}{365}\left[\frac{GP + 1}{2}(output - GVA) + GVA \times \Delta T)\right] \tag{9.5}$$

The growth period is a modelling input to be supplied to COCO-2. In general, there will be a series of losses representing areas subject to restrictions of different lengths ΔT.

The continuous production model assumes that plants are available for cropping in a sequence in which each term of the sequence is a day further from harvest. The growth period indicates how long an area of ground is being used by a crop before it can be re-sown.

For generality, and as discussed in Appendix C, some crops may not lose value if the restriction on their sale is less than or equal to a Buffer Time (BT) of a few days. Strictly, as well as there being no loss if the restrictions last for BT days or less there will be no loss associated with crops sown up to BT days before the start of the restrictions if the restrictions last for the entire growth period or less. If the restrictions are longer than the growth period plus BT days there will be a GVA loss from the planting that does not occur. A further generalisation recognises that crops in different areas will be restricted for different periods and thus, the total loss from restricting the sale of continuously produced crops for various lengths of time is given by Equation 9.6.

[*] Strictly fallow periods are implicitly included in the output and GVA values and in the averaging of the production over each EDINA grid cell.

[†] The divisor 365 approximates the number of days in the year and converts the annual output and GVA values to units £ per hectare per day. The units can be re-expressed in terms of a yield if required.

$$DL_{GVA} = \sum_n \frac{F_n(\Delta T_n - BT)}{365}\left[\frac{2GP + 1 - (\Delta T_n - BT))}{2GP}(output - GVA) + GVA\right]$$
$$\times [\theta(GP - (\Delta T_n - BT)) - \delta(\Delta T_n - BT - GP)]$$
$$+ \frac{F_n}{365}\left[\frac{GP + 1}{2}(output - GVA) + GVA(\Delta T_n - BT)\right]\theta(\Delta T_n - BT - GP)\ \forall \Delta T_n > BT \tag{9.6}$$

$$where\ \ \theta(x) = \begin{cases} 1\ \forall x \geq 0 \\ 0\ \forall x < 0, \end{cases} \quad \delta(x) = \begin{cases} 1\ x = 1 \\ 0\ \forall x \neq 0 \end{cases} \quad and\ \ \Delta T_n = \min(\Delta T_n, 730)$$

In evaluating Equation 9.6, COCO-2 expects to be provided with the growth period GP and buffer period BT, (which may be zero) as well as the hectares of crop F_n, restricted for each period ΔT_n where n labels the time period of the restriction*. After 2 years, it is assumed by COCO-2 that production elsewhere will replace any production lost through continuing local restrictions.

9.2.2 Animal products

Continuously produced animal products such as milk and beef require a slightly different formulation to that of crops. In the latter case, variable inputs can be stopped while this is not possible for animals, which must be maintained for welfare reasons or culled. Thus, lost output costs are given by Equation 9.7 for continuing production that cannot be sold:

$$DL_{GVA} = F \times \tfrac{output}{365} \times \Delta T \tag{9.7}$$

where $\Delta T = \min(\Delta T, 730)$ and F is the number of animals affected.

In Equation 9.7 F is, for example the number of cows whose milk production cannot be sold for a period of ΔT days after the accident or alternatively the number of beef cattle that cannot be sold. The output value is expressed in £ per animal per year. As in Section 9.2.1 it is assumed by COCO-2 that after 2 years production elsewhere will replace any production lost through continuing local restrictions. As indicated above Equation 9.7 will also apply if the dairy cows are dried-off but maintained on the farm, as variable input costs will continue to accrue. However, in this case disposal costs for waste milk need not be considered beyond the time $T_p < \Delta T$ when milk production stops.

If it is thought appropriate to end production quickly by culling the animals T_p days after the introduction of restrictions, then the loss from actual and potential sales will be given by Equation 9.8 where the GVA is in £ per animal per year and F is the number of animals affected.

* If it were easier to implement as part of an ACA code Equation 9.6 can be rewritten as an integral over the affected area with a spatially varying restriction time.

$$DL_{GVA} = \frac{F}{365} \times (output \times T_p + GVA \times (\Delta T - T_p)) \; \forall \Delta T > T_p \tag{9.8}$$

$where \; \Delta T = \min(T, 730)$

This approach, if applied to milk production, will reduce milk disposal costs while incurring the additional costs of disposing of the dead animals (see Appendix C) and the capital loss from their slaughter. However, if applied to beef production, no capital loss is assumed. It is a modelling issue and not a question for COCO-2 as to whether the parent beef herd is also culled (see Section 9.4).

9.3 Including indirect losses

The indirect loss from agriculture is calculated in a similar way to the calculation of the indirect business loss considered in Section 8.2 with two exceptions: only a single multiplier for agriculture is required and the time lag inherent in some agricultural production should be accounted for. This latter effect stems from the delay between the commitment of resources and the sale of the final product. Thus, it is possible for an indirect contribution to be made to the economy through the purchase of fungicides or fertilisers, etc, while the eventual product is subsequently restricted from sale. The indirect loss for periodic production in £ (IL_{GVA}) corresponding to the direct loss DL_{GVA} is given by Equation 9.9:

$$IL_{GVA} = (M_{A01} - 1) \times \left[F(Output + GVA) - DL_{GVA}\right] \tag{9.9}$$

where M_{A01} is the agricultural multiplier of Table 21 in Section 11.2.1 and F is the hectares of food or animal products restricted from sale. If all variable inputs have been committed, eg, the accident occurs near harvest, the indirect loss of Equation 9.9 is proportional to the lost GVA while if few inputs have been committed, eg, the crop has yet to be sown, then the indirect loss of Equation 9.9 is proportional to the output lost[*].

The continuous cropping model represented by Equation 9.6 includes a production lag to allow the crop to grow and inputs to be delivered. As with Equation 9.9, the indirect loss is proportional to the output that would be generated over the period of the restrictions less the variable inputs that have already been made. The indirect loss from continuous cropping is given by Equation 9.10:

[*] An output multiplier is used, as a GVA multiplier is not available. However, the main source of multiplier uncertainty stems from the use of a single representative multiplier for different types of agricultural loss. Horticultural and dairy farming are likely to differ in their impact on the wider economy. See the discussion of Section 11.2.1.

$$IL_{GVA} = (M_{A01} - 1) \times \left[\sum_n \frac{F_n(\Delta T_n - BT)(Output + GVA)}{365} \theta(\Delta T_n - BT) - DL_{GVA} \right] \qquad (9.10)$$

where ΔT_n is the duration of any restrictions for the crop covering an area F_n in hectares and BT is the buffer time before restrictions result in a loss. All other terms are as defined in Equation 9.9 except for the direct loss DL_{GVA}, which is given by Equation 9.6.

In comparison to Equation 9.6 the indirect loss stemming from the loss of continuous milk or beef production (IL_{GVA}) can be easily derived from Equation 9.7 and is in effect analogous to the calculation of the indirect loss from industry, eg, see Equation 8.2. The indirect loss is given by Equation 9.11:

$$IL_{GVA} = DL_{GVA}(M_{A01} - 1) \qquad (9.11)$$

where DL_{GVA} is the direct loss of Equation 9.7 and M_{A01} is the agricultural multiplier of Table 21 in Section 11.2.1. This equation will also apply to the indirect loss when the direct loss is represented by Equation 9.8.

9.4 Loss of capital stock

If a cull of producing animals is instigated, there will also be a capital loss, which can be approximated using information from Nix (2007)[*] on the cost of replacements and the effective depreciation rate. A replacement down-calving heifer costs £750, a cull cow is worth £300 and 25% of a herd is replaced every year, which implies that on average the cows culled to end milk production will be worth £525 each. Unless specific information is available on the beef production systems affected the same value can be used for the parent herd. A similar calculation based on information from Nix (2007) can be made for ewes to give an approximate value for culled sheep of £50 each.

Loss of farm machinery and housing is included under the discussions of Sections 8.4.5 and 8.4.4 respectively. If an area of land has restrictions placed on it, which prevent it being put to any productive use, then the capital loss is the area affected multiplied by the local value of agricultural land, estimates of which are available from the VOA[†].

[*] A cull cow was worth a little more (£310) according to Nix (2004) with all other values unchanged to give an essentially identical average value of £530.

[†] It would be inappropriate to assume that the land could be set-aside as this could only be a short-term management option.

10 MODEL APPLICATION: HEALTH

Health costs fall into two distinct categories: firstly, the cost that arises directly from the care and treatment of a patient and the net loss of that patient's productive output of both paid and unpaid work, and secondly, from the reduction in a patient's quality of life. This division and some of the philosophical associations were discussed in Section 7.

10.1 Value of preventable fatality

For consistency with estimates used throughout government, COCO-2 bases its WTP estimates on those derived by the DfT for the VPF from road traffic accidents. This has obvious advantages but there are inevitable complications that arise from the use of the DfT value in COCO-2. The DfT is interested in an aggregate willingness to pay for a risk reduction that, taken over the group affected, can be expected to prevent one premature fatality. However, unlike the COCO-2 situation any deaths rising from a road accident are unlikely to occur decades after the event and will not be from a dread cause such as cancer.

Jones-Lee et al (2007) discusses both the appropriate discounting to apply to cancers that are unlikely to appear until those exposed are elderly and the recommendation, in line with the conventional Department of Health approach, that no dread weighting is considered for cancer.

The mid-value of the VPF was estimated to be £1¼ million in 2002, which includes a small addition for resource costs, ie, medical care and net output losses on top of the WTP component. The component costs of this VPF are shown in Equation 10.1 rounded to the nearest thousand pounds.

$$\begin{aligned}
&\text{VPF} = \text{WTP} + \text{NetOutput} + \text{Medical} \\
&\text{Where VPF} = £1{,}250{,}000 \\
&\text{WTP} = £1{,}170{,}000 \\
&\text{NetOutput} = £81{,}000 = 430{,}000 - 349{,}000 \\
&\text{Medical} < £1000
\end{aligned} \qquad (10.1)$$

In Equation 10.1, net output is the difference between productive output and consumption where productive output is the output from paid employment. The reason for quoting the 2002 valuation is that it is reported by the Treasury (2005) in the above form whereas for historical reasons the DfT combines the WTP and consumption components obscuring the origins of the various terms.

The up rating procedure advised by the DfT and given by Equation 10.2 uses an index to reflect inflation and real per capita economic growth*.

$$1 + \frac{\%\ increase\ in\ nominal\ GDP\ per\ capita}{100} \qquad (10.2)$$

Table 11 gives the values supplied by the DfT for fatalities together with the interpolated values for WTP and net output based on the Treasury breakdown.

TABLE 11 Department of Transport VPF component terms[1]

Year	VPF £(000)	WTP £(000)	Net Output Lost £(000)	Medical cost £
2002	1,250	1,170	81	740
2003	1,312	1,228	85	770
2004	1,385	1,296	90	817
2005	1,430	1,337	95	840

[1]http://www.dft.gov.uk/pgr/roadsafety/ea/

It is clear from Table 11 that the WTP term completely dominates the costs assigned to road traffic fatalities. Before progress can be made in applying this information to COCO-2, it is appropriate to establish if this result will apply for radiation-induced disease. For example, one particular problem with the DfT assessment of WTP with respect to its application to radiation-induced diseases is that of deferred consequences. The WTP to reduce the risk of road traffic accidents represents a measure of the aversion to injury or death in the near future. However, if the majority of health effects following an accident were deferred for thirty or forty years the WTP to avert any manifested injury or subsequent death is likely to be greatly reduced by the effect of time preference. Although discounting can be applied to the DfT values, without a specific survey to assess the public view of paying to reduce deferred consequences, there will be uncertainty over the appropriateness of the valuation used (see Section 10.4).

10.2 Productive losses

Consider first the net output loss, which is perhaps the simplest term to understand even if it is not straightforward to value. If people die because of radiation induced cancers or deterministic injuries, their direct economic contribution to society in terms of both production and consumption will end. In terms of the productive loss, an estimate will be the current monetary value of the net future productivity lost due to radiation induced premature mortality. In these terms, the estimated cost to society of deaths resulting from the accident is the product of the number of deaths and the discounted value, with age and sex taken into account, of an individual's lifetime productivity including both

*The change in the nominal GDP per-capita is an approximate measure of the increase in the standard of living. However, household consumption is only one component of GDP and GDP per capita as a measure exaggerates the country's standard of living.

paid and unpaid work less the consumption occurring over the same time. Aspects of this calculation are discussed in HSE (1999), which illustrates how complex the whole calculation could be.

Except in the case of deterministic injuries any illness and death arising from an accident is most likely to occur many years after the event. The complexity of calculating the lifetime earnings of different age cohorts to estimate the potential loss over a lifetime of groups of different initial ages at cancer onset is therefore excessive when the great majority of those who have their life foreshortened will be relatively old when they get cancer[*]. Clearly, advanced age at cancer on-set is likely to depress this term, which can therefore be conservatively estimated using information on losses from road traffic deaths of Table 11 as road traffic deaths are not predominantly distributed towards higher ages.

Although production and consumption are considered, the net value of unpaid output is not. The experimental household satellite account (Holloway et al, 2002) does estimate such things as the gross value of voluntary activities but there is currently insufficient information to establish a net contribution. However, although important for completeness it is only likely to be a fraction of net paid output although this assumption should be confirmed, as indicated in Section 13.3. Thus, for COCO-2 the net output loss from fatalities is taken to be the loss provided by the DfT.

The value provided by the DfT determines a loss on death. However, if the illness is nonfatal, a different loss will result which can be compared to the loss from serious injury estimated by the DfT, as shown in Table 12.

TABLE 12 DfT Output and medical costs for serious injuries[1]

Year	Lost output £	Medical Costs £
2002	16,540	10,030
2003	17,380	10,530
2004	18,336	11,108
2005	18,920	11,460

[1]http://www.dft.gov.uk/pgr/roadsafety/ea/

Although there may be a decline in consumption due to illness and a risk of double counting consumption included with health care costs, it is assumed for simplicity that consumption is not seriously affected and the loss of productive output will be an appropriate measure of net lost output. However, the lost output is based on an assumption for the average length of time people are away from work and neither road accidents nor serious illness at work will necessarily reflect the time taken off work when undergoing cancer treatment[†]. In the absence of better data and in recognition that it is

[*] Childhood cancers are rare in comparison to those occurring at older ages.

[†]Lost output from serious or major injuries at work, eg, those requiring more than two months of work is less than the above estimate, ie, ~£13,000 after uprating to 2004 (HSE, 1999).

only likely to be a small component of the overall cost the DfT values of Table 12 are used. The availability and use of appropriate data are discussed further in Section 13.1.

10.3 Medical costs

The medical cost of an accident to the local or national economy is the additional cost of providing the various services required. For a road traffic fatality this is necessarily small as people die at the event or from severe trauma shortly afterwards. However, following a nuclear accident any resultant deaths from cancer will generally take longer and in most cases only after considerable medical intervention.

Deaths may occur relatively soon after an accident following exposure to deterministic doses although this is still likely to be over a longer period than a road traffic fatality. COCO-2 models the off-site economic consequences of an accident, including the contribution from medical costs incurred after exposure to deterministic radiation doses. Such high doses may be received by both those on-site and the public off-site. However, the medical costs of deterministic injuries off-site are likely to be small in comparison to the medical costs of treating cancers in the much larger number of people exposed to low levels of radiation and in many cases the sensibly larger number of deterministic effects on-site that might be inferred from the possibility of having deterministic effects off-site[*]. Thus, COCO-2 is likely to provide a more comprehensive estimate of total medical costs arising from low dose exposure than that likely from deterministic effects, which will be more strongly influenced by the numbers affected on-site.

The difference in the economic importance of deterministic and stochastic effects is complicated by the timings of their occurrence. Deterministic effects will occur relatively soon after exposure compared to stochastic effects, which are most likely to occur years after the dose was originally received. The delay in the onset of stochastic effects will have two consequences. Firstly, the estimated lethality and length of treatment of any cancers that arise are likely to have changed over the intervening period, which could be 40 or 50 years after the accident. Secondly, it is appropriate to apply time preference discounting to the estimated costs (Jones-Lee et al, 2007)[†]. Deterministic effects are discussed in Section 10.3.2.

10.3.1 Cancer costs

Every cancer type is unique and the term covers a very broad spectrum of diseases. However, there are general features that, for the purposes of COCO-2, can be used to provide an estimate of the cost of treatment. The properties of central concern are the

[*]The number of personnel on-site will be limited and therefore for sufficiently large events deterministic effects occurring off-site may exceed those occurring on-site. However, the influence of other factors can circumvent this effect, for example, due to substantial plume rise no members of the public received acute radiation doses following the Chernobyl accident (NEA, 2002).

[†]Time preference discounting recognises that an individual is less willing to pay now to avert a consequence occurring in 40 years than one that will occur tomorrow.

lethality of the disease and the treatment stages likely to be followed. The success of treating any cancer is strongly influenced by when the cancer is diagnosed. If it is not detected until the cancer has metastasised then the prognosis is poor and the treatment received may only be palliative. There will be interplay between the detection of a cancer, the likelihood of survival and the cost of treatment. Data from the ONS provides an estimate of the likely lethality of a cancer, some of which will be a consequence of the intrinsic difficulty of treating the particular disease and some of which will reflect the likelihood of detecting the cancer at a treatable stage.

The National Institute of Health and Clinical Excellence (NICE), as well as reviewing new drug treatments and interventions, issues guidance on the best practice approach to treating particular diseases. The sequence of diagnosis and treatment offered to patients presenting at different stages in the development of their cancer is termed the treatment pathway. As NICE comments in relation to lung cancer, a constraint on its analysis was the lack of systematically collected data on current care pathways. There are some data prepared by clinicians and health economists on the pathways for various diseases but, as indicated by the comment from NICE for such a prime exemplar of cancer as a disease class, a comprehensive analysis based on treatment pathways for all cancers of interest to COCO-2 is not possible. This situation will change with time as the use and importance of treatment pathways increase. For example, the NHS is increasingly interested in ‘payment by results’ and has introduced a budgetary system to identify aspects of the cost. Thus, ‘Health Resource Groups’ (HRG) classify diseases / procedures into broad groupings, with associated costs determined by representative lengths of spells in hospital. Unfortunately, spells, which are derived from patient data, are independent and there is currently no mechanism in place to collect statistical data that reflects the progression of patients requiring multiple procedures and therefore many spells in hospital. As a patient may attend several hospitals and clinics in the course of their treatment, preparing such data would require the linking of a large number of independent data sets. The central records system currently under development will make this a practical task in the future.

To allow progress COCO-2 generalises results from a few clinical pathway results and other supporting information. This necessary simplification obscures the differences between cancers for, although cancer treatments are superficially similar different drugs, surgical procedures and lengths of hospital stay for a particular treatment will occur. More importantly, some cancers are more aggressive, difficult to treat and have a poorer prognosis than others. However, this error is not as significant as at first it may seem because in addition to the variation in cost between cancers there is a comparatively large variation in the cost of treatment for a particular cancer. The cost is determined by when a patient presents and if the cancer then responds to treatment. The economic cost to the country of treating a cancer is essentially the mean cost for cancers of that type, which may be distinct from the mean cost for patients entering at the earliest diagnosis point of a clinical pathway.

Pathways are being developed to improve patient outcomes through establishing best practice and for assessing the cost of treatment. Ideally, from the perspective of COCO-2 a pathway would provide a description of the route through the health care system indicating what proportion of patients will go down each particular treatment path including those that join at later stages. The mean cost and treatment time for survivors and non-survivors would then be known which could be combined with epidemiological models of cancer induction following exposure to radiation. These are able to predict not only how many people will die of a particular disease but also, as incidence models are available, how many become ill.

The cost of cancer treatment in the UK cannot be readily established but the data of Table 13 provide information on cancer care in the USA for those who are aged 65 and over (Bosanquet and Sikora, 2004).

Table 13 Estimated national expenditure in the USA on medical treatment for common cancers[1]

Cancer type % of all new cancers	Expenditure (billions)$	% of total cancer treatment	Average Medicare payment per individual $	Equivalent value in 2004 £[2]
Breast 18·2	5·4	13·1	9230	6767
Colorectal 11·7	5·4	13·1	21,608	15,841
Lung 12·5	4·9	12·1	20,340	14,912
Prostate 13·6	4·6	11·3	8869	6502
Lymphoma 4·2	2·6	6·3	17,217	12,622
Bladder 4·0	1·7	4·2	10,770	7896
Cervix 2·3	1·7	4·1	13,083	9591
Head/neck 3·3	1·6	4·0	14,788	10,841
Leukaemia 2·1	1·2	2·8	11,882	8711
Ovary 1·7	1·5	3·7	32340	23,709
Melanoma 5·2	0·7	1·7	3177	2329
Pancreas 2·1	0·6	1·5	23,504	17,231
Oesophagus 0·9	0·4	0·9	25,888	18,979
All other 18·1	8·7	21·2	17,201	12,610

[1]Values are based on cancer frequency in 1996 and cancer-specific costs in 1995–98. Data are from US National Cancer Institute.

[2]The conversion to 2004 £ is given by a conversion to 1998 £ (0.632) obtained from the Purchasing Power Parities calculated by the OECD (www.oecd.org/std/ppp) multiplied a GDP deflator to convert 1998 £ to 2004 £ (1.16) obtained from the deflator series provided by HM Treasury on 28 March 2007.

The treatment approach in the USA is slightly different from that in the UK but as the USA tends to have better outcome statistics it can be argued that the UK regime will adopt practices from the USA and mainland Europe that are more effective (see, for example, the National Lung Cancer Audit (NHS, 2005)). For reference, the cost of treating breast cancer in the UK has been estimated by Dolan et al (1999) to be £7247 (£8207 in 2004 prices) while the cost of treating small cell lung cancer was found to be £11,556 (£ 12,905 in 2004) (Oliver et al, 2001). Small cell lung cancer has a poor prognosis and the likelihood of surviving for a year is low.

Data from Europe support the above estimates with, for example Dedes et al (2004) and Chouaïd et al (2004), estimating the costs of treating lung cancer in Switzerland and France respectively as shown in Table 14.

TABLE 14 Lung cancer costs

Type	Study	Sample size	Mean Cost € or $	Cost range € or $	Mean cost 2004 £[6]
NSCLC[1] 89%	Dedes et al (2004) costs in 1999 euros[4]	118	19,212 €	1821 – 80020 €	11,593
SCLC[2] 11%			20,992 €	5282 – 51840 €	12,667
All			19,408 €	1821 – 80020 €	11,711
NSCLC	Chouaïd et al (2004) cost in US $ based on Markov modelling from sample data[5]	428	20 691 $	5777- 50380[3] $	14,059
SCLC			31 833 $	15866 -64455[3] $	21,629

[1]non-small cell lung cancer (NSCLC), [2]small cell lung cancer (SCLC), [3]95% CI

[4] Convert to Swiss Francs at the average exchange rate in 1999 (1.60) and use a PPP adjustment to convert from Swiss Francs to Pounds to give an overall conversion factor of (0.534) and then apply a GDP deflator of 1.13 to convert to 2004 £ obtained from the deflator series provided by HM Treasury on 28 March 2007.

[5] Conversion to 2002 £ (0.641) (average exchange rate to give number of euros in France and PPP adjustment to covert to £) followed by the application of a GDP deflator (1.06) to convert to 2004 £ obtained from the deflator series provided by HM Treasury on 28 March 2007.

[6]The conversion to £ is illustrative as the details of the original cost estimates in euros and dollars are unknown.

The most notable feature of the Table 14 results is the asymmetry in the costs with a small number of patients having very long spells in hospital.

From the policy and planning perspective appropriate to COCO-2, there is little merit, with the current state of knowledge, in attempting to over specify the likely medical costs of cancer treatment. The WTP aspects of the cost will generally greatly exceed all other costs if the cancer is fatal. As statistical data become available within the NHS on actual pathway costs and probabilities, the COCO-2 methodology should be revised to cost cancer treatment separately for those that survive and those that succumb. It is in the former category that a more accurate assessment of cost will become important. There is also likely to be a move towards the use of expensive new drug treatments targeted at distinct subgroups of patients that, for example, have a particular genetic make-up and this may significantly alter the cost profile of those that survive compared with those that succumb.

The weighted mean cost of cancer treatment given by Table 13 is £11,725 and although individual cancer costs could be used the similar magnitude of costs found for different cancer types together with the likely high variance of treatment costs for particular cancers suggest that a more detail breakdown of costs is not currently justified*.

10.3.2 Deterministic effects

COCO-2 will often be used to assess the costs of extreme events and it is therefore appropriate to establish a cost for the treatment of deterministic injuries†, which will arise if people are exposed to high doses. The deterministic injury considered in most detail by COCO-2 is Acute Radiation Syndrome (ARS). However, radiation burns, pulmonary

* For simplicity, the same cost of treatment will be used for both fatal and non-fatal cancer. Note no health service specific inflation rate is used in common with the approach adopted when modelling other areas of the economy.

† Alternatively, deterministic injuries may be called harmful tissue reactions.

fibrosis and other effects are briefly considered. It was noted when assessing costs for cancer treatment that there was little merit in attempting to differentiate between the costs of treating different cancers due to the large variance in the cost of treating cancers of a particular type. Radiation induced deterministic injuries most commonly occur as a by-product of medical treatment or because of a medical or industrial accident and the medical consequences are therefore likely to be strongly influenced by the particular details of the exposure. There is therefore little advantage in attempting to obtain particular costs for a large variety of conditions and a more generic and conservative approach is therefore adopted.

The potentially most serious consequence of high dose exposure is Acute Radiation syndrome (ARS) which is a term for a group of syndromes that develop over a period from a few seconds to many weeks, following exposure to penetrating radiation with whole body doses greater than 1 Gy. The rate of onset of symptoms and their severity depends on the radiation dose. Whole body doses in the range 1-10 Gy predominately cause damage to the haematopoietic system, at 10-20 Gy the initial and lethal damage is generally to the intestine. At doses of 20-80 Gy catastrophic damage is manifest first by cardiovascular system effects and toxaemia while at about 100 Gy death appears to be as a result of cerebral disorders. If the average whole body dose is greater than ~10 Gy then there will generally be local tissue damage to the lungs, skin, eyes, intestines, extremities, etc (Gusev et al, 2001) see also (NRPB, 1996).

As high doses (≥10 Gy) are likely to be rapidly fatal, the cost of treating such patients is likely to be less than that of treating those that suffered slightly less exposure. It is therefore conservative to estimate costs based on a ‘moderate’ exposure of a few Gy as patients in this category may be ill for an extended period before dying or recovering. Patients who recover will inevitably have a heightened risk of developing cancer in future years. However, although this risk can be estimated the non-uniformity of any very high doses received will be important and very difficult to account for in the abstract.

To establish generic costs for COCO-2 purposes it is appropriate to consider in more detail the particular treatment regime to be costed. From a physical perspective, if someone receives a dose of 1-2 Gy they are only like to require outpatient observation for about a month. A more substantial exposure of 2-4 Gy will lead to hospitalisation with relevant precautions to cope with their impaired immune system. Up to 50% of those affected in this way will die within 6-8 weeks with the remainder going on to recover although a full recovery may take 2 years. COCO-2 therefore bases cost estimates on an assumed exposure of 2-4 Gy.

The costs for intensive or high dependency care in 2003–04 were £1,670 per day on average and £610 per day on average respectively[*]. Although there will be many components to the treatment pathway such as the use of antibiotics to protect a patient with an impaired immune system the most expensive aspect is likely to be the cost of maintaining the patient in a reverse isolation room or similar facilities. The cost of the G-CSF or other drugs used to stimulate the restoration on the patients immune system will

[*] Hansard - Written Answers *10 Oct 2005 : Column 264W*

also be an important contributor to the total cost. Overall, the treatment regime is probably analogous to the care of patients with severe immunodeficiency following radiation or chemotherapy treatment for leukaemia. The costs will therefore be similar to the cost for this stage of cancer therapy. Himmelmann et al (2002) give an average cost of € 1713 (~ £891 for the period September 1999 until April 2001) per patient for a 13-day course of treatment with G-CSF with the patient in hospital for an average of 56 days in a reverse isolation HEPA filter laminar airflow single room following bone marrow or blood stem cell transplantation*. This essentially matches the treatment scenario considered for a patient exposed to a few Gy of whole body radiation. COCO-2 therefore assumes that a suitable cost estimate for ARS treatment will be approximately equivalent to 13-day course of G-CSF while the patient is in isolation for 8 weeks with antibiotic therapy, parenteral nutrition and laboratory testing adding about $230 a day (~£150 for the period of the trial between 1994 to 1995 inclusive) to the costs (Tarella et al, 1998)†. The final cost estimate for a 2004 baseline year is ~£47,000, which is approximately 5 times the average cost of treating leukaemia reported in Table 13‡.

Recently, in addition to the component haematopoietic, gastrointestinal and central nervous system syndromes, forming ARS, Cutaneous Radiation Syndrome (CRS) has been introduced to describe the acute and potentially fatal radiation exposure of the skin (CDC, 2005). The skin is very vulnerable to external radiation exposure, with damage to the skin dependent on the absorbed radiation dose and the energy of the radiation as well as whether the radiation is electromagnetic or particulate. Following Chernobyl, it was found that radiation lesions in the skin led to death if 50% of the body surface was affected and the dose to the skin was greater than ~30 Gy at 150 mg cm^{-2} (Barabanova and Osanov, 1990). Fatality can also arise from radiation pneumonitis when the lungs are exposed to an organ dose of >5 Gy usually after inhalation, and an acute inflammation develops, which may lead to the loss of normal lung architecture (Pelagia et al, 2006) and even if survived to fibrosis of the lung (Effective Health Care, 1998).

Patients suffering from ARS, and skin burns following an accident will have common aspects to their treatment regimes namely, receiving Cytokines and antibiotics (Waselenko et al, 2004) while pneumonitis may be treated with growth factor inhibitors (Pelagia et al, 2006). However, if severe skin burns and pneumonitis occur off-site following a nuclear accident, it is likely to be in combination with ARS and COCO-2 assumes that the high dependency care required by these immunologically vulnerable patients will incur similar treatment costs for all these potentially fatal high dose injuries.

* This is achieved by converting from euros back to Swiss Francs using the average exchange rate over the period http://www.ecb.int/stats/exchange/eurofxref/html/index.en.html and then using a PPP conversion to give an effective rate of 0.520.

† Parenteral means injected, infused, or implanted.

‡ The costs were calculated in Italian Lire and converted by the authors to US $ for treatments during 1994 and 1995. The authors quoted a conversion rate of 1550 Lire to $1 and this was therefore used to reconvert the cost to lire. The irrevocable conversion rate of 1936.27 was then used to convert Lire to Euros and the average PPP for the period used to convert between Euros in Italy and Pounds in the UK. The resulting effective conversion factor from dollars to Pounds is 0.651.

In addition to the survivors of the potentially fatal conditions discussed above a number of other deterministic effects may cause serious illness and reduced quality of life. The morbidities that will arise include the impairment of lung function, hypothyroidism, cataracts and erythema or reddening of the skin. Of this selection, the potentially most serious is the impairment of lung function*. Impairment may also arise as a consequence of lung cancer or fibrosis of the lung produced as a by-product of cancer treatment. To this extent, the morbidity costs for survivors of cancer will incorporate the cost of lung impairment and these will in turn be incorporated into the costs incurred for ARS survivors, which are indirectly related to cancer treatment costs.

Cataracts, which may arise some time after the deterministic exposure were estimated by Räsänen et al (2006) to cost (in 2003 prices) € 2289 to treat if both eyes were affected and € 1318 if only one eye required treatment. However, based on a multi-dimensional assessment of the utility gained they concluded that the QALY benefit of the operation is comparatively small. Thus, the costs and benefits associated with surviving ARS are likely to exaggerate considerably the gain from cataract surgery. This is also likely to be true for other morbidities such as hypothyroidism and erythema.

As the extent, duration and nature of the morbidities that might arise are difficult to anticipate COCO-2 only uses a single set of costs for deterministic effects. This simple approach is essentially conservative with respect to the large variability in the potential cost of morbidities and reflects the dominance of the value of life in costing fatalities (see Sections 13.1 and 13.3).

10.3.3 Hereditary effects

There is a risk following the exposure of people to radiation that any offspring they subsequently conceive may suffer a health detriment. There are a large number of possible consequences linked to single gene (Mendelian) mutations, chromosomal abnormalities or heightened risks of multifactorial diseases. Furthermore, depending on the nature of the detriment, it may be realised at any time throughout life from birth to old age. However, currently no human studies provide direct evidence of a radiation associated excess of heritable disease and the most recent assessment by UNSCEAR (UNSCEAR, 2001) has resulted in a reduction in the estimated risk of these diseases occurring in the future offspring of those exposed to radiation.

Although the estimated risk has reduced, UNSCEAR has extended the categories of disease considered by including multifactorial diseases for the first time. Thus, COCO-2 requires a tractable method of assessing the cost to society from an increased incidence of any of the very large variety of diseases with a hereditary component, which might occur following the exposure of some time future parents after an accident. The range of effects being considered is very wide from an enhanced propensity to develop a particular cancer to minor or major congenital abnormalities to an increased likelihood of some mental health disorders such as bipolar psychoses. Such a wide variety of conditions with very different background rates of occurrence and consequences for the

* High dose but non-uniform exposure of extremities may result in their amputation but such exposures are not expected off-site following an accident.

quality and length of life of those afflicted can only be costed in an approximate and aggregate way.

ICRP (2007) follows the analysis of UNSCEAR (2001) and reduces the risk of hereditary effects following exposure of the whole population by a factor of 6 when compared to the recommendations of publication 60 (ICRP, 1991). Thus, in the assessment of the detriment associated with radiation exposure the hereditary risk to the first and second generations is estimated to be 0.2% per Sv dose to the gonads with an assumed lethality fraction of 80% and an estimate of the relative years of life lost in comparison to all cancers of 1.32.

Risk information is available for each of the broad subcategories of hereditary diseases, (mendelian, chromosomal or multifactorial) that contribute to the ICRP risk estimate. However, because the diseases within each sub-category remain diverse COCO-2 will only employ the aggregate information to provide an estimate of the cost for hereditary disease as a whole. No practical improvement in the robustness of the costing is thought likely with a more elaborate formulation. The details of the valuation are discussed in Section 10.4.

10.4 Valuation of health costs

On grounds of equity, neither the VPF of the DfT nor the QALY of NICE is age dependent[*]. However, as discussed in Jones-Lee et al (2007) both theory and empirical evidence suggests that the VPF, or strictly the dominant WTP component, will be a decreasing function of age for those of middle age and above and an increasing function of income[†]. Similarly, age dependent QALYs could be constructed if there was sufficient information. However, while an age dependent WTP / QALY formulation would be desirable, for simplicity and robustness an age independent formulation is followed. In the case of fatalities, the WTP determined by the VPF obtained by the DfT in 2004 is applied, while for morbidities a QALY based estimate is more representative of the value society places on health improvements.

The health cost of fatalities (HF_C) with no direct age dependence can be inferred from Equation 10.1 to be

$$HF_c = \sum_{n=1}^{n=N} \frac{(WTP_n + NetOutput_n + Medical_n)}{(1+r)^{l_n}} \qquad (10.3)$$

[*]A QALY of 1 should be interpreted as living at full health as appropriate for the age of the subject for a year. However, QALYs for subjects at different ages have the same weight ie the Value of a Life Year (VOLY) is constant.

[†]For young adults survey evidence suggests that WTP for a reduction in the risk of death is again less than for those of middle age. Although immediately interpretable with simplistic psychology that assumes that the young discount the benefits of a long life in comparison to immediate benefits (however, see, for example, Read and Read (2004)) it does imply, absurdly, that a year of extra life can have negative value, see Jones-Lee et al (2007).

Where N is the number of deaths, I_n the delay in years before the n^{th} fatality dies and r the "pure discount rate" for marginal utility, ie, 1.5%[*]. Although in Equation 10.3 the cost components associated with the death of a person are independent of their age at death, the overall cost is dependent on the length of the delay between the accident and each eventual death. The length of this delay is partly dependent on the age of a person when they are first exposed to radiation from the accident predominately through the variation of the cancer base rate with age in an exposed population. The evaluation of Equation 10.3 to produce a generic result is discussed in Section 10.5 and again in Appendix F for the example situation discussed in Section 12.

In Equation 10.3, the WTP, output and medical costs are given in Table 15. It is assumed in the case of fatalities that once people become seriously ill they will die shortly afterwards preventing excessive costs from being incurred during a long period of palliative care[†]. This care will therefore only make a small contribution to the overall cost.

The health cost of morbidity HM_C is estimated in Equation 10.4 using a VOLY valuation of £30,000 for a life year at full health and the QALY term indicating how many VOLY equivalents have been lost (see Appendix D and Jones-Lee et al (2007))[‡].

$$HM_c = \sum_{n=1}^{n=N} \frac{((1 - QALY_n) \times VOLY \times T_n + NetOutput_n + Medical_n)}{(1+r)^{I_n}} \qquad (10.4)$$

Where T is the length of treatment in years, N is the number of people that become ill, I, is the delay in years before subject n becomes ill and r is the pure discount rate, ie, 1.5%.

The health status of a patient undergoing cancer treatment is clearly larger than zero and as the patient is likely to recover within a few years with no assumed ongoing problems a single QALY value of 0.5, will be adopted as the characteristic health state of all those undergoing treatment[§]. This value is consistent with the estimate of Stouthard et al (2000) for the diagnosis and primary therapy phase of colorectal cancer.

---

[*] This is a combination of pure time preference and catastrophic risk where the latter is the likelihood that there will be some event so devastating that the future is altered radically and unpredictably such as a natural disaster or major war (http://greenbook.treasury.gov.uk/annex06.htm). Treasury green book advice suggests that a lower rate of discounting should be applied for events occurring beyond 30 years. However, as the pure discount rate is being used there would be little merit in introducing such a change. Thus, on grounds of simplicity and because of the uncertainties associated with such calculations only a single discount rate is provided (Jones-Lee et al (2007)).

[†] For simplicity, no allowance is made for any discounting of costs between the onset and ending of treatment for fatalities or during the treatment of morbidities represented by Equation 10.4.

[‡] Note the VOLY and other costs are not discounted over the period of treatment as the preference is for them to be incurred over as short a period as possible.

[§] It is important to note that Equation 10.4 applies to patients that survive, ie, generally those that are diagnosed early and are able to respond well to treatment. For example, Estey et al (2000) found a strong inverse correlation between time to complete remission and the time to death for Acute Myeloid Leukaemia (AML) patients. However, there will be a group of patients that are permanently impaired by

In Equation 10.4, a QALY / VOLY combination is being used as a simple and expedient way of assessing the CV associated with being in a particular health state for a given length of time. A WTP estimate would provide a more direct measure in line with the formulation of Equation 10.3. However, it is difficult to frame an appropriate question to determine the WTP to avoid a non-fatal outcome from a class of diseases that are likely to be perceived as potentially fatal. Consequently, there is a lack of appropriate valuations to draw on (see Appendix D and Jones-Lee et al (2007)).

10.4.1 Hereditary costs

It is assumed for simplicity that the costs of hereditary effects are adequately represented by Equation 10.3 based on the following proviso. COCO-2 conservatively assumes that all hereditary effects are fatal and that the relative years of life lost compared to the average for all cancers used by ICRP to assess detriment can be used to estimate an aggregate cost. Thus, as the average number of years lost from all cancers is ~13 (Burnet et al, 2005), this would suggest that on average approximately 17 years of life are lost to those that die from their radiation induced hereditary burden. In reality, some hereditary diseases will have only a minor effect on the lives of those affected while others suffering from a different range of diseases will require a high level of care before succumbing to an early death. It could be argued in the latter case that the cost is being underestimated. However, severe effects acting from birth will be rare in comparison to more minor or late onset conditions. Similarly, if a chronic condition were assumed, the total cost, estimated by a slight variation of Equation 10.4 that allows the annually accruing VOLY costs to be discounted over the life of the patient, will be similar to that estimated for premature death*. Thus, assuming that all those suffering from hereditary effects die early should more than account for the cost of those needing care over an extended period. In addition to this assumption, there is no discounting of the cost to account for the delay between the accident happening and the gradual appearance of the next generation. The subsequent generation is, for simplicity, also assumed to appear at a single time in the future.

10.4.2 Summary cost components

Table 15 summarises the health costs to be used in Equations 10.3 and 10.4.

the treatment or disease but who, nevertheless survive to die of other causes. The long-term costs of their reduced quality of life are not considered by COCO-2.

*Equation 10.4 discounts costs to the time in the future when a subject first becomes ill. As treatment is only assumed to last a few years, no further discounting is applied. For a chronic condition, discounting should be applied to the costs accruing every year.

TABLE 15 Summary of health cost parameters

Illness	WTP / VOLY £(000)	Net Output loss £	Medical £(000)
Cancer (fatal) Equation (10.3)	1,296	90,000	12
Cancer (non fatal) Equation (10.4)	30	18,336	12
Deterministic (fatal) Equation (10.3)[1]	1,296	90,000	47
Deterministic (non-fatal) Equation (10.4) [1]	30	18,336	47
Hereditary Equation (10.3)[2]	1,296	90,000	12

[1]Acute Radiation Syndrome (ARS) acts as a surrogate cost for all deterministic effects

[2]The assumption is made that all the children affected are born within a year of the accident, and die ~17 years premature.

If deterministic effects are likely, then, as shown in Table 16, they can be costed without any further simplification of Equations 10.3 and 10.4. Any deaths arising from deterministic effects will take place in the first year and similarly patients destined to recover from such exposures will tend to do so within the same period and thus no discounting will be required[*]. However, in the latter case the surviving patients will have a heightened risk of cancer for the rest of their lives, which, if it was thought likely to be a significant contributor to the total health costs predicted by COCO-2, would have be calculated and costed explicitly[†].

Hereditary effects, as shown in Table 16, are discounted, but the result is a simple cost factor applicable without any further calculation. To calculate the cost of hereditary effects life tables[‡] are used to predict the age of death of males and females born in 2004. Equation 10.3 is then applied assuming that the average years of life lost from cancer is 12.5 (Burnet et al, 2005) and the relative loss of life due to hereditary effects is 1.32 with respect to all cancers. The resulting male and female costs are then simply averaged to give a cost of £549,000 per hereditary effect in the first generation. In calculating the cost for the second generation, the average age of a mother at the birth of a child (29) is used as an additional discounting offset with all other parameters as before (ONS, 2007). The resulting averaged cost is £357,000 per hereditary effect in the second generation. If the detriment estimate of ICRP, which is the source of the relative loss of life of estimate, is soundly based then these values are likely to be conservative estimates of the cost.

[*]As previously stated in Section 10.4.1 full recovery may take 2 years but consistent with other COCO-2 estimates discounting is not applied.

[†] Although some morbidities may result in a permanent reduction in quality of life this loss is assumed to be captured by this cost.

[‡] Interim Life Tables, England & Wales, 1980-82 to 2004-06 ONS http://www.statistics.gov.uk/

TABLE 16 Cost of Deterministic Injuries and Hereditary effects

Effect	Cost per effect £
Deterministic (fatal)	1,433,000
Deterministic (non-fatal)[1]	80,336
Hereditary 1st generation[2]	549,000
Hereditary 2nd generation[3]	357,000

[1]Treatment in 1 year

[2]No delay assumed for production of next generation

[3]29 year delay assumed in the production of the second generation

Equations 10.3 and 10.4 were formulated to represent the costs arising from fatal and non-fatal cancers respectively. However, epidemiological models on the risk of radiation induced cancer use incidence and mortality data where the latter are a sub-set of the former and not a distinct group. To avoid excessive complexity when evaluating the equations it is convenient to assume that all cancer patients receive a similar level of treatment initially with those that are fatally afflicted subsequently receiving additional treatment such as palliative radiotherapy. This allows estimates for the overall cost of treating cancer to be made using the readily available incidence and fatality data*. This approach, which is demonstrated in Section 10.5, effectively doubles the treatment cost of those with fatal cancer when compared to those with non-fatal cancer. This would seem a reasonable assumption considering the large variance in cancer treatment costs discussed in Section 10.3.1 and the fact that treatment costs are a minor component of the cost of fatalities.

10.5 Practical cancer costings

The equations of Section 10.4 when applied to cancer incidence and death are time dependent through the discounting of cost over the period between the initial exposure after the accident and the time the exposed person is likely to become ill. Although this can be evaluated directly for any particular temporal pattern of exposure, it may be both easier and sufficiently robust to use partially processed results that are solely dependent on the numbers of deaths and the incidence of illness. For example, if COCO-2 were to be used within a PRA code this approach would allow the health costs to be evaluated without considering how the PRA code modelled the spatial and temporal variation of dose†. In other words, the cost can be estimated by considering only the total number of cancers predicted and an appropriate unit cost of a cancer without regard to the temporal distribution of cancers after the accident.

* If data are available, a more complex epidemiological calculation could be used to partition costs and should be considered if pathway information becomes available to reduce the variance in cancer costings as discussed in Section 13.1.

† The assumption is also required that any population age structure assumed by the PRA code is consistent with that used to generate the time independent costings of COCO-2.

To calculate the cost of accident induced illness Equation 10.3 can be recast as shown in Equation 10.5 below, which changes the sum over individuals into a sum over a range of age cohorts.

$$HF_c = \sum_{n=1}^{n=N} \frac{(WTP_n + NetOutput_n + Medical_n)}{(1+r)^{l_n}} \approx C \sum_{m=1}^{m=M} \frac{N_m}{(1+r)^{l'_m}} \qquad (10.5)$$

Where N is the number that die, N_m the number that die in the m^{th} of the M cohorts, I_n the delay in years before the n^{th} fatality dies, I' the corresponding delay for each particular age cohort at exposure and r the pure discount rate, ie, 1.5%. Finally, as no distinction is made in COCO-2 to the value assigned to deaths occurring at different ages, the constant C is the undiscounted cost of a death, ie, the sum of the WTP, Net output and Medical costs (however, see Appendix D for a discussion on this point).

To apply the above formulation, the number of radiation induced fatal cancers expected in the years following an accident, and the reduced life expectancy of those that die in each exposed age cohort is required. These were estimated for three different example temporal distributions of dose, by following the exposure of each age cohort through time. All the doses considered were within the low dose regime where a linear dose response is assumed. The resulting calculations permitted the effective cost of a cancer to be estimated for each of the dose regimes.

The latest UNSCEAR epidemiological model (UNSCEAR, 2008) was used to predict the number of deaths and the expected number of years of life lost for those that developed cancer and died for each age cohort using baseline mortality data for England and Wales (ONS, 2004). The calculation was in two parts; a putative colon dose was used to estimate the cost of solid cancers and a similarly assumed bone marrow dose used to estimate the cost of leukaemia. The exposed population was represented by 20 5-year age cohorts, distributed according to the age distribution for England and Wales in 2003, as shown in Table 17. The epidemiological calculation was applied separately to each age cohort to allow the loss of life expectancy to be estimated and appropriately costed for each cohort. The health costs results are given in Table 18 and displayed graphically as a function of age at exposure in Figure 3.

TABLE 17 Population age distribution in England & Wales 2003[1]

Upper cohort age	Number of people	Upper cohort age	Number of people
4	3008200	54	3314100
9	3235000	59	3392500
14	3442100	64	2599300
19	3397900	69	2347700
24	3282700	74	2079000
29	3261600	79	1720300
34	3928400	84	1318900
39	4179200	89	634300
44	3882400	94	149636
49	3409500	99	37957
Total		52620693	

[1]combined male and female ONS mid year population estimate 2003 extrapolated to age 99.

At the low doses under consideration, the number of deaths is directly proportional to the dose (delivered in a particular temporal pattern). However, the time at which those deaths occur is determined by the temporal pattern of dose delivery. If the majority of the dose is delivered early on, any cancers are likely to occur sooner and there will be less discounting of the cost. The cost of a cancer will therefore be higher, when the dose is delivered in one year, and lower, when the same dose is delivered over a long period.

As the epidemiological model follows an age cohort from a particular age to death, the collective dose received by a cohort will depend on the numbers surviving to receive a dose at a particular age, ie, due to natural causes it is likely that the cohort will be considerably smaller at the end of a long exposure period. Thus, the different temporal patterns of dose delivered also correspond to different collective doses.

TABLE 18 Economic cost of radiation induced fatal cancers

Temporal dose pattern[1]	Cancer type	No of Deaths per 10,000 population	Cost of a Cancer £
10 mSv in 1 year[2]	**Solid**	**5.16**	**770,600**
	Leukaemia	**0.38**	**965,211**
10 mSv in 10 years	Solid	4.48	750,958
	Leukaemia	0.35	917,026
10 mSv in 50 years	Solid	2.38	700,808
	Leukaemia	0.23	801,726

[1]Equivalent organ dose to the colon or bone marrow for solid cancers and leukaemia respectively

[2]Default costs shown in bold are based on the assumption that the majority of the dose is received in the first year

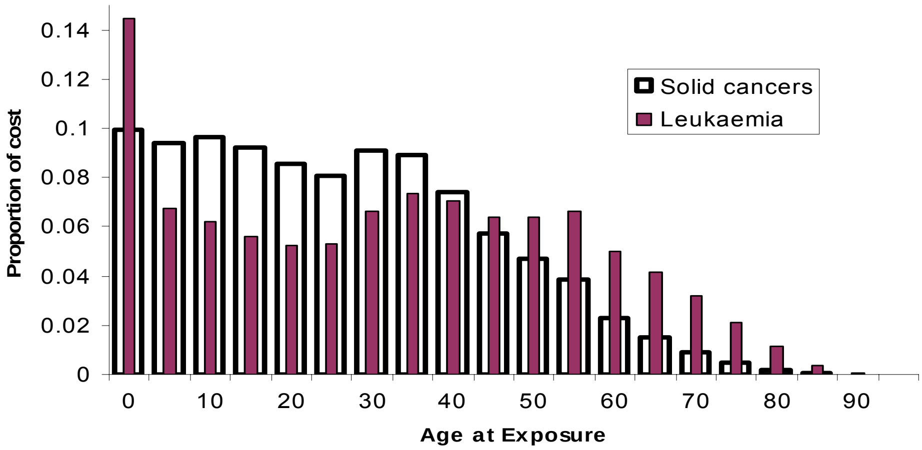

Figure 3 Proportion of cost arising from different age cohorts following the 1 year exposure of Table 18

If the doses received after an accident are thought likely to follow a common temporal distribution and an estimate can be made of the rate of decline of the dose then the values from Table 18 may be used to estimate the cost using only the numbers of solid cancers and leukaemias predicted by a PRA model. Indeed if when incorporating COCO-2 within a PRA model it is either inconvenient or inefficient to check the temporal distribution of dose, the assumption that the majority of the dose is delivered in the first year will, as shown in Table 18, provide a conservative estimate of the cost of fatal cancers.

A similar calculation can be performed to cost the losses arising from the period of treatment of those that get radiation induced cancer. The results for the same dose scenarios as considered for fatal cancer are shown in Table 19.

TABLE 19 Economic cost of radiation induced non-fatal cancer[1]

Temporal dose pattern[2]	Cancer type	Incidence per 10,000 population	Cost of Cancer incidence £
10 mSv in 1 year[3]	**Solid**	**10.47**	**62,239**
	Leukaemia	**0.626**	**83,507**
10 mSv in 10 years	Solid	8.865	60,398
	Leukaemia	0.46	76,592
10 mSv in 50 years	Solid	4.44	56,394
	Leukaemia	0.253	65,566

[1]This cost is based on cancer incidence some of which will be fatal. It is assumed that there will be additional costs incurred in treating fatal cancers and that these are given in Table 18

[2]Equivalent organ dose to the colon or bone marrow for solid cancers and leukaemia respectively

[3]Default costs shown in bold are based on the assumption that the majority of the dose is received in the first year

The same observation as noted for fatal cancer costing applies and therefore, as shown in Table 19, costs based on the majority of the dose being received in the first year following the accident will provide an appropriate conservative cost estimate.

11 DATA SOURCES AND ATTRIBUTES

The COCO-2 model requires a considerable amount of data covering a wide variety of different topics to be assembled. The data sets assembled for the model (see Section 11.2) are generally, but not exclusively, taken from public sources, but whatever their origin are often manipulated to produce the values required for the model. This section summarises the manipulations undertaken and the consequences of the choices made for the maintainability and accuracy of the model. Further details of data manipulation are given in Appendix B.

The data for COCO-2 can be divided into various categories, which will be discussed In turn below. Of primary importance is the input-output information produced for the UK by the ONS. This level of data is produced by the ONS on a regular if infrequent basis and the most recent data from 1995 (ONS, 2002) is used to derive appropriate multipliers[*]. It is recognised that the relationships between model components (the technical factors – production coefficients) change slowly and therefore the error introduced by using the 1995 relationships with up-to-date value added output estimates should not be too great. The main problem is the general shift of the UK economy away from manufacturing and towards services, which are generally not as well represented by Input-Output models. The other source of error is the use of nationally derived multipliers in the estimation of local losses when the local economy could deviate from the structure of the national economy.

In addition to economic data, any implementation of COCO-2 is likely, directly or indirectly, to require information on the affected population and the built and natural environment affected. It is generally expected that the required information will be provided by the PRA code applying the COCO-2 model. However, for convenience some supporting information has been included in the accompanying COCO-2 file. In addition, information on the nighttime population is available from the 2001 census and information on the daytime population is provided by HSL through their work to develop a National Population Database (HSE, 2005). This database provides estimates of particular populations such as those in care homes or schools as well as residential populations during the day. The database also provides estimates of the working population although it should be noted that these are distinct from the working population estimates used to estimate the GVA of local industry obtained from the ONS under the constraints of a chancellor of the exchequer's notice to preserve

[*] More recent multiplier data are available for Scotland.

confidentiality. The latter information cannot be disclosed while the former has been modelled and estimated by HSL from publicly available data sources*.

11.1 Methodology and data issues: industry and tourism GVA

As noted in earlier sections the most appropriate, acceptable and comparable measure of the worth of economic activity to a locality is Gross Value Added (GVA). This section explains how the total industry-related GVA is estimated for small areas allowing the direct loss to be calculated. Appendix A illustrates how this information can be used in conjunction with the UK Input-Output Tables to assess the supply chain (multiplier) related economic losses outside the directly affected areas and Appendix B discusses the process of mapping the derived data to a 1km x 1km grid for use in COCO-2.

11.1.1 Losses in directly affected industries

Whilst the GVA 'unit of analysis' is properly the firm (or plant) within which the economic activity takes place, information on the levels of GVA for individual firms and plants is not available. As an alternative, COCO-2 estimates the GVA *per employee* for individual industries in individual census Super Output Areas (SOA) using ONS published data. The GVA density (GVAD) is then given by the GVA per employee for each industry summed over the number of employees of each industry in each SOA normalised by the area of the SOA as given by Equation 11.1.

$$GVAD_{SOA,SIC} = \frac{E_{SOA,SIC} \times X_{SOA,SIC}}{A(SOA)} \qquad (11.1)$$

Where $E_{SOA,SIC}$ is the Full Time Equivalent (FTE) employment in each SOA per Standard Industry Classification (SIC)† sector and $X_{SOA,SIC}$ is the GVA per FTE in each SOA per SIC sector per year. SOAs have a wide range of sizes and shapes and, for convenience, the data supplied in the accompanying file has been mapped to a regular 1 km grid.

Estimates of full-time equivalent employment for each SOA and 30 industries (including 15 sub-sets of manufacturing) are drawn from the *Annual Business Inquiry (Part 1*). These are complemented by estimates of value added per worker, which are derived for the same set of industries at the *regional* level. As this information is not directly available from published sources, it is derived from the comparison of two separate ONS datasets. Firstly, the ONS *Regional Accounts* were scrutinised to assess the level

* HSL has prepared population information specifically for COCO-2 from their national population database. However, OS licensing restrictions apply and application should be made to HSL for the use of these data.

†The SIC is an industrial classification applied to the collection and publication of a wide range of economic and industrial statistics.

of value added in the 30 reported industries for the reference region*. Secondly, a headcount of FTE employees working in the industry of the region was obtained from *Annual Business Inquiry* data. The consequent division provides an approximate measure of regional value added per employee for 30 industries. This is then applied to the employee count by industry in each SOA.

The data for this estimation were drawn from a number of ONS data sources and required care to be exercised to achieve a reasonably accurate estimate. However, some limiting assumptions remained to influence the modelling, which are summarised below.

- Productivity

  Information on productivity is typically only available nationally, or at best regionally. Thus, productivity (value added per worker) in each of the 30 industries reported is assessed using *Regional Accounts* datasets, which enable an estimate of regional productivity levels to be made, if the GVA is divided by a (separately achieved) estimate of total regional employment in each reference industry. Over- or under- estimates may occur should workers in a specific industry in a specific locality be substantially more or less productive than the regional average; for example due to differing occupation, industrial or capital mix. The different vintages of industrial assets across space but within identical industrial classifications can also create problems in this respect.

- Part-Time Employment

  Data from the *Annual Business Inquiry* provides details of the number of part-time workers in industries, but not the number of hours worked. Whilst COCO-2 adheres to the well-established ratio of 2:1 for part-to-full time workers, there may be some industries (for example, retail) where part-time workers in fact have a lower working week on average. In this case, worker productivity may be somewhat overstated.

- Self-Employment

  Figures from *Annual Business Inquiry* exclude the self-employed and, except for the 2001 Census data, there is very limited information on the levels of self-employment in local areas. COCO-2 includes the value of self–employed income in its estimate of productivity, as this is included in the ‘mixed income’ component of regional value added. However, some errors may occur in local areas where levels of self-employment are higher or lower than the industry-region average (for example, in some tourist intensive rural areas where micro businesses are prevalent).

*A special workplace-based dataset was obtained from ONS as regional accounts are usually published on a residence basis – ie, the value added of employees is usually attributed to their region of residence, not workplace, as required for COCO-2. This is only an issue for London, South East and East regions.

Notwithstanding the above, the COCO-2 method provides the most reasonable estimate of the value of economic activity in small areas of the UK that can be achieved with current data and resource limitations. It is not thought that the errors discussed will have a substantial impact on the usefulness of derived estimates of accident costs for safety case assessments.

11.1.2 Tourism Losses

As Section 5 clarifies, tourism losses are primarily related to the loss of income experienced by businesses in an affected area should visitor numbers fall following an event. This lost income can be equated to a loss of value added which is comparable to (indeed in some ways a sub-set of) industry value added discussed in Section 11.1.1. However, unlike the industry losses evaluated using Equation 11.1 tourism-related losses are not *net national* losses. The assumption is made that in the majority of cases visitors will go to alternative destinations within the UK. This, of course excludes incidents with very widespread effects, which may affect the overall levels of visitors to the UK (such as occurred in the 2001 Foot and Mouth outbreak). Further research will be required to discover if the response of visitors to a geographically circumscribed event such as a large nuclear accident, where major consequences are nevertheless confined to a relatively small area, has a similar effect on tourist numbers as a diffuse incident, occurring at many locations throughout the country, such as the FMD outbreak.

Tourism losses in COCO-2 are reported in terms of tourism gross value added (TGVA). This is the most appropriate measure of the 'true' economic value of tourism, as it is an estimate of how much industry value added is dependent upon income from visitors' spending. It is a more conservative estimate than that formerly used where tourists' gross expenditure was assumed to equate to the 'impact' of tourism.

TGVA is derived following the construction of a Tourism Satellite Account (TSA). A TSA effectively refines the system of national or regional accounts to reveal more clearly the economic consequences and contribution of tourism consumption. This statistical system has been accredited by a number of international agencies including the UN World Tourism Organisation, OECD and EUROSTAT, as well as the DCMS in the UK. Estimates of TGVA are available in experimental form for English Regions, Scotland and Wales.

COCO-2 apportions the TGVA of each SOA prior to transcribing it to 1x1km squares using the levels of employment in key tourist related industries such as accommodation and recreation[*]. These industries were selected following examination of the UK Tourism Satellite Account (see Section 11.2.2).

The regional tourism GVA is therefore allocated to each SOA using a straightforward scaling factor based on those employed in key tourism sectors as shown in Equation 11.2:

[*] Data are not generally available on the number of visitors to areas smaller than statistical regions. A proxy for the number is therefore derived for super output areas using levels of employment in key tourist related industries.

$$TGVA_s = \frac{KE_s}{KE_r} TGVA_r \qquad (11.2)$$

where KE_s is the FTE employment in key tourist industries in each SOA, KE_r is the regional FTE employment in the same key tourist industries and $TGVA_r$ is the corresponding region's total Tourism Gross Value Added.

This approach raises a number of methodological issues, which are discussed in turn below.

- **Ratios of 'Tourism Dependence'**

  Tourism related industries, especially restaurants and bars, may be differentially dependent upon visitors and residents' spending across space; thus, for small areas with a relatively large number of pubs and takeaways serving locals, estimates of tourism value added may be too large. However, given the relative concentration of TGVA, (and indeed the fact that locals on a non-routine visit to a restaurant could be considered 'visitors' under international guidelines) this is not considered a significant problem.

- **Different levels of productivity across space**

  COCO-2 allocates tourism value added according to FTE employment, whereas industries may in fact be more productive in certain locations than others. For example, the preponderance of larger hotels in city centre locations will drive a higher level of value added per employee*. The method could somewhat under estimate TGVA for such areas.

- **The Nature of Regional Estimates of Tourism Gross Value Added**

  COCO-2 uses estimates of TGVA from Tourism Satellite Account analyses for the English Regions and Celtic nations for the base-year 2000. These estimates are, however, experimental and suffer (in the English cases particularly) from quality and reliability issues. It is unclear whether these data will gain in quality following involvement from the ONS, and thus all tourism loss estimates should be considered indicative.

11.2 GVA related economic data

COCO-2 relies upon a variety of data sources to estimate industrial and tourism losses following an incident. These data sources are of varying authorship and quality; some ONS surveys have the status of a National Statistic. Others, particularly on tourism are the result of public-sector sponsored *ad hoc* analyses. They are nevertheless in each case the best or only option to inform COCO-2. Table 20 details the main ONS datasets that have been used to derive estimates of economic value added for small areas. The

* Large hotels are more likely than small to have more efficient labour practices, greater gross margins and hence higher value added per worker.

UK regional annual economic accounts for 2003 have been used to provide estimates of headline GVA for 15 industries in 11 regions with information on 15 subsets of manufacturing used to adjust national estimates of industrial productivity to reflect regional differences. Table 20 also comments upon the status, suitability, limitations and timeliness of the data. Some additional comments are given below.

- ***Reference Year***

  In addition to the limitations listed, and expanded upon in the sections below, there is the additional problem that the data sources vary in timeliness and reference year. The data has thus been reflated to a 2004-base year (which was the latest year available for key data sources) using additional data sources, primarily *Office for National Statistics* series of deflators for gross value added based on the chain linked GVA project[*], and tourism *UK Tourist Statistics* and *International Passenger Survey* data sets[†]. Other data did not require reflation, either being available for 2004 or, in the case of economic and tourism multipliers, being simple ratios.

- ***Data Confidentiality***

  Data on employee numbers taken from the Annual Business Inquiry are confidential to primary and secondary signatories to a Chancellor of the Exchequer's Notice. To avoid the necessity of obtaining such a notice while ensuring confidentiality the data in question have been additionally randomised by WERU. The details of this randomisation process are not rehearsed here (for obvious reasons), but analysis has shown a maximum resultant deviation from ABI totals (and hence errors in GVA estimates) of 21% for a single SOA. Typical deviations for single SOAs are between 3%-5%. As the number of SOAs within the affected area rises, the level of error decreases quickly to negligible levels. The procedure applied will prevent an analysis providing information on the exact level of employment at any plant. Thus, together with the transposition to 1x1km grid squares and the rounding of industry GVA estimates to the nearest £100,000 in all datasets, no confidential company-provided information can be gleaned from COCO-2 supplied data.

[*] http://www.statistics.gov.uk/StatBase/tsdataset.asp?vlnk=206&More=N&All=Y

[†] See www.staruk.org.uk and www.statistics.gov.uk/ips

- ***Data Quality and Future Updates***

  As Table 20 shows, and as is highlighted elsewhere in this report, COCO-2 relies in part on estimates that are of high quality and regularly updated, but it also makes use of data sources that are *ad hoc* and of far lower quality. In some cases, it is be expected that COCO-2 could be updated in the medium term as new data became available (for example, the publication by ONS of a new set of Analytical Input-Output Tables would provide updated industry multipliers). In other areas, it is unlikely that new and better data will become available, even in the medium term (for example, relating to tourism GVA for English Regions). In this latter case, whilst other data sources would typically be available to provide an indication of future trends, it is inevitable that COCO-2 will suffer degradation in the quality of these estimates as the distance from the base-year increases.

Table 20 – Main COCO-2 Data Sources

Quantity	Source	Description	Currency and Updates	Use	Limitations
Annual Business Inquiry (Part 1)	www.statistics.gov.uk/abi	This is the main business survey of GB; Part 1 relating to employment. The ABI is a stratified random sample, using SIC92/ 2003, employment and country as stratifying variables.	2004 data used but it is annually updated.	Estimates of FTE employment by SOA for both industry and tourism analysis, plus estimates of FTE employment in statistical regions.	Limitations include lack of stratification by statistical region; poor coverage of micro firms; no estimates of self-employment.
Headline Regional Gross Value Added	http://www.statistics.gov.uk/articles/economic_trends/ET627_Marais.pdf	ONS Estimates of industry gross value added by 16 industries plus sub-sections of manufacturing. Derived from ABI financial returns plus PAYE and other information.	2004 data used. http://www.statistics.gov.uk/downloads/theme_economy/Regional_GVA_December_2007.pdf	Estimates of regional value added per FTE employee for industry (when used in conjunction with ABI part 1 data)	Year-by-year smoothing irons out volatility in estimates, raising questions of quality. Based largely on non-regionally stratified ABI data. No other variables are available.
UK Input Output Balances (Supply and Use Tables	www.statistics.gov.uk/inputoutput	The UK national economic account	2003. Supply and Use Tables updated annually	Provision of Type I multipliers to assess indirect industry effects (supply chain)	Full analytical tables & multipliers only available for 1995 base year. There are no short-term plans to update.
English Regions Tourism Satellite Account – First Steps	http://www.nwda.co.uk/pdf/EnglishRegions_TSA_ReportAug05.pdf	Pilot estimation of headline tourism indicators for English Regions.	2000. Ad-hoc analysis, unlikely to be updated in short term	Tourism Gross Value Added for English Regions	Top-down estimate of TGVA achieved by allocating England TGVA on basis of tourism industry presence and total tourism consumption.
Tourism Satellite Account for Scotland - 2000	http://www.scotland.gov.uk/Publications/2004/10/20075/44987	Analysis undertaken by Scottish Executive.	2000	Tourism Gross Value Added for Scotland	Of relatively high quality but unclear whether or when it will be repeated
Wales Tourism Satellite Account 2000	http://www.weru.org.uk/Review17_1/Wer17_1.pdf	Analysis by WERU for VisitWales.	2000 data used. 2003 now available (not public domain).	Tourism Gross Value Added for Wales	Ongoing work with 1998, 2000 and 2003 base years and environmental extensions. Provides tourism multipliers.

11.2.1 Multipliers estimating indirect effects

The economic multipliers used in COCO-2 are of two forms with the more complex of the two providing an attenuation function to account for potential direct effects of an accident on suppliers. The first set of multipliers is shown on Table 21. These will be applicable in most circumstances but should the accidental release be very large then they may overestimate the consequences of secondary effects. In this case, the attenuation function discussed in Section 11.2.3 should be applied.

TABLE 21 Industry & Tourism Multipliers

SIC[1]	Explanatory text	Multiplier[2]
01 : A01	Agriculture (part), hunting and related service activities	1.91
01-02 : A	Agriculture (part), hunting, forestry, logging and related service activities	1.83
05 : B	Fishing, operation of fish hatcheries and fish farms	1.66
10-14: C	Mining & quarrying	1.75
15-16: DA	Manufacturing food prods; beverage & tobacco	2.14
17-18: DB	Manufacturing Textiles prods	1.66
19 : DC	Manufacturing Leather Tanning and dressing of leather; luggage, etc	1.99
20 : DD	Manufacture of wood and products of wood and cork	1.93
21-22: DE	Manufacturing pulp, paper; publishing, printing	1.71
23 : DF	Manufacturing of coke, refined petroleum products and nuclear fuel	1.95
24 : DG	Manufacture of chemicals and chemical products	1.79
25 : DH	Manufacture of rubber and plastic products	1.79
26 : DI	Manufacture of other non-metallic mineral products	1.83
27-28: DJ	Manufacturing basic metals, fabricated metal prods	1.86
29 : DK	Manufacture of machinery and equipment not elsewhere classified	1.84
30-33: DL	Manufacturing electrical & optical equip	1.73
34-35: DM	Manufacturing transport equipment	1.79
36-37: DN	Manufacturing not elsewhere classified	1.87
40-41: E	Electricity, gas, water supply	2.07
45 : F	Construction	2.09
50-52: G	Wholesale, retail; repair of vehicles & household goods	1.76
55 : H	Hotels and restaurants	1.71
60-64: I	Transport, storage & communication	1.73
65-67: J	Financial Intermediation	1.78
70-74: K	Real Estate, renting & business activities	1.53
75 : L	Public administration and defence; compulsory social security	1.51
80 : M	Education	1.45
85 : N	Health and social work	1.41
90-93: O	other community, social & personal service activities	1.74
95-97 : P	Private households with employed people	1
99 : Q	Extra-territorial organisation and bodies	1
Tourism GVA Multiplier M		*1.63*

[1]This is the Standard Industry Classification an internationally agreed scheme to identify sectors of the economy showing both the sub-sections (A, B, C, DA, etc)) and their component divisions.

[2] M_{SIC} is the multiplier referred to in Equation 8.3. The demands that lead to the multiplier are calculated for the relevant industry supply chain using the UK IO Analytical Tables for 1995. The multiplier shown is the GVA weighted average multiplier of the multipliers for the component SIC divisions. The Tourism multiplier is Type 2 (ie, includes indirect effects as above but also induced wage effects) and the GVA multiplier from the 2000 Wales Tourism Satellite Account (see Table 20).

In Table 21 both the aggregated agriculture and forestry class (A) and the component agriculture class (A01) are listed[*]. The former is used as the GVA multiplier for business losses within the sector using the procedures of Section 8 while the latter is used as the multiplier for farming losses evaluated using the procedures of Section 9. The direct loss of GVA due to the temporary closure of businesses is calculated from ABI information, which, although including agriculture related activities, specifically excludes the contribution of farming to the A01 agricultural category. The farming losses of Section 9 are thus additional to the ABI loss estimates and no double counting of direct farming losses therefore occurs. However, when calculating indirect losses, although forestry is excluded, separate multipliers for the sub-categories of the A01 class are not available (Mahajan, 2008). This prevents the separation of farming from agricultural related activities and introduces some uncertainty into the calculated indirect loss from restrictions placed on agriculture. This is raised as a topic for further work in Section 13.2.

11.2.2 Tourist data

The estimates of loss from tourism are primarily of interest for those considering effects at the local and regional level where the disruption to tourism activity may have significant economic consequences. This loss does not reflect the consequences in the wider economy and the local loss should therefore not be combined with the national loss estimate.

The direct loss estimates for tourism use the First Steps Tourism Satellite Accounts for the English Regions[†], the Welsh Tourism Satellite Account for 2003[‡] and the Scottish Tourist Satellite Account 2000[§]. The multiplier determining the *indirect* effect of the loss of tourist demand in the local economy is calculated using information from the Welsh Tourism Satellite Account (TSA) for 2000, as this is the only new source of tourism multipliers in the UK since the 1992 Scottish Tourism Multiplier Study.

Data on the economic value of tourism are problematic at any level below that of the entire UK; industry data poorly estimate the contribution of the important self-employed and micro businesses whilst data on tourism consumption have been incomplete, of dubious quality and available typically only for more aggregated geographies. However, following an examination of the UK Tourism Satellite Account, the dominant industries that supply the needs of tourists were identified (Table 22) and the incidence of FTE employment in these SICs was then used to disaggregate (already estimated) levels of TGVA across small areas. There are a number of methodological issues raised by this method, which are discussed in Section 11.1.2.

---

[*] A full description of the SIC codes and their meaning is available from ONS at http://www.statistics.gov.uk/methods_quality/sic/

[†] http://www.nwda.co.uk/pdf/EnglishRegions_TSA_ReportAug05.pdf, http://www.culture.gov.uk/NR/rdonlyres/261C1D71-BFEA-499D-8A45-B4F5C7DC1B9C/0/tsafirststepprojectappendices.pdf

[‡] Not public domain contact VisitWales http://www.visitwales.co.uk/

[§] http://www.scotland.gov.uk/Publications/2004/10/20075/44991

TABLE 22 Definition of Visitor Facing Industries

SIC 2003 class (4 digit)		SIC 2003 group (3 digit)	
9213	Motion picture projection	551	Hotels
9231	Artistic and literary creation and interpretation	552	Camping sites and other provision of short-stay accommodation
9232	Operation of arts facilities	553	Restaurants
9233	Fair and amusement park activities	554	Bars
9234	Other entertainment activities not elsewhere classified	611	Sea and coastal water transport
9252	Museum activities and preservation of historical sites and buildings	612	Inland water transport
9253	Botanical and zoological gardens and nature reserve activities	621	Scheduled air transport
9261	Operation of sports arenas and stadiums	622	Non-scheduled air transport
9262	Other sporting activities		
9272	Other recreational activities not elsewhere classified		

The tourist industry has a high seasonal dependence and to account approximately for the variation in the generation of TGVA throughout the year seasonal adjustment factors based on national tourist expenditure data have been produced as shown in Table 23. Nationally, winter is 9% below average receipts, the shoulder quarters just below and Q3 (July-September) is 15% higher than a notional average quarter. As the data used is national as opposed to regional or even local, it is likely to exhibit much less variation than might occur locally. If this is considered important local survey information can be used to measure the change in visitor numbers and expenditure with season.

TABLE 23 Expenditure weighted seasonal tourism dependence

Season	% visitors			Seasonal factor qf
	UK Tourist Statistics[1]	International Passenger Survey[2]	Day Visitor Survey[3]	
q1	22	20	24	0.223
q2	26	25	23	0.248
q3	29	31	27	0.287
q4	23	24	26	0.242
Expenditure weighting (£bn)	41.8	16.1	31.7	

[1] http://www.tourismtrade.org.uk/MarketIntelligenceResearch/DomesticTourismStatistics/UKTS/UKTS.asp

[2]http://www.statistics.gov.uk/STATBASE/Source.asp?vlnk=348&More=Y

[3] http://www.countryside.gov.uk/LAR/archive/presscentre/gbdv.asp (2002-2003 Leisure Day Visit Survey for England, Wales and Scotland)

Alternatively, if seasonal adjustments are omitted the qf will be identical and Equation 8.4 will reduce to Equation 8.2 with TGVAD replacing GVAD.

11.2.3 The attenuation function

Section 11.2.1 described the multipliers used in COCO-2. These account for second order effects on the economy from the temporary closure of factories and other businesses in response to an accident. However, this multiplier effect on the loss of demand may be overestimated if the businesses supplying those businesses directly affected are also directly affected. This phenomenon will vary with the size of the accident. It is unlikely that a large number of suppliers of directly affected businesses will themselves be directly affected if the accident is small. However, it will be inevitable that some will be if the accident is large. The proposed method of coping with this eventuality within COCO-2 is to attenuate the multiplier determining the size of the indirect effect. The exact form of the attenuation is uncertain however, the function should ideally be asymptotic to both zero and one. The simple sigmoid functional form shown in Equation 11.3 has been adopted which, as shown in Figure 4, has the right general properties. The function reflects the fact that:

- In very local geographic areas, suppliers of distinct goods will be scarce and thus it is likely that all suppliers will be outside a very small affected area (hence the multiplier attenuation has no effect on overall multiplier size; ie, all indirect impacts are assumed to be outside the affected area).

- For extremely large (tending to whole of GB or whole-of-region) theoretical accidents, it is likely that all supplier/indirect impacts will be within the affected area as businesses will not typically choose to purchase supplies from further away than any alternatives due to higher transportation/communication costs. Thus, the attenuation factor will rapidly tend to 0 as almost all suppliers of local businesses are directly affected.

The function shown in Equation 11.3 was chosen to reflect these a priori assumptions rather than because of any theoretical considerations.

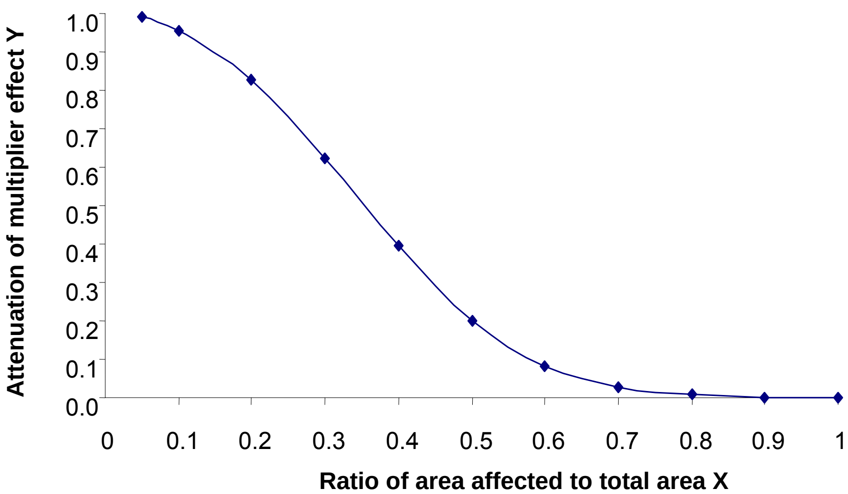

Figure 4 The attenuation function

$$y = \left(\frac{2}{1 + e^{8.76 x^2}} \right) \qquad (11.3)$$

In Equation 11.3 x is the ratio of the area affected to the total area of the economic region. The total area is therefore the area, either of the country or, in the case of tourism, the area of the Government office Region (GOR) affected. The remaining term y is the dimensionless attenuation factor modifying the indirect multiplier. Strictly the function, as well as having a value of 1 when x=0 and the accident is sufficiently small and localised that suppliers are not directly affected, should have a value of zero when x=1 and all industries are directly affected and no indirect multiplier is required. A more complex function with this property could be devised but there would be little merit in the extra complexity as only values near to x=0 are relevant as accidents significantly beyond this level of severity are incredible and the COCO-2 economic loss model will break down if such an event did occur. As tourism, losses are considered at a regional scale it is likely that the attenuation of indirect costs will be a more significant effect. However, as the estimation of tourism losses is constrained by the available data and limited by the unknown effect of the accident on elective spending decisions the use of an attenuation parameter is not recommended except for research purposes.

The attenuation function is also likely to vary with SIC code as some activities and their supply industries will tend to cluster more. Such higher order effects will not be considered further although if it was thought to be important local survey information could be used within a regional loss model (see Section 13.2).

11.3 Capital stock

To estimate the loss that would arise if the capital invested in plant and machinery were written off requires an estimate of the net value of productive capital assets at any location for the industries considered by COCO-2. As discussed in Section 8.4.5 a PIM model has been developed by the ONS to estimate this at the national scale (Giffen et al, 2005). The PIM estimates the value of capital stock still in use by summing the original investment data for these assets over their lifetimes adjusted to reflect capital consumption (depreciation). The PIM assumes straight-line depreciation, so that the stock purchased in any year decreases in value in each subsequent year by a constant amount, with assets assumed to be retired near to their average life length as specified by an appropriate retirement function. To obtain an approximate measure of the local stock value of industry a simple ratio of the stock value per sector with the GVA generated per sector is taken. The latter is available from ONS regional data as the so-called raw UK standard industrial classification of economic activities for gross value added by region 1989 - 2004*. Table 24 shows the result per sector of taking this ratio. The approach assumes that the plant and machinery used has a uniform mix of ages throughout the UK and that other factors such as distance from markets do not affect the GVA generated at a particular location.

* http://www.statistics.gov.uk/statbase/Product.asp?vlnk=14650

TABLE 24 Net capital stock by sector as fraction of sector GVA 2004[1]

SIC	Explanatory text	Plant And Machinery per sector GVA (PMR)	Transport Equipment per sector GVA (TER)
A,B	Agriculture, Forestry and Fishing	0.68	0.13
C	Mining and Quarrying	3.02	0.20
DA	Food products; beverages & tobacco	0.79	0.02
DB,DC	Textile and leather products	0.72	0.02
DD	Wood and wood products	0.41	0.03
DE	Pulp, paper & paper products	0.77	0.01
DF	Coke, refined petroleum products & nuclear fuel	1.86	0.00
DG	Chemical products and man-made fibres	1.28	0.01
DH	Rubber and plastic products	0.79	0.03
DI	Other non-metallic mineral products	0.88	0.02
DJ	Basic metals and fabricated metal products	0.68	0.03
DK	Machinery and equipment not elsewhere classified	0.51	0.02
DL	Electrical And Optical Equipment	0.71	0.01
DM	Manufacturing Transport Equipment	1.02	0.01
DN	Manufacturing not elsewhere classified	0.38	0.05
E	Electricity, Gas and Water Supply	2.90	0.01
F	Construction	0.17	0.05
G	Distribution	0.54	0.05
H	Hotels and Restaurants	0.42	0.01
I	Transport and Communications	0.81	0.44
J	Financial Intermediation	0.24	0.02
K	Real Estate, Renting & Business Activities	0.19	0.08
L	Public Administration including Roads	0.20	0.06
M	Education	0.06	0.01
N	Health	0.09	0.01
O	Other Services	0.34	0.05

[1]Capital Stocks, Capital Consumption and Non-Financial Balance Sheets 2005 (Giffen et al, 2005) and raw GVA by region 2004 (http://www.statistics.gov.uk/statbase/Product.asp?vlnk=14650)

The level of sector detail provided in Table 24 is slightly less than that used in GVA estimates (see Table 20) and care should be taken to sum the appropriate entries, eg, the GVA data supplied in the accompanying file for SIC codes A01, A02 and B will use the same PMR and TER values.

11.4 Data revision

The data used by COCO-2 will become less representative of the UK economy over time. It is therefore important to consider the best ways of maintaining and revising the data with respect to both the thoroughness of the result and the effort required. This report provides sufficient detail for a comprehensive update of the data to occur using new datasets derived from revisions of the original sources or their future equivalents. However, as noted in Section 11.2 some data, eg, tourism, are unlikely to be improved in the near future without major development work.

This report, by establishing the detailed COCO-2 methodology, ensures that any future comprehensive update will be a comparatively simple exercise to implement. However, it is nevertheless likely to require a substantial amount of work, particularly if a Chancellor of the Exchequer's notice is required to obtain data, which must then be transformed to a regular grid format using the approach described in Appendix B. This sort of upgrade should be considered if a considerable period has passed since the last full update and in particular, if ONS revises the IO Analytical Tables for 1995, as the new multipliers will then be a better representation of the altered structure of the economy. In the former case although the Analytical Tables have not been upgraded, a revision will partially capture the consequences for regions that have undergone significant structural change. For example, a change from heavy manufacturing or extractive industries to lighter industrial or service industries will modify the GVA per employee, which, together with a changed density of employment, will result in a different rate of GVA generation per unit area.

Data, which are not represented within the IO model using an appropriate GVA/SIC for every grid square, can be comparatively easily up-rated by using the approach applied to generate the original information. For example, capital values, agricultural costs and health costs. The inhabited area data involved will still require GIS processing effort to convert, for example, capital values into the appropriate regular grid of information but there is no requirement for GIS processing of the health or agricultural costs, as they do not vary regionally. However, to ensure consistency consideration should also be given to the need to update the population and agricultural production data required by the PRA model implementing COCO-2. If it is thought inappropriate to attempt a full revision, three partial update options are considered in Sections 11.4.1, 11.4.2 and 11.4.3 below.

11.4.1 Regional update

In many cases, only a relatively small area near to the site of a postulated accident will be subject to the disruption of economic activities modelled in Section 8. Thus, for studies of sites within a single region only an update of the inhabited area data for that particular regional will be required. The requirements for agricultural and health data will generally be more extensive but as the cost data in each case are not location dependent the task of updating that information is both easier and automatically provides comprehensive coverage. Updating small area economic data will however, remain a comparatively difficult and time-consuming option because of the need to obtain a Chancellor of the Exchequer's notice to obtain the raw data, to apply a randomising algorithm to maintain data confidentiality and then to use GIS tools to produce a regular grid of information.

11.4.2 Revalorisation

A much simpler alternative to the full or regional update is to rescale the inhabited area data. This will consider the GVA/SIC generated within each region from revised national statistics and update the COCO-2 data as required. This approach has the great merit of simplicity, but it will degrade the spatial quality of the data. The rescaling will effectively adjust the contribution of every business of a particular type in the same way and be unable to take account of the fact that some businesses will grow more than others will and that activity will move within a region as retail and industrial parks develop, etc. This sort of upgrade will become progressively worse as time goes on and, at some stage, a full upgrade will be required. Although it is difficult to give robust guidance on when such an approach will be no longer acceptable, the decline in the spatial adequacy of the data can be qualitatively but easily checked by reviewing changes in the size of towns, in communication links and in the location of retail, commercial and industrial sectors. One particular problem with the approach is that it will not capture the appearance of high value new industries (eg, biotechnology) very well, as any existing representation of the appropriate SIC codes related to more traditional activities (eg, brewing) is likely to be in an entirely different location and have a very different GVA per employee.

To complete the revalorisation both health and agricultural costs should be reviewed and revised if new data are available.

11.4.3 Partial revalorisation

The third option is simply to upgrade the agricultural and / or health values without considering any change to the inhabited area data. In many cases, the overall cost of an accident will be dominated by the costs arising from agriculture and health and therefore updating these sectors will account for the great majority of the revalorisation required. An approximate assessment of the effect of using old inhabited area data can be made by simply rescaling the COCO-2 prediction of GVA lost by the ratio of the new to old value of GVA in the region. If necessary, the comparison can be extended to consider approximate changes in capital losses.

12 EXAMPLE CALCULATION

Although of broader scope, where similar endpoints are sought COCO-2 has many features in common with the previous COCO-1 model (Haywood et al, 1991). Nevertheless, in a number of these areas significant changes have been introduced to the specific calculations performed. This has been done to take advantage of the greater availability of information as well as to address specific deficiencies identified during the development of the COCO-1 model. It is therefore of interest not only to consider example results from the new model but also to compare those results with corresponding results obtained using the old model suitably revalorised. The sections below discuss an example comparison undertaken and the results found. It should be borne in mind that the scenario chosen was to a degree arbitrary, and was selected as a convenient compromise between demonstrating the capabilities of the new model and the practical constraint of the model not yet being available as an option within a PRA code. This example should not be treated as an indication of the precise results that would be obtained for any particular implementation within a PRA.

Table 25 gives details of the scenario examined with each of the component parts of the scenario elaborated in the following sections and in more detail in Appendix F.

TABLE 25 Example Scenario

Aspect	Comment
Accident	A large and unlikely release is assumed to occur suddenly on the 1st of June. The size of the assumed release has the advantage of allowing most aspects of the model to be tested while the timing is likely to maximise agricultural losses.
The release	A containment bypass (CB) accident characteristic of a fault sequence in a pressurised water reactor was assumed. The release termed CB1 is the largest of this general category of accident with an estimated frequency of ~4 x 10^{-8} y^{-1}. The release predominately consists of a variety of radioactive noble gasses, together with radioactive isotopes of iodine (Barnes, 1990).
Dispersion	A CB1 accident sequence is estimated to last an hour. In this case, it was assumed to consist of a plume of material dispersing directly towards the nearest town and then onwards across the country. It is assumed for simplicity that the wind maintained a constant direction, for the entire travel period of the plume passing over the UK. It is further assumed that the plume travels at a constant velocity of 5 ms^{-1}, no rain occurs during the travel of the plume (Higgins and Jones, 2003) and that the most common daytime atmospheric stability category termed Pasquill D applies (Arya, 1999).
Countermeasures	Emergency, food and longer-term countermeasures were considered. In particular, sheltering of the population occurred up to 40 km from the site, food restrictions were introduced that extended approximately 400 km from the site and two zones were defined where decontamination was carried out with the population relocated for 7 days and a month respectively for the larger and smaller zones.

12.1 Accident scenario

The example calculation assumes that a severe containment bypass occurs as this allows a more comprehensive comparison of the new model with the old. For the purpose of the example, the accident was postulated to take place at a reactor sited in the south west of England. The release was assumed to occur in dry conditions and last an hour with the plume of radioactive material dispersing under constant atmospheric conditions including a constant wind velocity towards the nearest town.

COCO-2 has not yet been implemented within a PRA code and therefore *ad hoc* combinations of modelling tools were required to calculate the example results. The release, the radiological consequences and the countermeasures implemented to reduce the doses received by the public and assist in post accident recovery were modelled using a combination of the PC Cosyma (Jones et al, 1996) PRA code and other tools including the use of GIS. PC Cosyma provided dose estimates for the exposed population from all sources of exposure, with due account of the mitigating effects of the countermeasures applied*. In particular, PC Cosyma was used to provide estimates of the expected numbers of health effects that were then costed using the approach of Section 10.5. The remainder of the economic effects from disruption of economic activity in inhabited areas to the cost of food restrictions were calculated with the aid of a GIS and a simple atmospheric dispersion model mirroring the results of the dispersing plume in PC Cosyma. The use of GIS allowed the additional gridded

*Additional corrections were applied to the Cosyma estimates of individual dose to overcome limitations in the countermeasure dose adjustment to include the effect of sheltering on estimated long-term doses.

information required by COCO-2 to be applied in combination with background mapping providing coastal boundaries, etc. The details of the dispersion modelling employed should not affect the comparison being made on grounds of economic costs between the COCO-1 and COCO-2 models although it may affect the overall size of the losses predicted. Although the accidental release was large, it was found that no attenuation factors were required in the estimate of indirect losses in the general or tourist economy.

A combination of tools have been employed to produce the estimated costs of the example accident some of which were produced on an ad hoc basis while others such as PC Cosyma, which is predominately intended for PRA work, were co-opted. The combination of calculation components from different sources imposes limitations on the intercomparisons that can be supported. Thus, although each calculation is internally consistent, health effect costs cannot be compared to either the predicted urban area or agricultural losses[*]. The limitations of the example comparison are discussed in more detail in Section 12.7.

12.2 Emergency countermeasure assumptions

The details of the release given in Section 12.1 impose some constraints on the timing and extent of the emergency countermeasures applied in response to the release. In particular, the lack of warning and the short travel time to the nearest town are assumed to lead to the population being advised to shelter initially and not to evacuate[†]. Thus, to estimate costs, Equations 8.3 and 8.5 were used to calculate the economic loss from sheltering for 1 day with the appropriate multiplier for each sector drawn from Table 21.

The accident under consideration is beyond a design basis event and therefore the site emergency plan would be used to guide the response under the extendibility provisions. For such a severe accident, it was assumed that actions are more likely to be triggered near to upper ERL values although the exact arrangements to be put in place are not of primary concern for the COCO-2 example except in as far as a reasonable scenario can be constructed. More details on the scenario are given in Appendix F.

12.3 Temporary relocation assumptions

Following the end of sheltering it was assumed that the population, within the area to be remediated, were temporarily relocated while work went ahead to decontaminate the area. For simplicity, contaminated areas were defined as areas where the long-term dose (from direct irradiation and resuspension) received from material deposited on the

[*] For technical reasons an ad hoc approach was used to calculate agricultural losses using new agricultural production data and GIS modelling while the number of health effects were estimated by PC Cosyma using, in part, older agricultural data and a differently designed grid.

[†] It was assumed that the population most directly affected was temporally relocated shortly after the release ended to allow decontamination work to take place.

ground, was predicted to exceed 10 mSv a year*. For the example calculation the area with doses exceeding this value was divided into two decontamination zones, Zone A and Zone B. The larger Zone (A) represented the area where the residual dose in the first year after the emergency was less than 17 mSv per annum and could be reduced to less than 10 mSv per year using category A methods within 7 days of the accident occurring. Category A methods (NRPB, 1997), are characterised as effective if applied quickly and are relatively inexpensive. Zone B was defined as the much smaller area where the residual dose was initially >17 mSv per year and decontamination was assumed to take place over 30 days using category B methods (NRPB, 1997). It was assumed that all industries and businesses within each zone were closed for the duration of the decontamination procedures: 7 days for Zone A and 30 days for Zone B.

The total surface area of each surface type within each countermeasure zone was estimated using information from the Generalised Land Use Database (GLUD) (See Section B4) which supplied an estimate of the surface area for each surface type, eg, Green space, Gardens, Roads, Paths, Domestic buildings, and Non-domestic buildings where the latter two outputs were used to estimate roof areas. This allowed several different clean-up methods to be applied with the choice at each location depending on the particular surface being treated. The cost of applying a particular countermeasure per unit area, provided by the UK Recovery Handbook (HPA-RPD, 2005), was used to calculate the cost of decontaminating a single surface type, for example the cost of grass cutting in areas of green space and gardens. The decontamination methods considered were under category A: fire hosing, vacuum sweeping and grass cutting and for category B: high pressure hosing and turf cutting with different costs used for some techniques when applied to large and small areas respectively as noted by the UK Recovery Handbook (HPA-RPD, 2005).

In addition, from an estimate of the deposition density of radioactive contamination and the amount of material collected by the various techniques applied, an estimate was made of the radioactive concentration of the waste arising and, by calculating the mix of beta-gamma and alpha radionuclides in the waste, what category of waste would be produced. The amount and categorisation of the waste was then used to give an estimate of the total cost of waste disposal. For simplicity, it was assumed that exempt and Very Low Level Waste (VLLW) was sent to landfill (using commercial waste costs from Oxford county council†) and Low Level Waste (LLW) was sent to the Low Level Waste Repository near Drigg using standard costs (BNFL, 2006).

Thus, the costs incurred in decontaminating an area are composed of the direct costs of applying particular procedures together with the business and tourism losses of Equations 8.3 and 8.5, the cost of evacuation as given by Equation 8.6 and the cost of

* As PC Cosyma calculates either short term doses received over a few days or doses received over 50 years, the external dose received in the first year less the dose in the first week was approximated by applying the pattern of temporal dose decline estimated from the modelled deposition of iodine and caesium using the GRANIS model (Kowe et al ,2007) to the PC Cosyma estimated 50 year dose from deposition.

† Commercial waste cost from Oxford county council website, http://portal.oxfordshire.gov.uk Wednesday 23 August 2006.

temporary accommodation given by Equation 8.7. As with countermeasure costs in general, COCO-2 assumes that the direct costs of applying any decontamination measures and disposing of the waste generated are supplied by the PRA model implementing COCO-2. Thus, the procedure outlined above for estimating such costs for the example calculation is not part of the COCO-2 model. No calculation of lost household capital services for those relocated for a month was calculated because, as a small fraction of the housing costs, it would be a negligible contributor to the total cost of the accident.

12.4 Restrictions on crops

The very large accident postulated in this example would result in restrictions on the sale of food over an area that extends from the west coast to the east coast. For simplicity, it was assumed that the areas subject to restrictions were limited to those that are predicted to exceed the CFIL limits on permitted radioactive concentrations in food.

The particular foods considered for the example calculation are milk, cow meat, sheep meat, cereals, green vegetables and potatoes. It was also assumed that the restrictions placed on these crops were revised at progressively longer intervals, eg, after 7 days, 30 days, 90 days, 180 days, 1 year, 2 years and at particular harvest times for potatoes and cereals. In line with the discussion of Section 6, it was also assumed that no further economic losses occurred in the agricultural sector after the second year of any restrictions.

In addition to the restrictions imposed on the sale of crops, a range of other countermeasures could be applied to restore production more rapidly and reduce the overall cost. However, for simplicity, no further actions were considered and the example calculation assumed that the restrictions on the sale of crops simply required any unsold crop to be destroyed and disposed off. This is likely to give an upper limit on the likely cost of agricultural losses. The equations of Section 9 were used to provide an estimate of the direct and indirect losses from agriculture, where as discussed in Section 11.2.1 a multiplier value of 1.91 was used to represent the indirect contribution of farming to the economy.

The cost of disposing of the production, which could not be sold, was also considered. Following the advice of the UK Recovery Handbook (HPA, 2005) it was considered both practical and appropriate to assume that arable crops were ploughed in at negligible cost. The costs of disposing of the large volume of milk restricted from sale were estimated by assuming that the milk could be discharged via a sea outfall. In addition to milk, the scenario resulted in some sheep and cows being restricted for more than two years and for simplicity, it was assumed that these animals were culled and the remains disposed of. The costing approach of these and the various other agricultural disposal options available are discussed in detail in Appendix C.

12.5 Health effects estimation

The number and severity of the cancers arising from the accident were estimated using the PRA model PC Cosyma (Jones et al, 1996) and the resulting costs estimated using the default costings recommended in Section 10.5. The appropriateness of using the default costings was confirmed by undertaking an initial calculation to establish approximately how a representative annual organ dose is likely to vary with time (see Section 10.5 and Appendix F). This temporal pattern of dose delivery was a good match to the dose profile used in the estimation of the default costs of Tables 18 and 19. The total cost of cancers was therefore estimated by multiplying the default costs by the predicted numbers of cancer deaths and incidences. This demonstrates, as discussed in Section 10.5, that the use of default costs circumvents the problem of not knowing in detail the temporal distribution of dose, which is in principle required to calculate the appropriate discounting. However, if a substantial population were likely to receive doses at the higher end of the stochastic regime or beyond, it may be appropriate to carry out particular calculations of the expected temporal distribution of cancers within this group. The example accident scenario avoided any population near to the site of the release and therefore PC Cosyma did not predict any deterministic effects. PC Cosyma also estimated that approximately 95% of the collective dose arose from the ingestion pathway, which, due to the countermeasures invoked, would be delivered at very low dose rates. In addition to the cancer estimates, PC Cosyma provides estimates of the likely number of hereditary effects, which can therefore be costed using the values of Table 16.

12.6 Example results

As stated in Section 12 one of the primary objectives of these calculations is to provide a comparison of COCO-2 estimates with those obtained using the COCO-1 model. A parallel calculation has therefore been undertaken using the COCO-1 formulation where costs have been adjusted using appropriate deflators to allow an appropriate cost comparison to be made. Naturally, to provide a fair comparison the costs estimated for COCO-1 are based, as far as possible, on the same scenario and where differences necessarily arise, these are discussed. In some cases, multiple COCO-1 values are given to show the effect of different methods of updating the COCO-1 base data from 1987 values. The two approaches adopted either use a deflator, to convert the COCO-1 valuations, or COCO-2 data within a COCO-1 formulation. However, the latter option, which should be the most reliable, is not always possible due to differences in the modelling approach.

Additional information on the calculations undertaken and some more detailed results are given in Appendix F.

12.6.1 Inhabited area costs

Table 26 summarises the COCO-1 and COCO-2 non-health and non-agricultural costs estimated for the example scenario. Noting that COCO-1 estimates an approximate combined cost for decontamination and waste disposal the two models can be seen to agree on the ranking of costs from least to most significant. Indeed even though the estimated transport cost accounts for the empty return journeys of a coach that is repeatedly reused, the cost of transporting those temporarily evacuated remains negligible in comparison to the other costs arising from the accident. It is also in very good agreement with the revalorised COCO-1 estimate*.

TABLE 26 Economic losses and costs excluding the agriculture and health sectors £ 000

Cost type	COCO-1	COCO-1 revalorised[1]	COCO-2
Transport[2]	32	59	51
Accommodation[3]	227	416	424
Production losses[4]	951	1,742	3,147
Decontamination[5]	3,250	5,952	999
Waste disposal	NA	NA	8,668
Total	4,461	8,169	13,289
Local Tourism Loss	NA	NA	227

[1]The results are revalorised using a deflator (1.831) to convert from 1987 to 2004 values.

[2] The COCO-1 cost is based on a total journey of 30 miles and an 80%, 20% private public transport mix. The COCO-2 cost assumes relocating those affected a distance of 50 km. It is assumed that for each outward trip with passengers a coach makes a return journey empty.

[3]The similarity of the COCO-1 and COCO-2 results is coincidental.

[4]The COCO-1 costs are based on a GDP per capita estimate while the COCO-2 estimate includes both direct and indirect costs.

[5] COCO-2 does not supply a cost for decontaminating an area but refers to the UK Recovery Handbook (HPA, 2005). COCO-1 costs are based on Table 14 of Haywood et al (1991) assuming residential areas decontaminated by factors of 2 and 5 for zones A and B respectively and including an allowance for disposal costs.

The COCO-1 method of estimating the cost of accommodation is based on a per capita imputed rental value for the housing stock of the region whereas COCO-2 estimates local house prices and the number of properties affected. Thus, although both schemes impute a rental value the similarity of the revalorised COCO-1 value and the COCO-2 estimate is thought to be coincidental. If the change in housing costs is well represented by a deflator applicable to the whole economy, it suggests that the area affected has a mix of housing that is representative of the region or that the housing stock in the region is broadly homogeneous. No such coincidence occurs in the comparison of decontamination costs. COCO-2 is able to take advantage of the large amount of work that has occurred in this area over the intervening period. The COCO-1 report provides a cost for estimated reductions in external dose while the COCO-2 calculations make use of a more detailed representation of a particular combination of techniques applied to remove or immobilise material on the various contaminated surfaces likely to be present. In addition, this process allows an estimate of the amount of waste arising to be made, which can then be costed.

* The cost of using coaches to transport people from affected areas is based on sufficient coaches being available locally. This will become progressively less likely the larger the number of people that must be moved. However, if a small number of coaches are used repeatedly then the cost of their travelling empty will be a surrogate measure of the cost of bringing in coaches from elsewhere.

The example predicts that the local loss from restrictions on tourism only amounts to 7% of the production losses that occur throughout the country. This minimum loss estimate does not incorporate any concept of blight and indicates what might be achieved if the response were well handled.

Although the comparison between COCO-1 and COCO-2, shown in Table 26, is approximate, the difference between the revalorised COCO-1 result and COCO-2 is small with the revalorised COCO-1 giving ~60% of the COCO-2 cost.

12.6.2 Agricultural costs

Table 27 compares the estimated agricultural loss predicted by the two models. Original and revalorised COCO-1 results are shown together with the corresponding COCO-2 results. Both the direct and indirect COCO-2 contributions to the cost are shown separately to highlight the similarity that exists between many COCO-1 costs and the COCO-2 direct costs. This arrangement also highlights the importance of the indirect contribution, which is not considered in the COCO-1 model (see Appendix F).

TABLE 27 Agricultural losses excluding disposal costs £m

Crop	COCO-1	COCO-1 revalorised[1]	COCO-2 Direct	COCO-2 Indirect	COCO-2 Total
Milk	39.79	44.25	44.25	40.27	84.53
Cattle[2]	28.92	31.05	31.05	28.26	59.31
Sheep[2,3]	40.47	6.06	1.34	1.25	2.60
Green Vegetables[4]	38.78	3.10	2.44	1.66	4.10
Potatoes[4]	0.33	1.22	1.03	0.90	1.93
Grain[4]	114.22	57.29	54.46	28.93	83.38
Total	**262.51**	**142.97**	**134.7**	**101.16**	**235.85**

[1]The COCO-1 model evaluated using COCO-2 product values

[2]COCO-1 provides output and GVA values per head of livestock, which are independent of the type of livestock. These values are applied to the cattle and sheep numbers considered in the corresponding revalorised COCO-1 estimate and COCO-2 calculations.

[3]The COCO-2 model assumes that there is no loss if lambs are sold before the end of February, ie, 270 days after the assumed accident at the beginning of June. If the losses are applied to lambs restricted for any length of time, COCO-2 predicts a direct loss of £5.01m and an indirect loss of £4.36m.

[4]COCO-1 provides output and GVA values per km^2 of crop, which are independent of the particular crop grown. These values are applied to the crops considered in the corresponding revalorised COCO-1 estimates and COCO-2 calculations.

The COCO-1 economic losses shown in Table 26 were revalorised using a deflator to account for the change in the value of money between 1987 and 2004. This approach is also used for revalorising the disposal costs of agricultural wastes. However, such an approach for agricultural production would be severely distorting and the COCO-2 crop values were therefore used instead. This had the added benefit of providing a larger number of commodity costs for use in the COCO-1 formulae. Thus, for example, only the original COCO-1 model estimate of Table 27 assumes the same value per head for cattle and sheep losses*.

Implicit within the above costs are modelling assumptions such as the continuing production of contaminated milk, the disposal of which must be costed. Table 28 provides an estimate of these costs.

TABLE 28 Agricultural disposal costs £m

Disposal Costs	COCO-1[1]	COCO-1 revalorised[2]	COCO-2
Milk[3]	5.81	10.65	0.17
Cattle[4]	0	0	0.44
Sheep production[5]	0	0	0.28
Sheep flock[6]			2.71

[1]COCO-1 assumes a zero cost of disposal for all products other than milk.

[2]A deflator of 1.831 is used to convert 1987 values to 2004 values.

[3]The COCO-2 cost assumes direct disposal to sea. Some alternative options such as biological digestion would cost considerably more, eg, £36.33m while spreading on farmland as part of post accident recovery would be less expensive.

[4]The disposal cost is composed of the direct and indirect output loss from cattle to be restricted from sale for more than 2 years plus the capital loss of the parent herd plus the cost of rendering and incineration of the calves and cattle. Note some dairy cattle may be included in this calculation although milk restrictions are not required beyond 2 years.

[5]The cost of rendering and incinerating the lambs that will be restricted from sale for more than 270 days because they are assumed to have lost value.

[6]The cost of rendering and incinerating all the sheep in a flock where the sheep produced are restricted from sale for more than 270 days together with the capital loss of the parent flock.

Only a small number of cattle remain restricted at the end of two years and it was thought appropriate that these should be culled as a simple management option appropriate to a PRA application.

Additional costs can also be calculated for the incineration of crops as a management option but for example, as ~30% of straw is currently ploughed in (Li, 2004 and Stott, 2003) it would seem reasonable to neglect any additional costs as marginal over those of normal operations.

The major cost in Table 28 arises from the slaughtering and disposal of the sheep flock. However, the requirement to dispose of such a large number of sheep makes it likely that an alternative management arrangement would be introduced, if possible, to obviate the need for such an extensive cull. Thus, in contrast to the built environment results of Table 26 where disposal costs are a significant fraction of the total cost, they are only a small component of total agricultural losses. However, they may be a more visible component of the loss and have a disproportionate effect on post accident recovery. In particular, sheep may be the only viable farming option in less favoured areas. From the perspective of COCO-2, this is a PRA modelling issue for agreement between the

* Unlike COCO-2 estimates, COCO-1 animal loss estimates include an allowance for the loss of GVA from the slaughtering of animals.

producers and users of the code as to what is an appropriate practice. COCO-2 can then be used to calculate whatever costs are required.

12.6.3 Health costs

Table 29 provides the estimated cost of the health effects induced by the accident using the two COCO-1 approaches (human capital and subjective) and the single COCO-2 approach. The costs reported for cancer incidence include the costs incurred during treatment of those that eventually go on to die of the radiation-induced cancer. The estimated number of hereditary effects was calculated using a risk of 0.2% per Sv in line with the latest ICRP recommendations (ICRP, 2007) and consistent with the costing approach developed for COCO-2 (see Section 10.3.3).

TABLE 29 The cost of health effects £m

Health effect	Outcome[1]	COCO-1 Human Capital (HC)	COCO-1 (HC) updated[2]	COCO-1 Subjective (S)	COCO-1 (S) updated[3]	COCO-2
Solid cancer	Fatal	213	361	1218	1562	2869
Leukaemia	Fatal	75	130	271	348	522
Total	**Fatal**	**288**	**491**	**1489**	**1910**	**3391**
Solid cancer	Non-fatal	124	244	218	345	364
Leukaemia	Non-fatal	25	50	45	70	56
Total	**Non-fatal**	**150**	**293**	**262**	**415**	**421**
Hereditary[4]		58	47	145	146	103
Grand total		**496**	**831**	**1897**	**2470**	**3915**

[1]The non-fatal costs include an allowance for the early stage costs of treating those that eventually die

[2]Uses COCO-2 treatment costs and a deflator to convert earnings from 1987 to 2004

[3]Uses COCO-2 valuations

[4]COCO-1 assumes hereditary effects can be discounted over 40 years

The very large disparity in fatal cancer costs between the two COCO-1 methods shown in Table 29 clearly illustrates the limited scope of the human capital approach. The difference between the superficially similar COCO-1 subjective method and COCO-2 is dominated by the difference in discount rates. Although the COCO-2 estimate includes the net output loss from those that die, this only adds approximately £218m to the calculated cost of fatalities. It is the use by COCO-1 of an adjusted discount rate to account for changes in wages and costs in the economy while neglecting increasing expectations of health care in the future, which is the dominant difference. COCO-2 allows for increasing health care expectations by only applying the smaller pure discount rate in part reflecting the common social and psychological preference to value immediate benefits more highly than deferred benefits.

The costs of hereditary effects are accounted for slightly differently in the COCO-1 and COCO-2 models. In the former case very serious effects were costed and discounted over 40 years while in the latter early death was used as the measure of a broader range of hereditary effects.

12.6.4 Summary

For the particular scenario considered, agricultural losses dominate those from the urban and other manufacturing sectors. However, strictly, the results are only applicable to the particular scenario examined and while this may be broadly representative of large accidents at coastal sites further studies will be required to confirm this and to examine the behaviour of the model for a variety of accident scenarios. Unfortunately, although consistent within themselves, the agricultural and health losses cannot be directly compared because of calculational differences, eg, the use of a polar agricultural production grid in PC Cosyma (used to estimate the health effects) and a regular grid in the GIS based COCO-2 calculations that estimate agricultural losses.

However, making use of a very rough and approximate scaling it is thought that a revised PC Cosyma that is able to use contemporary data in the same way as the other cost calculations may reduce health costs by about a factor of three. This will nevertheless still result in health being the dominant accident cost (see Appendix F). A true ranking of costs will be possible when a PRA model becomes available that fully implements the COCO-2 model.

It is clear from the discussions of Sections 12.6.1 to 12.6.3 that a naïve revalorisation of COCO-1 by multiplying the results of each calculation (Inhabited, Agriculture and Health) by a single deflator would be very misleading. The improved agricultural costing of COCO-2, the introduction of indirect costs and a more appropriate discounting of health effect costs results in a more complex relationship between the results of the old and new models. It should also be remembered that only a single scenario has been examined and that other scenarios could demonstrate different relationships between the COCO-1 and COCO-2 results. Thus, although the example demonstrates the functioning of the new model and provides some context for the estimates produced it is unwarranted to draw from these results any simple scheme of scaling factors that could be applied to results obtained using COCO-1. Section 12.7 discusses some of the limitations of the example calculation further.

12.7 Limitations of the example calculation

A single scenario has been examined which limits the inferences that can be drawn, in particular, with respect to the consequences of different sizes and durations of release. For the large accident at a remote location considered in the example, health and agriculture are the dominant costs and these costs are likely to be strongly correlated through the contribution of food to the total collective dose received. In addition, the variance in the magnitude of far field effects through geographic constraints may easily be greater than the changing contribution from local effects on the nearest inhabited areas. Thus, in the case of the example, an alternative release direction is likely to result in a lower inhabited area cost (all other things being equal). However, the contributions from agriculture and health could vary by far more depending on where the dispersing plume of radioactive material reaches the coast and if, in so doing, it passes over distant conurbations*. Although the direction chosen for the example cannot be confirmed as the most economically damaging, the plume was able to travel a considerable distance before reaching the coast while passing over a large area of farmland.

COCO-2 is intended for use within a PRA environment but until it is incorporated within such an environment, it is impractical to provide the standard result of a PRA economics module of expected cost estimates averaged over weather sequences. Thus, the example calculation only considered one weather sequence. Instead of averaging over all directions, it was thought appropriate to attempt to maximise local consequences as this allowed many of the new features included within COCO-2 to be demonstrated. However, as discussed above this may not maximise the overall cost.

COCO-2 introduces the possibility of considering the influence of seasonality on the estimation of agricultural losses; this approach has been adopted in the example calculation. In many PRA applications, it will be sufficient to consider annual average agricultural losses: the expected agricultural loss in such a PRA assessment is likely to be slightly less than that calculated in the example. This may in turn affect the contribution of health effects to the total cost of an accident. However, the role of seasonality on agricultural costs is complex and is discussed in more detail in Appendix F.

A more comprehensive indication of the results of applying COCO-2 will be obtained once it has been implemented in a PRA code and a detailed analysis made.

13 FUTURE DEVELOPMENTS

The COCO-2 model provides a practical methodology for assessing the economic cost to the UK of a nuclear accident and has the advantage of offering significant improvements over the previous approach of COCO-1 while remaining readily tractable. However, as with all models, there is scope for future development. This section suggests areas where further work may be beneficial and the relative priority thought appropriate to particular development choices. The suggested areas for further work are organised using the descriptions of Table 1, which partitioned the problem into four sub-classes depending on whether the effect was a direct result of the accident or not and whether it could be easily valued, ie, given a market value. The scale at which the model operates is also briefly discussed.

The example calculation of Section 12 highlights the importance of the health and agricultural sectors in establishing the overall level of economic loss expected. The practical and theoretical model improvements discussed below should be considered in the light of this finding. For example, a minor increase in the detail considered in agricultural modelling may have a larger impact than a more radical change in a less significant part of the model. Thus, while every effort should be made to maintain the

* Distant conurbations, mountain ranges, forests, etc, within the path of radioactive material dispersing after an accident will reduce the potential collective dose contribution from food.

coherence of the model, some loss mechanisms should be represented in more detail. If further improvements in the resolution of the model in these areas are impractical, there may be little point in making radical changes elsewhere.

13.1 Direct tangible losses

COCO-2 devotes substantial effort into providing methods that can estimate the loss from the directly tangible effects likely to occur. However, there remain areas where additional developments would be beneficial.

When assessing the cost of lost capital assets in Section 8.4.4 COCO-2 provides estimates of the loss likely to occur if the possessions inside a house and the cars and motorcycles nearby are written off due to contamination. However, the values lack detail and are approximate. It is therefore appropriate that improved data should be sought and used if it becomes available. However, this cost component is only likely to make a small contribution to the total capital asset losses and will therefore only be important when those latter losses are a significant fraction of the total economic loss.

The health costs discussed in Section 10 do not differentiate between the costs of treating different cancers because the large variance in the treatment cost of any one cancer is likely to be greater than the variation in the median cost of treating different cancer types. However, as treatment pathway information becomes more readily available the variance in treatment costs will be resolved to a degree by the proportion of patients following different treatment pathways. It may be inappropriate to require such a complex analysis to be used in COCO-2 for fatal cancers, as medical costs are only a small part of the total cost associated with a death. However, the treatment cost for those that recover is likely to be a more significant fraction of the health cost as cancer treatments develop. Thus, the statistical information required by COCO-2 in terms of treatment durations, costs and outcomes is likely to be both more available in the future as cancer treatment improves and progressively more important.

Improved knowledge of treatment pathways will also provide better estimates of the total time spent in treatment and convalescence, which will aid estimates of output loss through cost of illness (COI) assessments, which in addition to treatment cost consider foregone earnings (Boyd et al, 2006 and Kuchler and Golan, 1999).

In addition to the uncertainty over the appropriate valuation to place on a period of morbidity, as discussed in Section 10.4, there is conceptual uncertainty over the form and nature of the relationship between WTP and QALY based approaches (see for example Pearce (2000)). Thus, in addition to any sensitivity analysis of the VOLY that may be undertaken, the particular formulation used to cost morbidity should be kept under review (see Appendix D and Jones-Lee et al, 2007).

Advantage should be taken of any data that become available that will permit a better estimate of the years of life lost through hereditary effects, for example, by having a different estimated length of life for each class of effect with a distinct risk coefficient.

13.2 Indirect tangible losses

The introduction of indirect loss into COCO-2 represents one of the main developments over the COCO-1 formulation by allowing the direct effects of an accident to be amplified down the supply chain and into areas potentially remote from the site of the accident. However, the model does not currently incorporate an estimate of the value of lost government services. Firstly, as non-market services, these cannot be easily related to their marginal or average cost of provision, generating philosophical and consistency issues. Secondly, government services are typically excluded from or treated separately in industry financial data, raising further methodological issues. As well as being difficult to value a lost service, eg, a library or a day centre for the elderly, it would be difficult to know what services would incur significant addition costs if there was alternative temporary provision. Any future revision of COCO-2 should consider if an enhanced assessment of losses from this sector would be either practical or useful in the light of experience of using COCO-2.

As previously noted in Section 8.4, COCO-2 does not consider induced effects on employment and income. Similarly, COCO-2 does not consider resource shortages, for example, the effect on the availability of housing if large numbers of people had to be permanently moved. These effects would be difficult to account for and it is suggested that any methodological developments are applied in the first instance to an improved regional representation using input output modelling. There would be numerous advantages in being able to assess the impact of an accident at both a national and regional scale. However, it is unlikely that appropriate information will become available in the short or medium term for a regional model, which would therefore have to be to be imputed, ie, it would be a mathematical construct that was consistent with the available national and local data but with a large margin of uncertainty. The advantage of a regional approach would be the improved representation of the local economic impact. For example, this would allow tourism losses to be considered with other regional losses in a coherent way although it would not remove the uncertainty due the effects of sentiment on future tourism numbers.

As mentioned in Table 3 the disruption of road and rail links has not been considered by COCO-2 as it is thought likely to be a small effect following an accident at a power reactor sited in a remote location. However, if, for example, an accident were to occur at a port or near marshalling yards there may be disruption of shipping, passenger and freight operations that would otherwise be unaffected. This problem should be considered if COCO-2 were to be extended to include accidents at chemical facilities and factories that are sited near to communication hubs. Similarly, COCO-2 does not consider a proximity effect on businesses in nearby areas, which, although not directly affected, nevertheless lose custom if the nearby population has been advised to shelter or has been evacuated, ie, custom is lost because of access problems and because the customer base has been relocated. The overall economic loss in the second case is likely to be small as custom will generally be deferred for short delays or transferred elsewhere.

Section 11.2.1 discusses the uncertainty surrounding the appropriate value to use as a multiplier for agricultural losses. Although only a relatively small change to the multiplier may be expected, because of the importance of agricultural losses (as demonstrated by the example of Section 12), this could produce a change in the total estimated cost of an accident which is larger than the contribution from some other sectors of the economy. It is therefore recommended that in any future revision particular attention is devoted to establishing a robust valuation for this multiplier.

Currently the attenuation function is the result of expert judgement and work could be carried out to improve the form and parameterisation of the function. However, this would require information that is difficult to obtain without survey work and, as the rate of attenuation is also likely to vary with SIC code (as some activities and their supply industries will tend to cluster more than others), the cost of a general survey of the country may be prohibitively expensive. A smaller scale survey, either in an area of particular interest, or to improve the generic attenuation function, would provide support for the COCO-2 formulation.

13.3 Direct Intangible losses

The value of the direct and intangible loss associated with a radiation-induced illness has been equated with pre-existing WTP estimates. These WTP results were derived to help in decisions on road safety improvements and not for the development of safety cases related to potential nuclear accidents. In the former case, the public is familiar with the nature of the risk and the consequences of an accident are immediate. However, in the latter case, the public are less familiar with the nature of the risk and the health consequences are likely to be delayed for several decades. It is not clear that the same result would be produced and further research is required (Frederick et al, 2003). Additional work is also required on the age dependence of the value of life and the relation between WTP formulations and QALYs. Further work in this area would also assist in the valuation of long-term morbidity discussed in Section 10.3. Appendix D discusses a tentative approach to this problem but further work is required to resolve the issue.

More generally, a detriment in quality of life may be because of an actual or perceived degradation of the environment (see for example MacDonald et al (1987), Guntermann, (1995) and Simmons and Kruse (2000)). Environmental change and loss has not been considered in COCO-2. Thus, COCO-2 has not considered existence or bequest values related to the potential loss of an environmental good. Radioactive contamination of the environment may run the full gamut of effects from negligible to minor changes to agricultural practices and crops, to more substantial changes, to finally the complete exclusion of the population from an area for an extended period. The assessment of the change in value associated with the changed landscape use is complex with the extreme consequence of exclusion not necessarily providing the greatest loss of value as wilderness may be more valued by society than say a forest monoculture and of greater value as a wildlife habitat.

In addition to the general detriment in the quality of life due to the degrading of the environment, no account is currently taken of the intangible loss suffered by those affected by countermeasure restrictions including those evacuated and relocated, eg, the loss suffered from having to stay temporarily in a school hall. The construction of appropriate social survey instruments and the subsequent questioning of appropriate groups would be very difficult particularly as there could be large differences between the appropriate amounts of CV for different groups in society. The alternative of considering court awards for approximately similar events may be more tractable but less direct and fraught with difficulties. Although awards might be based on a set of rules, which would allow punitive elements to be removed, there is no guarantee that a fair representation of the expected level of CV appropriate to those subject to countermeasures after a nuclear accident could be constructed. Future work to explore the importance of the CV not currently assessed as a direct tangible cost would be beneficial.

Unpaid output is not valued by COCO-2 although following evacuation and relocation some of the costs are likely to be explicitly manifested because, for example, of the need to provide care services for people who would normally be cared for by their relatives. Although the loss of unpaid services is difficult to quantify and not thought significant in comparison to the other costs considered it would be useful if this could be confirmed.

13.4 Indirect intangible losses

Those subject to evacuation, relocation or other measures introduced to protect them from the direct health consequences of a nuclear accident may be stressed by the disruption to their way of life, which will lower their quality of life and may lead to morbidities manifested as both physical and psychiatric problems. Although it is not thought practical to attempt to include such an effect within a COCO-2 framework, it may be possible to gauge the significance of any potential costs by reviewing the consequences of major accidents and natural disasters.

14 CONCLUSIONS

COCO-2 provides a simple and robust model, which accounts for the major sources of loss expected following a nuclear accident. The model has up-to-date costs referenced to the original source material and based, where possible, on official statistics. The clear sourcing of the data and structure of the model should enable it to be readily maintained in the future. In addition, both methodologically and practically, COCO-2 provides a more comprehensive representation of the expected losses than the previous COCO-1 model. In particular, the introduction of input-output modelling allows COCO-2 to account more effectively than COCO-1 for the spatial variation in accident consequences at both local and national scales. COCO-2 will therefore contribute to an improved assessment of accident consequences when implemented within a PRA code.

15 ACKNOWLEDGEMENTS

We would like to thank Philip Agulnik[1], Michael Spackman[2], Graham Loomes[3] and Michael Jones-Lee[4] for their support in wrestling with the difficulties of relating measures of the value of preventable fatalities and quality adjusted life years. We would also like to thank Nick Hesketh[5] for his help in costing the disposal of agricultural waste.

[1]HSE economics group, [2]NERA Economic Consulting London W1C 1BE, [3]University of East Anglia Norwich, [4]Newcastle University Newcastle upon Tyne NE1 7RU, [5]Now at United Kingdom Atomic Energy Authority

16 REFERENCES

Arya SP (1999). Air Pollution Metrology and Dispersion OUP ISBN 0-19-507398-3.

Baker R, Chilton S, Donaldson C, Jones-Lee M, Metcalf H, Shackley P (2003). Determining the Societal Value of a QALY by surveying the public In England and Wales: A Research Protocol Submission to National Institute for Clinical Excellence and National Coordinating Centre for Research Methodology. http://www.pcpoh.bham.ac.uk/publichealth/methodology/research.shtml

Barabanova A and Osanov DP (1990). The Dependence of Skin Lesions on the Depth-dose Distribution from β-irradiation of People in the Chernobyl Nuclear Power Plant Accident. *Int J Rad Biol*, **57**(4), 775-782.

Barnes M (1990). The Hinkley Point Public Inquiries: The risk of accidents **6** Chap 42-49. ISBN 011412955 X.

Benson C and Clay EJ (2004). Understanding the Economic and Financial Impacts of Natural Disasters. Disaster Risk Management Series No 4 Washington, DC. World Bank (ISBN: 0-8213-5685-2).

Blake A, Sinclair MT and Sugiyarto G (2002). The Economy-Wide Effects of Foot and Mouth Disease in the UK Economy. In Third Annual Conference European Trade Study Group, Sept 2001.

BNFL (2006). BNFL Low Level Waste Management Services. Starter Pack BNFL Waste Management and Decommissioning.

Boisvert R (1992). Indirect Losses from a Catastrophic Earthquake and Local, Regional, and National Interest in Indirect Economic Consequences of a Catastrophic earthquake. Washington DC: National Earthquake Hazards reduction Program, Federal Emergency Management Agency 207-265.

Bosanquet N and Sikora K (2004). The economics of cancer care in the UK. *Lancet Oncol*, **5**, 568-74.

Boyd R, Cowie H, Hurley F and Ayres J (2006). The true cost of occupational asthma in Great Britain. HSE RR-474.

Brown J and Simmonds JR (1995). FARMLAND A dynamic model for the transfer of radionuclides through terrestrial foodchains. Chilton, NRPB-R273.

BTE (2000). Road Crash Costs in Australia. Bureau of Transport Economics Canberra. Report 102.

BTCE (1992). Social Cost of Transport Accidents in Australia. AGPS, Canberra BTCE Report 79.

BTCE (1996). Valuing Transport Safety in Australia. Canberra BTCE Working Paper 26.

BTE (1998). The Willingness to Pay Method for Valuing Road Accidents. Report prepared for the Road User Costs Steering Group, Austroads, September.

Burnet NG, Jefferies SJ, Benson RJ, Hunt DP and Treasure FP (2005). Years of life lost (YLL) from cancer is an important measure of population burden – and should be considered when allocating research funds. *BJC*, **92**, 241-245.

Burton T, Chilton S, Covey J, Gilbert H, Pidgeon N, Jones-Lee M, Loomes G, Robinson A, Twist J and Spencer A (2001). Valuation of benefits of health and safety control: Follow-up study. HSE Research Report 315/2001.

Cartwright JV, Beemiller RM, Gustly RD (1981). Regional Input-Output modelling system (RIMS-II) estimation, evaluation and application of a disaggregated regional impact model. Washington Department of Commerce.

CEC (1987). Council Regulation (Euratom) No 3954/87 Laying down the maximum permitted levels of radioactive contamination of foodstuffs and feedingstuffs following a nuclear accident or any other cause of radiological emergency. *Off J Eur Commun*, L371/11, amended by Council Regulation 2218/89, *Off J Eur Commun*, L211/1 (1989).

CDC (2005). Acute Radiation Syndrome: A Fact Sheet for Physicians. http://www.bt.cdc.gov/radiation/pdf/arsphysicianfactsheet.pdf

Chilton S, Jones-Lee M, Metcalf H, Loomes G, Robinson A, Covey J, Spencer A and Spackman M (2007). Valuation of Health and Safety Benefits: Dread Risks. HSE RR541.

Chouaïd C, Molinier L, Combescure C, Daurès JP, Housset B and Vergnenègre A (2004). Economics of the clinical management of lung cancer in France: an analysis using a Markov model. *BJC*, **90**, 397-402.

Cochrane HC (1974). Predicting the Economic Impact of Earthquakes in HC Cochrane, JE Hass, MJ Bowden, RW Kates (Eds). Social Science Perspectives on the Coming San Francisco Earthquake. Natural Hazards Research Paper 25, NHRAIC Boulder University of Colorado.

Cochrane HC (1995). Forecasting the Economic Impact of a Midwest Earthquakes in BG Jones (Ed). Economic Consequences of Earthquakes: Preparing for the Unexpected Buffalo NY National Centre for Earthquake Engineering Research 223-247.

Cochrane HC (1999). Indirect Economic Losses in Earthquake loss Estimation Methodology. HAZUS99 Technical Manual 3. Washington DC Federal Emergency Management Agency, 16-1:16-63.

Cole S (1997). Decision Support for Calamity Preparedness: Socioeconomic and interregional impacts in M Shinozuka, A Rose and RT Eguchi (Eds). Engineering and Socioeconomic impacts of Earthquakes. Buffalo NY Multidisciplinary Centre for Earthquake Engineering Research 125-153.

Cookson R (2003). Willingness to pay methods in health care: a sceptical view. *Health Economics*, **12**, 891–894.

Cooper T and Mayers K (2000). Prospects for household appliances. Halifax, Canada: Urban Mines.

Curtis L and Netten A (2006). Unit Costs of Health and Social Care 2006. Personal Social Services Research Unit, University of Kent, Canterbury. ISBN: 971-1-902671-45-1.

Dedes KJ, Szucs TD, Bodis S, Joerger M, Lowy A, Russi, EW, Steinert HC, Weder W, Stahel RA (2004). Management and Costs of Treating Lung Cancer Patients in a University Hospital. *Pharmacoeconomics*, **22**(7), 435-444.

DfT (2002). Highways Economics Note No 1.

DH (2004). Policy Appraisal and Health DH_4095414[1].pdf http://www.dh.gov.uk/en/Publicationsandstatistics/Legislation/Healthassessment/DH_4093626.

Dolan P, Torgerson DJ and Wolstenholme J (1999). Costs of breast cancer treatment in the United Kingdom. *The Breast*, **8**, 205–207.

Effective Health Care (1998). *Management of Lung Cancer*, **4**(3). ISSN: 0965-0288.

Estey EH, Shen Yu and Thall PF (2000). Effect of time to complete remission on subsequent survival and disease-free survival time in AML, RAEB-t, and RAEB. *Blood*, **95**(1), 72-77.

Frederick S, Loewenstein G and O'Donoghue T (2003). Time discounting and time preference: A critical review. In G Loewenstein, D Read, and RF Baumeister (Eds). Time and decision;

Economic and psychological perspectives on intertemporal choice. New York: Russell Sage Foundation.

Griffin N, Hopps B, Foroma J, McLaughlin P and Rafiq A (2005). Capital Stocks, Capital Consumption and Non-Financial Balance Sheets 2005.

Gordan P and Richardson H (1996). The Business Interruption Effects of the Northridge Earthquake. Lusk Centre Research Institute, University of Southern California, Los Angeles, USA.

Guntermann KL (1995). Sanitary Landfills Stigma and Industrial Land Values. *J Real Estate Research*, **10**(5), 531-542.

Guðnason R (2003). Owner Occupied Housing: Market Price Approach to User Cost. Statistical Commission and United Nations Economic Commission for Europe (UNECE), International Labour Organisation (ILO), Conference of European Statisticians, Joint UNECE/ILO Meeting On Consumer Price Indices Geneva, 4-5 December.

Gusev IA, Guskova AK and Mettler FA (2001). Medical Management of Radiation Accidents. Second Edition, CRC Press.

Gyrd-Hansen D (2005). Willingness to Pay for a QALY: Theoretical and Methodological Issues. *Pharmacoeconomics*, **23**(5), 423-432.

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.

Higgins NA and Jones JA (2003). Methods for interpreting monitoring data following an accident in wet conditions. Chilton, NRPB-W34.

Himmelmann B, Himmelmann A, Furrer K, Halter J and Schanz U (2002). Haemopoietic growth factors Late G-CSF after allogeneic bone marrow or peripheral blood stem cell transplantation: a prospective controlled trial. *Bone Marrow Transplantation*, **30**, 491–496.

Holloway S, Short S and Tamplin S (2002). Household Satellite Account (Experimental) Methodology. ONS.

HPA-RPD (2005). UK Recovery Handbook for Radiation Incidents: 2005. Chilton, HPA-RPD-002.

HSE (2005). A National Population Database for Major Accident Hazard Modelling, Report 297 http://www.hse.gov.uk/research/rrhtm/index.htm.

HSE (1999). The cost to Britain of workplace accidents and work related ill health in 1995/96. ISBN 0-7176-1709-2.

ICRP (2007). 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Ann ICRP*, **37**.

Jones JA, Mansfield PA, Haywood SM, Hasemann I, Steinhauer C, Ehrhardt J and Faude D (1996). PC Cosyma (Version 2): An accident consequence assessment package for use on a PC. European Commission, EUR 16239.

Jones-Lee M, Loomes G and Spackman M (2007). Human Costs of a Nuclear Accident. HSE http://www.hse.gov.uk/economics/research/humancost.pdf.

Kawashima K, Hideki S, and Takashi K (1991). Estimation of Earthquake Induced Economic Damage. *Report of Public Works Research Institute*, **186**, 1-57 (in Japanese).

Kowe R, Carey AD, Jones JA and Mobbs SF (2007) GRANIS: A Model for the Assessment of External Photon Irradiation from Contaminated Media of Infinite Lateral Extent. Chilton, HPA-RPD-032.

Kuchler F and Golan E (1999). Assigning Values to Life: Comparing Methods for Valuing Health Risks. Agricultural Economics Report No AER 784. Economics Research Service, USDA, Washington, DC, Available at: http://www.ers.usda.gov/publications/aer784.

Leontief W (1941). The structure of the American economy 1919-1929: An empirical application of equilibrium analysis. Cambridge Mass. Harvard University Press.

Li HYY (2004). Bioenergy: Framework for Sustainable Biomass Use Assessment MSc Thesis School of Environmental Science University of East Anglia University Plain Norwich NR4 7TJ http://www.uea.ac.uk/env/all/teaching/eiaams/pdf_dissertations/2004/Li_Yvonne.pdf

MacDonald DN, Murdock JC and White HL (1987). Uncertain Hazards, Insurance and Consumer Choice: Evidence from Housing. *Land Economics*, **63**, 361-71.

Mahajan S (2008). ONS personal communication.

Mayeres I (1998). The Distributional Impacts of Policies for the Control of Transport Externalities: An Applied General Equilibrium Model. Fondazione Eni Enrico Mattei Working Paper No 8.99. http://ssrn.com/abstract=158411.

NHS (2005). National Lung Cancer Audit. Health and Social Care Information Centre (HSCIC): http://www.ic.nhs.uk.

Nord E, Richardson J, Macarounas-Kirchmann K (1992). Social evaluation of health care versus personal evaluation of health states: evidence on the validity of four health state scaling instruments using Norwegian and Australian survey data. Centre for Health Program Evaluation working paper 23. ISBN 1 875677 00 3.

NEA (2002). Update of Chernobyl Ten Years On, Radiological and Health Impact, OECD/NEA, Paris.

NRPB (1996). Risk from Deterministic Effects of Ionising Radiation. *Doc NRPB*, **7** (3).

OECD (2000). Methodologies for Assessing the Economic consequences of Nuclear Reactor Accidents. ISBN 92-64-17658-6.

OECD (2005). The Valuation Of Environmental Health Risks To Children: Methodological And Policy Issues. ENV/EPOC/WPNEP(2004)15/FINAL http://www.oecd.org.

OECD, European Commission, United Nations World Tourism Organization (2001).Tourism Satellite Account: Recommended Methodological Framework. ISBN: 9789264193635.

ONS (2007). Social Trends No 37. ISBN 978-1-4039-9394-6.

ONS (2005). United Kingdom Input-Output Analyses 2005, edited by Sanjiv Mahajan. ISSN 1741-7155.

ONS (2002). United Kingdom Input-Output Analytical Tables, 1995 edited by Sanjiv Mahajan. www.statistics.gov.uk/inputoutput.

Okuyama Y, Hewings GJD and Sonis M (1999). Economic Impacts of an Unscheduled, Disruptive Event: A Miyazawa Multiplier Analysis in GJD Hewings, M Sonis, M Madden and Kimura Y (Eds). Understanding and Interpreting Economic structure. *Springer-Verlag*, 113-144.

Okuyama Y and Lim H (2002). Linking Economic Model and Engineering Model: Application of Sequential Industry Model (SIM). 49th North American Meeting, Regional Science Association International, Nov 14-16, San Juan, Puerto Rico.

Oliver E, Killen J, Kiebert G, Hutton J, Hall R, Higgins B, Bourke S and Paschen B (2001). Treatment pathways, resource use and costs in the management of small cell lung cancer. *Thorax*, **56,** 785–790.

Pearce D (2000). Valuing Risks to Life and Health: Towards Consistent Transfer Estimates in the European Union and Accession States. Paper prepared for the European Commission (DGXI) Workshop on Valuing Mortality and Valuing Morbidity, November 13, 2000, Brussels. Revised, December 2000.

Pelagia G, Tsoutsou MD and Koukourakis MI (2006). Radiation Pneumonitis and Fibrosis: Mechanisms Underlying its Pathogenesis and Implication for Future Research. *Int J Radiation Oncology Biol Phys*, **66**(5), 1281-1293.

Räsänen P, Krootila K, Sintonen H, Leivo T, Koivisto A-M, Ryynänen O-P, Blom M, Roine RP (2006). Cost-utility of routine cataract surgery. Health and Quality of Life Outcomes, **4:74**, BioMed Central http://www.hqlo.com/content/4/1/74 doi:10.1186/1477-7525-4-74.

Read D and Read NL (2004). Time discounting over the lifespan. *Organisational Behaviour and Human Decision Processes*, **94**, 22-32.

Rose A, Benavides J, Chang SE, Szczesniak P and Lim D (1997). The regional Economic Impact of an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions. *J Regional Science*, **37**(3), 437-458.

Rose A and Benavides J (1998). Regional Economic Impacts in M Shinozuka, A Rose and RT Eguchi (Eds). Engineering and Socioeconomic impacts of Earthquakes. Buffalo NY Multidisciplinary Centre for Earthquake Engineering Research, 95-123.

Scottish Executive (2007). Bus and Coach Statistics: 2005-06 Statistical Bulletin Transport series. ISBN 978 0 7559 6520 5.

Scottish Executive (2006). Bus and Coach Statistics: 2004-05 Statistical Bulletin Transport series. ISBN 0-7559-2953-5.

Simmons KM and Kruse JB (2000). Market Value and Perceived Risk: Empirical Results. *J Economics*, **26**, 41-51.

Slovic P, Fischhoff B and Lichtenstein S (1980). Facts and fears: understanding perceived risk in societal risk assessment. In R Schwing and W Albers (Eds). *Societal Risk Assessment: How Safe is Safe Enough*?

Slovic P, Fischhoff B and Lichtenstein S (1982). Risk aversion, social values and nuclear safety goals. *J Trans Am Nucl Soc*, **41**, 448–9.

Slovic P, Fischhoff B and Lichtenstein S (1984). Modelling the societal impact of fatal accidents. *Management Science*, **30**(4), 464–474.

Smith D (2006). The case of industrials. Investment Property Databank IPD Impulse Trend – industrials, April.

Smith DI, Handmer JW, McKay JM, Switzer MAD and Williams BJ (1995). Non-structural Measures for Flood Mitigation: Current Adoption in Urban Areas, Volume 1. Report to the National Landcare Program, Centre for Resource and Environmental Studies, ANU, Canberra.

Smith R, Olsen JA and Harris A (1999). A Review of Methodological Issues in the Conduct of Willingness-to-Pay Studies in Health Care III: Issues in the Analysis and Interpretation of WTP Data. Centre for Health Program Evaluation (CHPE) working paper 86. ISBN 1 875677 98 4.

Stott E (2003). Straw availability in the UK. BioRegional Development Group BedZED Centre, 24, Helios Road, Wallington, Surrey. SM6 7BZ. UK. http://www.bioregional.com/index.htm.

Stouthard MEA, Essink-Bot M-L and Bonsel GJ (2000). Disability weights for diseases A modified protocol and results for a Western European region. *Euro J Public Health*, **10**(1), 24-30.

Tarella C, Castellino C, Locatelli F, Caracciolo D, Corradini P, Falda M, Novarino A, Tassi V and Pileri A (1998). G-CSF administration following peripheral blood progenitor cell (PBPC) autograft in lymphoid malignancies: evidence for clinical benefits and reduction of treatment costs. *Bone Marrow Transplantation*, **21**, 401–407.

Thompson P and Handmer J (1996). Economic Assessment of Disaster Mitigation: An Australian Guide. Centre for Resource Environmental Studies, ANU and Flood Hazard Research Centre, Middlesex University for the Australian IDNDR Committee.

Treasury (2005). Managing risks to the public: appraisal guidance. www.hm-treasury.gov.uk.

UNSCEAR (2008). United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Effects of Ionizing Radiation. UNSCEAR 2006 Report to the General Assembly, with scientific annexes. New York, United Nations (in press).

UNSCEAR (2001). United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Hereditary Effects of Radiation. UNSCEAR 2001 Report to the General Assembly, with scientific annex. United Nations. ISBN 92-1-142244-2.

Varjonen J et al (1999). Proposal for a Satellite Account of Household Production. Eurostat Working paper 9/1999/A4/11.

VIDA (2003). Veterinary Investigation Surveillance Report 2003 Veterinary Laboratories Agency. ISBN 1 8995 1322 1 http://www.defra.gov.uk/vla/reports/docs/rep_vida03_intro.pdf

Viscusi WK and Aldy JE (2003). The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. *J Risk and Uncertainty*, **27**(1), 5–76.

Walker GP (2000). Urban Planning, hazardous installations and blight: an evaluation of responses to hazard-development conflict. *Environment and Planning C*, **18**(2), 27-143.

Waselenko JK, MacVittie TJ, Blakely WF, Pesik N, Wiley AL, Dickerson WE, Tsu H, Confer DL, Coleman N, Seed T, Lowry P, Armitage JO and Dainiak N (2004). Medical Management of the Acute Radiation Syndrome: Recommendations of the Strategic National Stockpile Radiation Working Group. *Ann of Intern Med*, **140**(12), 1037–1051.

Wilson R (1982). Earthquake Vulnerability Analysis for Economic Impact Assessment. Washington DC: Information Resources Management Office, Federal Emergency Management Agency.

West P and Clifton-Fearnside A (1999). The Capital Stock of the United Kingdom - some new developments in coverage and methodology. *Economic Trends*, No 544.

APPENDIX A Modelling Changes In An Economy: Multiplier Analysis

Dr Calvin Jones & Prof Max Munday

WELSH ECONOMIC RESEARCH UNIT UNIVERSITY OF CARDIFF

A1 INTRODUCTION

At a national level, Input-Output tables provide a representation of the national accounts of a country (ONS, 2002). Whilst showing the internal workings of an economy, the layout of the tables also provides reconciliation with the production, income and spending constituents of gross domestic product (gross value added). For example, at the UK level the Input-Output tables are linked methodologically to the UK national accounts and balance of payments (ie, Blue and Pink Books)[*].

However, the Input-Output framework can also be used for basic economic modelling purposes. The Domestic Use table is a platform for the derivation of what are termed Analytical Tables. These tables provide a mechanism through which the impact of changes in the economy can be assessed.

For example, an increase in demand for the goods produced by the electronics sector in the UK, would lead to an increase in the output of electronic goods (direct effect). However, as electronics producers increase their outputs, their suppliers in the UK will also have an increase in demands for their goods, and then also the suppliers to the suppliers experience extra demands, and so on (indirect effects). The shock of the increase in final demand for electronic goods ripples through the supply chain. Moreover, because of these supply chain effects, the level of income in the economy will increase, and a portion of this income will be spent on UK-sourced goods and services leading to further increases in demand. This is termed an induced income effect. *The ratio of the direct, indirect and induced income effect to the direct effect is termed a Type II output multiplier.* A Type I output multiplier excludes the induced effects, ie, it is the ratio of direct and indirect to direct effects. Multipliers can also be derived with regard to employment and income (see Table A1).

Analytical Tables are the basis for exploring the multiplier effects of changes in final demand. The remainder of this section outlines the process through which Analytical Tables are derived, explaining differences in the magnitudes of multipliers.

[*] The *United Kingdom National Accounts - the Blue Book and the United Kingdom Balance of Payments - the Pink Book:* http://www.statistics.gov.uk.

TABLE A1 Definitions of Output, Income and Employment Multipliers and Effects (Type II)

Output multiplier	Output multiplier for an industry is the ratio of direct, indirect and induced output effects to the direct change in output resulting from a unit increase in industry final demand.
Income multiplier	The relative change in income (wages, salaries, etc) in the economy consequent on a change in final demand. Measured as the ratio of direct, indirect and induced income changes to the direct income change.
Employment multiplier	The ratio of direct, indirect and induced employment change to the direct employment change generated as a result of changes in final demand.
Income effect	The direct, indirect and induced income effect generated as a result of a unit change final demand.
Employment effect	The direct, indirect and induced employment effect generated as a result of a unit change in final demand.

A2 NOTES ON METHODS

A Domestic Use table shows UK industry purchases in terms of products, and then how each defined product is sold to industries, and then through to final demand (ie, consumers, government, etc). To undertake multiplier analysis it is necessary to move from the industry by product Domestic Use table, to an industry-by-industry Domestic Use table (or a product-by-product table, ie, a symmetrical table is required).

The industry-by-industry Domestic Use table is very similar to the industry by product Domestic Use table. The critical difference is that the rows are no longer purchases of products, but are purchases from each industry (the reader is reminded of the distinction between industries and products given above). The methodological steps in moving from the Domestic Use (industry by product) to the industry by industry Domestic Use tables are described in the publication *UK Input-Output Analytical Tables 1995* (ONS, 2002; see also Bulmer-Thomas, 1982). This is a complex process, which is summarised below.

In the Domestic Use table, there is not a direct relationship between industries and products (ie, some industries produce more than one product). Then the products, which are the secondary outputs of industries, have to be re-allocated to the industry of which they are the principal product. For example, if the steel industry produces a construction product, this has to be reallocated to construction. In overall terms, the supply of construction in the economy is unchanged, but the output of the steel industry is changed. However, for any elements of the table that are moved around, there must also be an equivalent adjustment of the inputs in the Domestic Use table such that the identity between industry input and output is maintained (ie, if outputs are moved from a source to destination industry, then equivalent inputs must also be moved).

The method through which the transfer of inputs between industries is achieved is dependent on the technology assumptions used. For more information on this see the *UK Input-Output Analytical Tables 1995* (ONS, 2002).

The industry-by-industry Domestic Use table shows industry-to-industry linkages. An example now shows how such a table is used to derive simple multipliers.

If an economy has just two industries X and Y, then a simple industry-by-industry Domestic Use table would take the following form:

TABLE A2 Example Industry by Industry Domestic Use Table in arbitrary units

	Industry x	Industry y	Final Demand	Total
Industry x	40	80	180	300
Industry y	0	20	120	140
Value added Wages	180	20		200
Value added Profits	80	20		100
Total Output	300	140	300	740

The rows in Table A2 show that firms in industry X sell £40 to other firms in Industry X, and sell £80 to firms in Industry Y, and sell £180 to final demand (government and consumers). The columns show, for example, that firms in industry X buy £40 from their own industry, buy nothing from Industry Y, but then pay £180 in wages, and make £80 in profit. The above can be converted to a Direct Coefficients table (Table A3) relating industry input to output, by dividing each element by industry total output.

Table A3 Direct Coefficients Table

	Industry X	Industry Y
Industry X	0.13	0.58
Industry Y	0.00	0.14
Value added Wages	0.60	0.14
Value added Profits	0.27	0.14
Total	1.00	1.00

If an assumption is made that these coefficients remain fixed then this shows that if Industry Y had a sales increase of £10, then it would need an increase in outputs from Industry X of £5.80, £1.40 from its own industry, while increasing wages by £1.40, and gaining additional profits of £1.40. The total labour needs associated with a £10 sales increase in Industry Y would be greater than £1.40, because Industry X would also have to use more labour to supply Industry Y (ie, £5.80 multiplied by 0.6 which is £3.48), and Industry Y would also need around £0.20 more labour (£1.40 multiplied by 0.14).

Moreover turning to outputs, the £10 increase in demand for the products of Industry Y would need £5.80 of inputs from Industry X, and £1.40 of inputs from Industry Y. However, the demand for inputs from X and Y requires additional inputs from X and Y and so on. In the above example, the effects would be the same, but negative, if demand for the product was to decrease by £10.

This pattern can become complex very quickly as the number of industries increases. To take account of all these complex interactions it is possible to derive a total requirements table. Mathematically this can be derived by computing the matrix: $(I - A)^{-1}$ where I is an identity matrix and A is the Direct Coefficients matrix of inter-industry requirements. The result of this process is the Total Requirements table otherwise termed as the Leontief Inverse.

Table A4 Total Requirements Table

	Industry x	Industry y
Industry X	1.15	0.78
Industry Y	0.00	1.16
Total	1.15	1.94

Table A4 is interesting because it shows for this simple economy the direct and indirect requirements of each industry to produce an extra £1 of output. For example if Industry Y produces an extra £10 of output, it must actually produce £11.60 in total (the extra £1.60 being the indirect effects on industry Y described above), as well as needing £7.80 worth of output from Industry X, then summing to £19.40. The ratio of direct and indirect output change to the direct change is 1.94, ie, the Type I output multiplier. Related processes can be used to derive employment and income multipliers. This, however, requires information on incomes per unit of output, and employment per unit of output to translate output effects to income and employment effects.

Differences in the values of the output multiplier reflect factors such as the degree of vertical integration in firms in the industry, and the level and nature of the regional purchasing propensities of the industry. For example, larger output multipliers tend to be found in the services sector of the economy because of their generally lower reliance on imports, compared to the greater reliance found in most manufacturing sectors[*]. However, even within manufacturing some variation is expected in the value of output multipliers, with sectors such as food tending to make larger local purchases, whereas selected engineering sectors have a greater dependency on imported goods and services.

The relative changes in income in the economy following a change in demand (ie, income multipliers) are far more difficult to interpret. In part, their magnitude is conditioned by the local purchasing propensity of the industry concerned. However, care must be taken in using the multipliers. For example, a large income multiplier may be derived because income to output ratios in an industry are very low (ie, highly capital-intensive sectors), but where the industry buys from sectors that are more labour intensive. As a result any change in output will only generate a small direct income effect in the local economy but when relating the total (supplier and induced) income effects to the very low direct effects the multiplier may be very large even though the total effects on incomes may be small. Oil processing and chemicals are a case in point. Direct incomes in these sectors are low in proportion to output, but the production of this output requires inputs from sectors where incomes are a higher proportion of output. However, sectors such as retail and catering are directly labour intensive such that their income multipliers will be lower. Due to these difficulties in interpretation, it can be more

[*] There is an increasing trend to place service functions, such as call centres and back office staff, offshore. Because the multipliers under discussion describe effects on the UK economy, this trend will reduce the multiplier effect on the UK economy of demand changes that have an effect on these sorts of services.

meaningful to examine income generated directly and indirectly per unit change in final demand[*].

A3 LIMITS ON THE USE OF THE BASIC INPUT-OUTPUT FRAMEWORK

There are limits on the extent to which Input-Output tables can be used for analysis and modelling. Firstly, there are the assumptions implicit in the linear Input-Output framework. It is assumed as industry output increases, input proportions will remain constant. So, for example, a 10% increase in the demand for food and drink products will lead to a proportionate 10% increase in the various inputs of the industry, in other words constant returns to scale are assumed.

If this assumption does not hold then the output growth of the food and drink industry will not have the size of effects predicted by the Input-Output tables (although the 'direction' of effects will hold). Also implicit is the assumption that as the food and drink sector expands, supplying industries have no constraints in expanding their outputs and employment to meet demand from the food and drink sector. This might be reasonable under certain economic conditions. However, if labour or product markets are tight, some industries may experience great difficulty in expanding to meet new demands from customers, leading to either unfilled demand or a revision in supplier arrangements – and hence multiplier size.

A linked issue is prices. As the food and drink sector expands, it may be unable to employ additional labour or source additional inputs at the same price. Once again, in a tight labour market, higher demand would be expected to result in increased wages. Generally, and in the longer term, changes in the prices of material and labour inputs, might lead to factor substitution, eg, a smaller number of skilled workers could be used to replace a larger number of unskilled. Then, a significant increase in final demand for food and drink products could lead to some firms substituting new capital for labour and changing the nature of their production function.

Secondly, timeliness is a problem if Input-Output tables are to be used for forecasting purposes. Due to data collection problems, and analytical time, the UK Supply and Use tables for 2004 only become available in 2006, and analytical tables are unavailable for later than 1995[†]. Consequently, the task is one of examining changes now, in the

[*] Examining income and employment effects directly avoids the use of multipliers, which reflect the differences in the income contribution of the customer and supplier economic sectors.

[†] The ONS state (ONS, 2005) that 'Member States are now required under EU statistical regulation to produce I-O Analytical Tables and submit them to Eurostat. The UK submitted the 1995 I-O Analytical Tables in December 2002. Although the I-O Analytical Tables have been published roughly every five years, our plan to produce these tables annually following publication of the 1995 tables, consistent with the I-O Annual Supply and Use Tables, has been in abeyance. This plan has been reconsidered in the light of changed priorities within the ONS. In particular, National Accounts production is being thoroughly reviewed as part of a re-engineering project. As a result, there are no explicit plans to produce another set of I-O Analytical Tables.'

context of an historic Input-Output table, which could be giving a distorted view of contemporary inter-industry relationships.

Any modelling framework is a simplification of the real intricacies of the economy with the consequence that estimates produced with reference to Input-Output tables should always be closely accompanied by the assumptions involved. Too often headline multiplier figures are used to assess the effect of industry change, but without a full appreciation of the assumptions underlying the estimation process.

A4 REFERENCES

Bulmer-Thomas V (1982). Input-Output Analysis in Developing Countries. Wiley, Chichester.

ONS (2005). United Kingdom Input-Output Analyses 2005 edited by Sanjiv Mahajan. ISSN 1741-7155.

ONS (2002) United Kingdom Input-Output Analytical Tables, 1995 edited by Sanjiv Mahajan. www.statistics.gov.uk/inputoutput

APPENDIX B Preparing regular gridded data for COCO-2

The greater availability of spatially resolved data allows COCO-2 the opportunity, not previously available, to model the economic effects of an accident using local data within a general Input-Output framework (see the main text and Appendix A). However, one consequence of the greater refinement is that COCO-2 will make greater demands on resources when implemented as a module within a PRA model. In an effort to provide greater flexibility to future users of COCO-2 in the context of PRA and more generally, it was decided that the supplied data should map to a regular grid. Spatially referenced data are generally available from the Office of National Statistics (ONS) at a variety of resolutions based on Census output areas and various aggregations of these. These data require a GIS to be used to display and manipulate the results efficiently. However, rectifying the data to fit onto a regular square grid, while loosing some refinement on the boundaries between output areas, avoids this restriction. Thus, although there will be advantages in using a GIS to display the results of calculations, the actual calculations can be carried out outside a GIS environment. The net result is that it should be possible to carry out calculations more quickly or with less advanced GIS programming.

The disadvantage of mapping the data onto a regular grid is that it will smooth out natural spatial variations and produce what could be considered a less accurate answer. However, the uncertainties inherent in both the economic and radioactive transport modelling are such that this is unlikely to be significant.

The Health and Safety Laboratory (HSL) undertook the task of transforming the data used by COCO-2 to fit on a regular grid. The work included extracting a range of population data from the Health and Safety Executive's (HSE) National Population Database (NPD). The data extracted from the NPD included a count of the size and location of residential and sensitive populations (eg, schools, hospitals, care homes, etc). This was combined with other data sets of land use, economic activity including tourism, housing and rental value data. These data sets were all mapped to a 1 km grid that covered the whole of England, Scotland and Wales. In addition, agricultural data were obtained directly by the HPA on a regular 2 km grid from the EDINA national data centre in Edinburgh[*]. The agricultural data are licensed and should be obtained directly from EDINA. Appendix C provides advice on the use of these data within COCO-2.

This appendix presents details of the procedure followed to create the grids of data, together with relevant supplementary details on each data set not reported in Section 11. The grids of data produced, excluding those subject to licence requirements, are provided in the accompanying file (see Section B7).

[*] http://www.edina.ac.uk

B1 CREATING THE 1 KM GRID

Data derived directly or indirectly from ONS and Ordnance Survey (OS) sources were mapped to regular 1 km grids. Section B2 discusses the National Population Database, Section B3 GVA data, Section B4 land use data and Section B5 illustrates how new land use information can be generated where existing datasets are inadequate or missing.

A grid was created that mirrored the 1 km national grid of the OS using a combination of MapInfo Professional and ESRI ArcView GIS software packages*. The grid was created by splitting the country into regions and then only including cells that intersected with dry land. This method allowed data to be processed in smaller amounts, to improve computational performance.

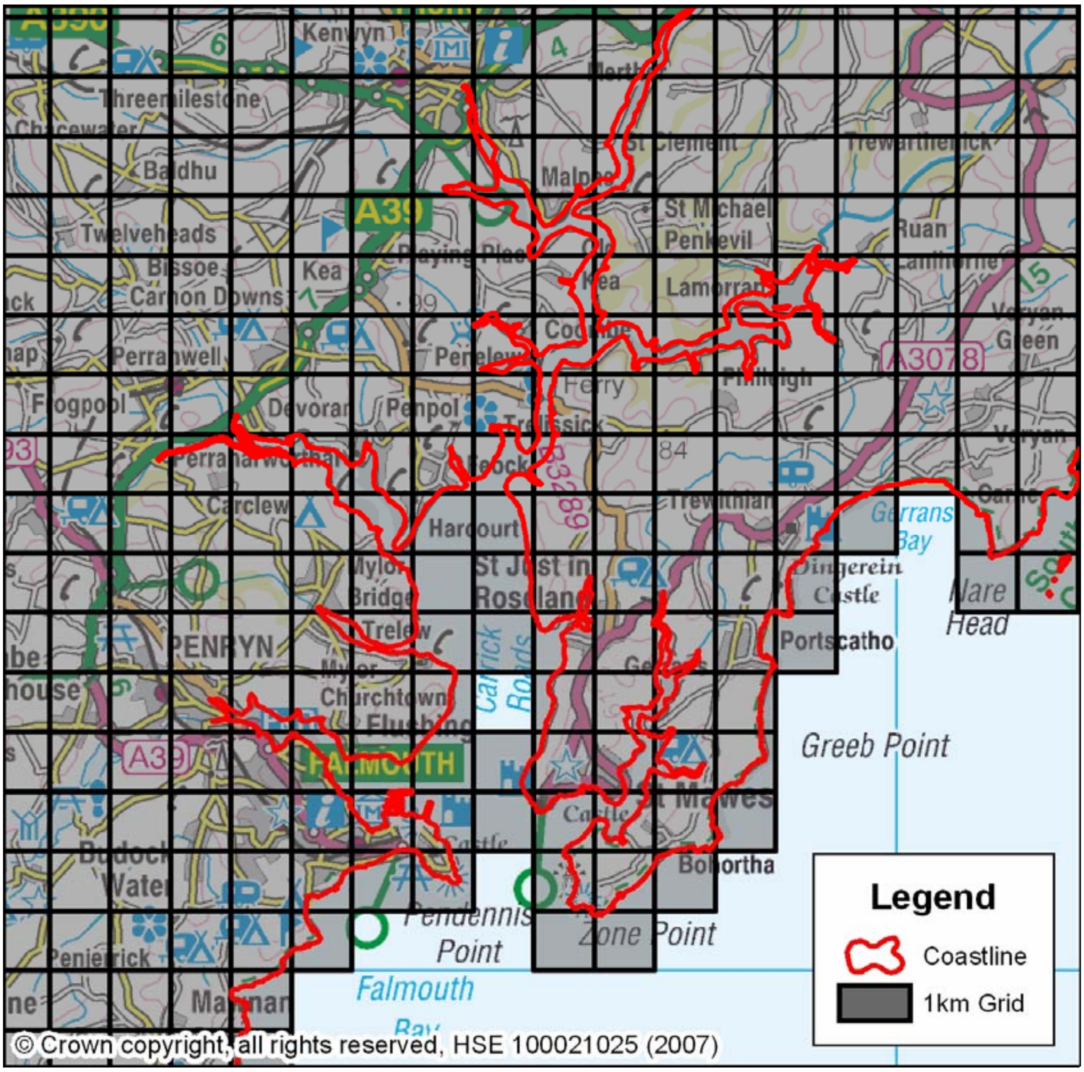

Figure B1 Grid cells that intersect with land near Falmouth

* http://www.mapinfo.co.uk, http://www.esri.com

The country boundaries and coastline contained within the 'Counties' map of the Meridian 2 dataset from the Ordnance Survey was used to represent the landmass of the country. This map has a reasonably detailed coastline and it was decided to use this as the standard coastline for the other datasets. Figure B1 shows the area around Falmouth in Cornwall and illustrates how very small amounts of overlap with the land will cause a grid cell to be included in the dataset. Notice also the single 1 km cell in the estuary that has not been included in the grid dataset, although surrounded by cells that have.

For computational ease, England was split into the following regions; Southwest, Southeast, East Anglia, West Midlands, East Midlands, Northwest, Yorkshire and Humberside, and the Northeast while Wales and Scotland were treated as single regions.

B2 THE NATIONAL POPULATION DATABASE

The National Population Database (NPD) is hosted, run and maintained by HSL on behalf of HSE. The database provides an estimate of the density and distribution of a range of populations, including residential, sensitive, workplace, and transport and retail populations. The data is available either as a 100 m grid or in the form of point locations with population figures attached. A full description of the NPD methodology and dataset is available (HSE, 2005).

The NPD data was used to provide population estimates for each 1 km grid cell in England, Scotland and Wales. The populations obtained were Residential - nighttime, Residential - daytime school term-time, Residential - daytime non-school term-time, School and Boarding school pupils, Hospital patients, Care home residents and Prison inmates. Although the NPD is based on ESRI ArcGIS software, MapInfo Professional was used to find the data points within each grid cell and then sum their values to give the respective populations in each category, as MapInfo can perform both calculations in a single step. Figure B2 shows an example of gridded nighttime residential population values in the South West Region.

A workplace population estimate was also calculated using the workplace layer of the NPD. This layer is based on census output areas (OA) rather than point locations, so a different methodology was required. The functionality of MapInfo Professional to assign populations from one set of polygons to another based on the amount of overlap between the two was utilised, eg, if a quarter of an OA overlapped a particular grid cell, a quarter of its population would be assigned to the grid cell. This methodology inevitably assumes that the population inside each OA is evenly distributed. However, there is no alternative readily available and this assumption is consistent within the error bounds expected of COCO-2 data and calculations.

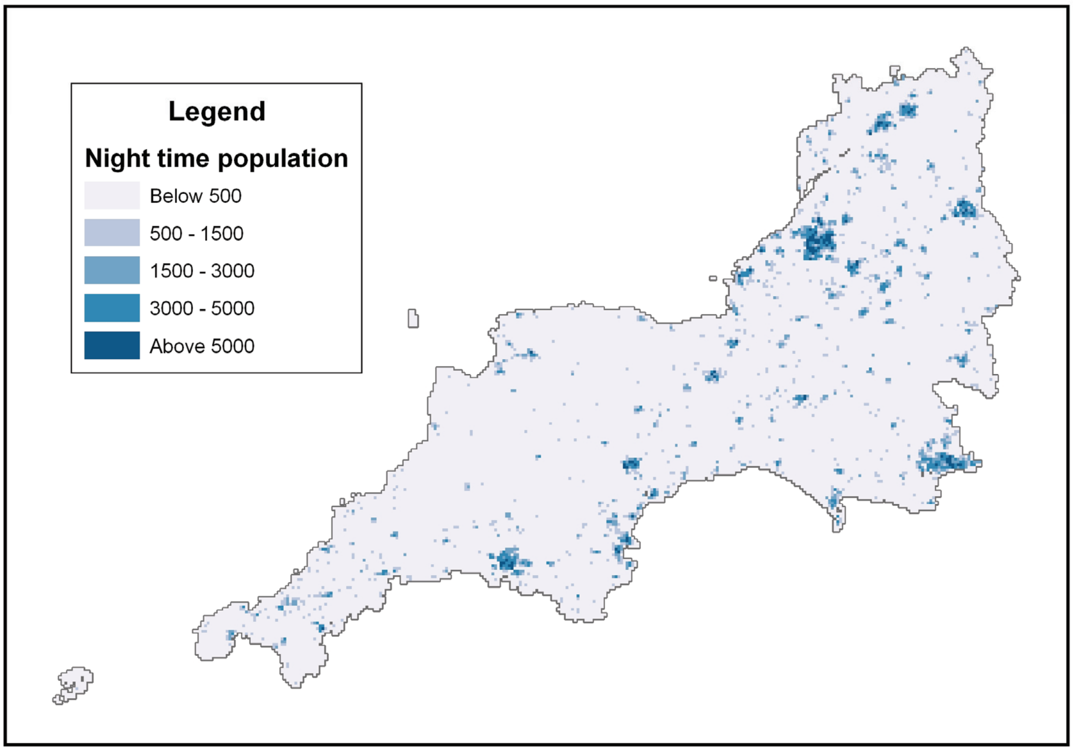

Figure B2 Gridded values for nighttime residential population in the South West Region

As the workplace calculation was based on the size of OAs, it was important to use a realistic coastline. The standard OA boundaries enclose large amounts of sea particularly in bay areas, and areas when there are islands near to the main land. Figure B3 shows an anomalous OA, which connects two islands to the mainland near Bristol. This type of OA includes sea as well as land and therefore has an inflated area associated with it, which in turn reduces the population density and therefore leads to lower population estimates. Clipping the coastline using the OS Meridian 2 data set ensured a more realistic representation of population density in these types of coastal areas. Note considerations of this kind would be required even if the approximating step of introducing an intermediate grid were not used.

A count of the number of workplaces was provided as an accompaniment to the population estimates. This count was based on the point locations of workplaces and was obtained from the NPD.

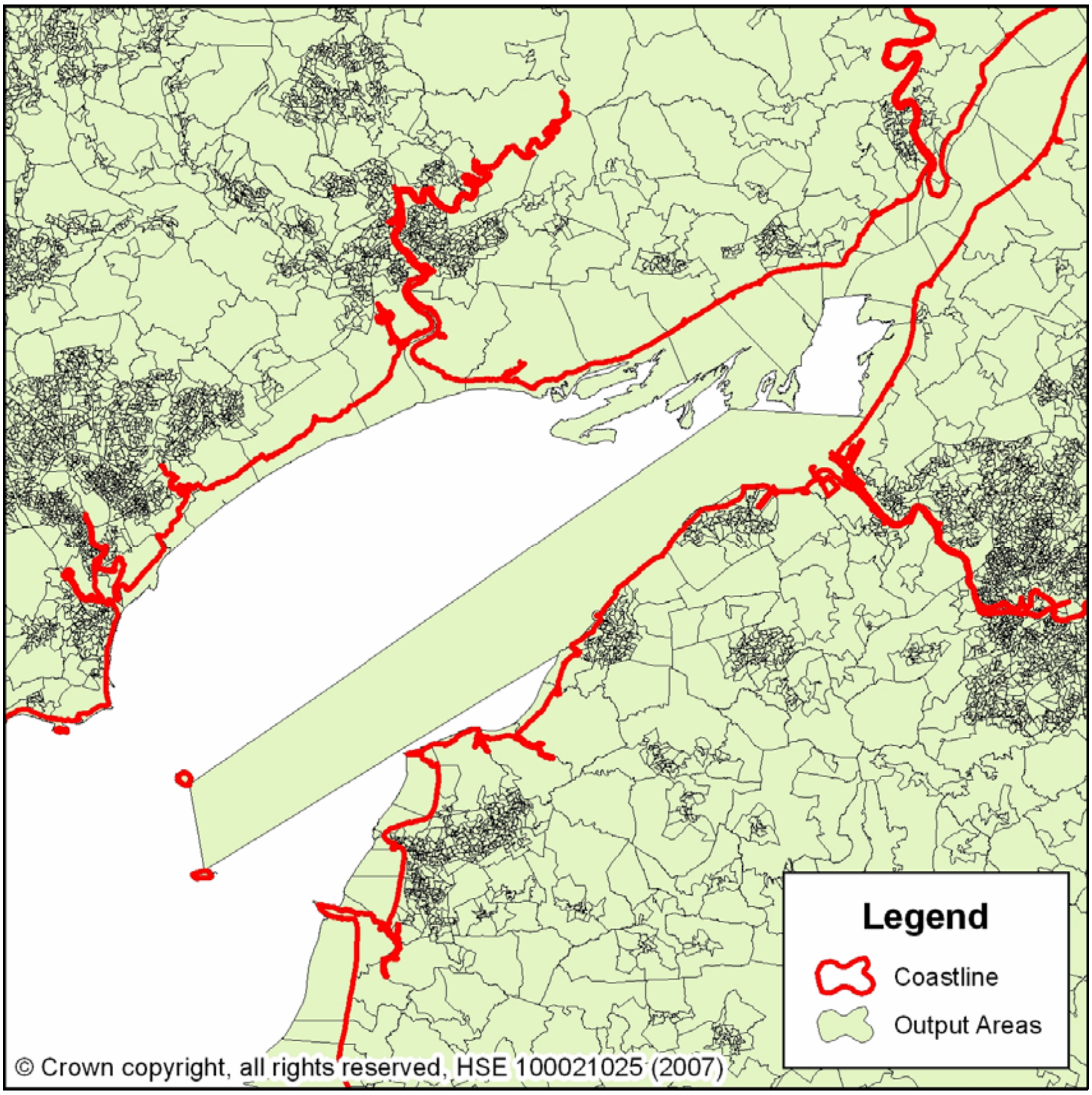

Figure B3 Census output area boundaries around the Severn Estuary

B3 ECONOMIC DATA

The Welsh Economy Research Unit (WERU) based at Cardiff University provided data for the UK on a number of economic activity indicators at Lower Super Output Area (LSOA) level, in particular Gross Value Added (GVA) for Standard Industrial Classification (SIC) codes as described in Section 11. A super output area is composed of several adjoining OAs with the number involved determined by the split into medium and lower level SOAs. LSOA resolution is more refined.

The methodology used by HSL to process the NPD workplace data was used to attach the economic data to the 1 km grid, and combine it with the population and land type data. Once again, the coastline was clipped using the Counties layer of the OS Meridian 2 product. Economic data values were then assigned to the grid based on the amount of overlap, as before. Figure B4 shows gridded tourism data for the South West region.

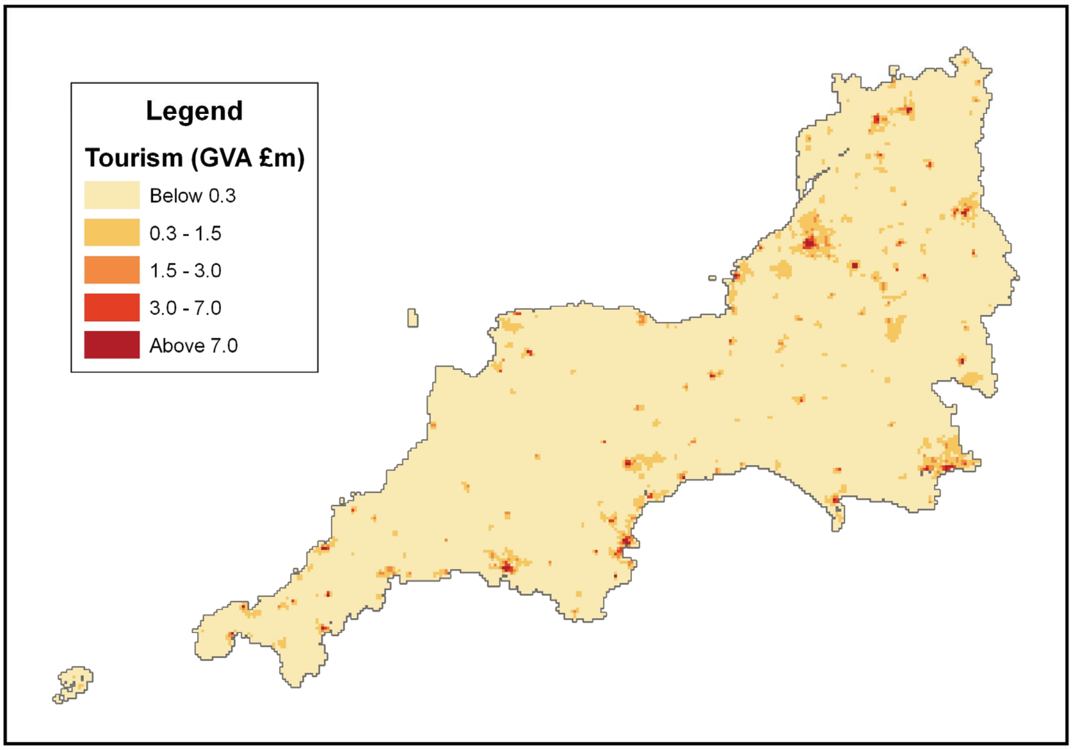

Figure B4 Gridded values for Tourism in the South West Region

B3.1 Housing and commercial buildings

Data on imputed rental values and house prices were used to create the housing grid. The data for the numbers of houses of a particular type came from Census data supplied by ONS (England and Wales), and the Scottish Executive (Scotland), which allowed house numbers to be mapped using OA boundaries and Intermediate Zones (IZ) for England and Wales, and Scotland respectively. House price data, including total stock value and rental return, for England and Wales were provided by WERU at the MSOA level. These data were derived from information available from the ONS supplied by the DCLG from Land Registry data*. Counts of house type and housing values were converted to a grid format using the methods discussed previously. Figure B5 shows gridded house price data for the South West region.

* The data set used is Changes of Ownership by Dwelling Price, 2004.

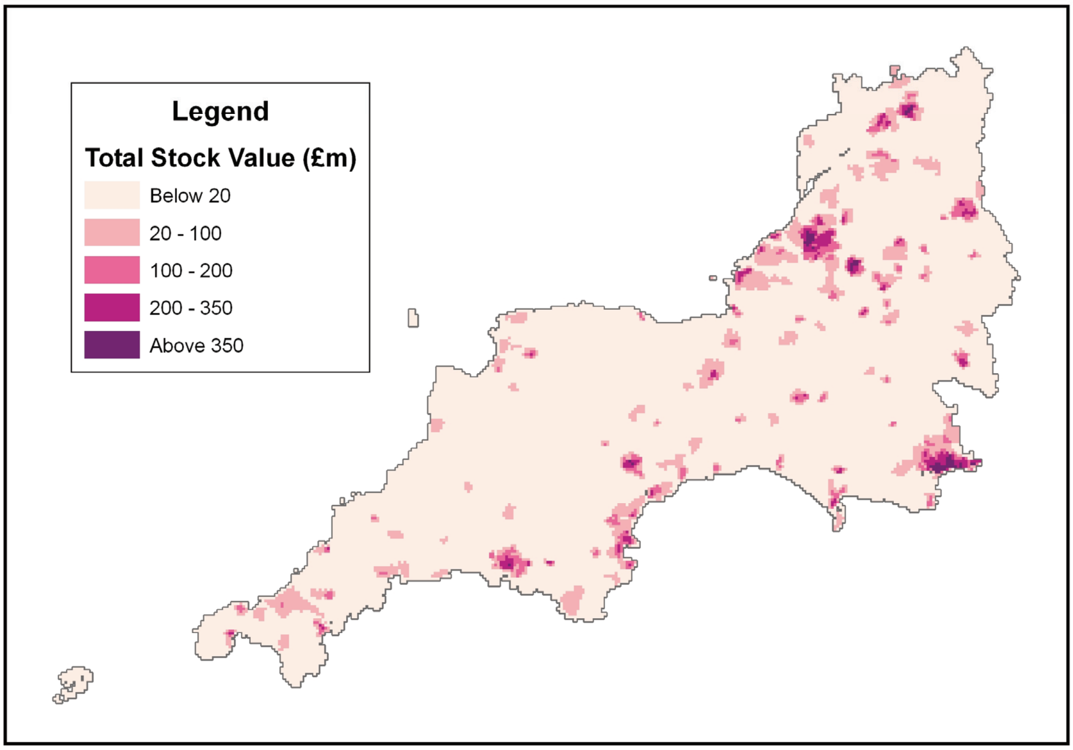

Figure B5 Gridded values for house prices in the South West Region

A similar GIS procedure was used to provide estimates for England and Wales of the capital value of offices, factories, warehouses and shops derived from VOA data on rateable value and estimated rental yield. Rateable value data for Scotland are only available at an individual address level. It was therefore considered impractical to generate data applicable to the whole of Scotland. If required data for small areas could be processed.

B4 LAND USE DATA

The Generalised Land Use Database (GLUD), published by the Department of Communities and Local Government (DCLC) (formerly the Office of the Deputy Prime Minister (ODPM)) in 2005, was used to provide information on land type. GLUD data are available for England at OA and lower and medium super output area (SOA) resolution; data at LSOA resolution were used.

The GLUD provides an estimate of the amount of land being used for different purposes, including domestic buildings, non-domestic buildings, gardens, green space, water, roads, rail, paths and other uses (ODPM, 2005) for England but not for Scotland or Wales.

HSL attached the GLUD data to the 1km grid using a similar methodology to that employed to extract the NPD Workplace OA population data with the LSOAs trimmed to match the same coastline as that used for OAs, for consistency. Gridded GLUD green space data are shown in Figure B6. As LSOAs are larger than OAs, the land use data prepared for COCO-2 was derived from lower resolution data than that of some other data sets prepared for the model. However, although GLUD data are available at the higher resolution of the OA, it was thought appropriate to use LSOA because of the considerable saving in computation time and, due to the nature of the original data capture, the greater level of error associated with the use of higher resolution data (see Section B5).

The LSOA zones that intersected the trimmed 1km grid were selected and used in the data calculations, which resulted in the values from the GLUD being assigned to grid cells based on the amount of overlap between the LSOAs and grid cells. As GLUD data are only available for England, Section B5 illustrates how such a dataset could be constructed for Wales and Scotland or for England if improved resolution were required, using generally available, but licensed, data.

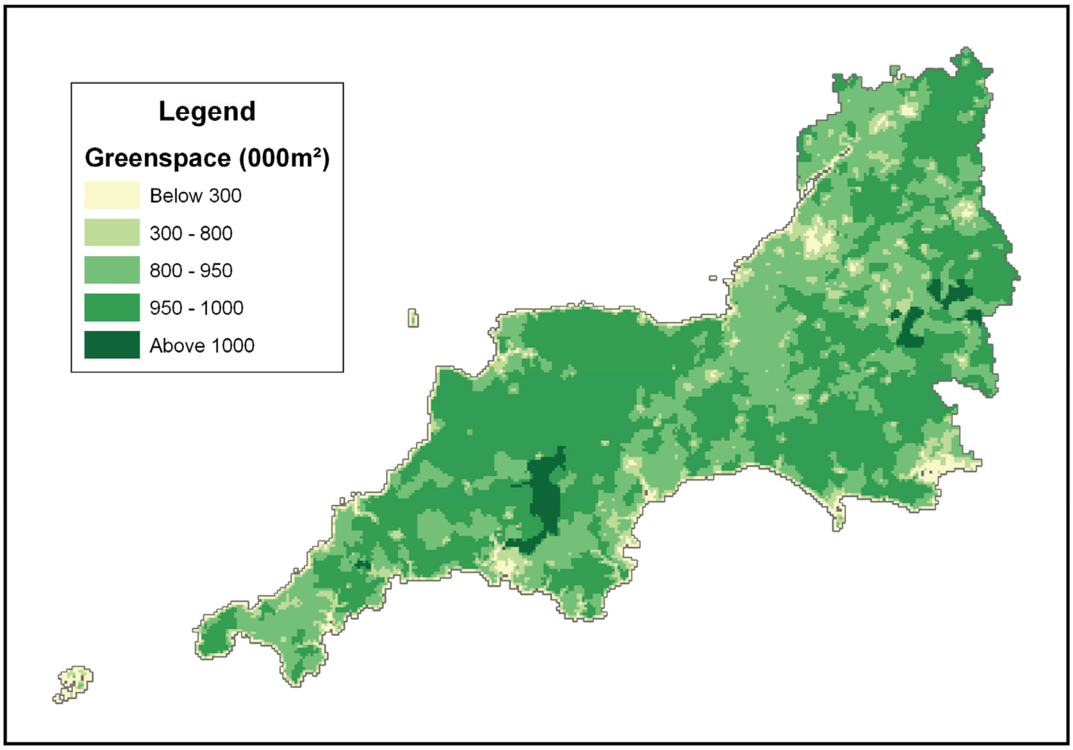

Figure B6 Gridded values for green space in the South West Region

B5 CREATING A LANDUSE GRID

GLUD data are not directly available for Scotland and Wales. However, as the GLUD data are derived from the topographic layer of an OS product called MasterMap equivalent data may be prepared for any location in Great Britain. MasterMap is the basic large-scale, vector mapping product from which other OS products are derived and contains data at a scale of 1:1250. The term vector mapping refers to the format used to store the map data and indicates that the map is made of a set of objects (composed of lines, points and polygons) that can be represented at any scale with associated attribute data that can be queried, rather than being merely a picture. Thus, each object within the map has associated data, for example, the information collated in the GLUD.

To create the GLUD data for each census zone (output area), the centroid of each appropriate map object, eg, an area of green space, was used to assign that data to the census zone within which the object or polygon centroid falls. This is a simplistic approach, as a single point is not a particularly realistic representation of a polygon, especially polygons that are large and have a complex shape. For example, in some cases, it is possible for a MasterMap object to be larger than the census zone assigned to hold its attributes, eg, an area of green space may be larger than the OA. This result may be further distorted if the data are then placed on a uniform grid. However, the uncertainties inherent in the economic modelling of COCO-2 and associated radioactive transport modelling to determine which areas are affected are such that this is unlikely to be significant. The advantage of the method is the speed of calculation as the level of detail in the MasterMap dataset means that to assign area values for the whole country based on the proportion of each appropriate MasterMap object contained within a census zone would take an extremely long time.

The approach adopted (use of MasterMap directly without further processing, allocating particular types of area to an OA for direct use, or gridding the OA or MasterMap attributes using centroids or by proportioning areas) will depend on the coverage and accuracy required, time available and eventual use in an implementation of COCO-2.

B6 SCOTTISH IMPUTED RENTS

In Section 8.3.2 a description of the method employed to estimate the imputed rent of housing stock evacuated in England & Wales was described. Data limitations prevent a similar procedure being used in Scotland and this section describes the alternative, more approximate, approach employed. However, for any particular assessment, only data on house prices in the area local to the postulated accident site are likely to be required. Thus, if it were thought appropriate to use more locally representative data this could be generated using data on house sales in the area, which are available from the General registers of Scotland for a fee. This information, once generalised to give an approximate value for every class of house, will allow the total value of houses in a local area to be estimated. COCO-2 uses Census data as an approximate estimate of the number of houses in an area but, if appropriate, it is likely that a more up to date estimate could be obtained for the area of interest from the local authority.

B6.1 House price data

Following the methodology adopted for the rest of the UK, the value of the housing stock for small areas was assessed, and a regional annual percentage return on property value estimated. The value of the housing stock in an area was derived using the following approach.

An average price for different property types over the whole of Scotland was estimated using HBOS data on the value of houses subject to mortgage offers*. HBOS data also provided an estimate the average price of all properties in 47 post towns, with which to scale to local conditions the whole of Scotland result.

Each of the 1,235 Census intermediate zones (IZ) in Scotland was allotted to the geographically closest post town, so that the known value of property in the 'local' post town could influence the value in the neighbouring intermediate zones. For each stock-type (ie, detached, semi-detached, terraced, etc) in each IZ, the ratio of the local average price to the average Scottish house price was multiplied by the ratio of the average price of each house type to the average over all house types. This provides an (albeit crude) estimate of the value of each house type in each IZ.

Information from the 2001 Census was then used to estimate the total level of stock by type for each IZ, with each stock item valued appropriately. An estimate of the total value of all (unshared) dwellings in 2004 in each IZ was therefore produced. In common with the rest of UK, ARLA data (for Scotland) on buy-to-let percentage returns was used as a proxy measure of the annual value of services flowing from housing stock.

B6.2 Data Issues

The detailed methodology adopted varied from the rest of the UK in several ways, all driven by data availability. In summary, the differences are as follows:

- Land registry data on achieved prices provided the source of primary data for other regions of the UK, but similar data were not freely available for Scotland. Reports from HBOS on the average price of houses which were offered mortgages was therefore used. No systematic bias arising from this difference is foreseen.
- Whilst HBOS reports average prices for bungalows separately, the 2001 Census makes no distinction in stock-type between single and multi storey dwellings. Conversely, the HBOS data does not distinguish between terraced, semi- and detached bungalows. Data from the Building Research Establishment (Utley et al, 2001) suggests that bungalows form around 2% of overall Scottish housing stock. HBOS average house prices for terraces, semi-and detached houses (that each excludes bungalows) were applied to Census stock levels that include bungalows; ie, we make the implicit assumption that a bungalow of a given type carries no price premium or penalty compared to a multi-storey dwelling of the same type. Again, this is not thought likely to result in substantial or systematic error. In some cases and areas, bungalows carry a price penalty (because they typically have less floor space) and in others a price premium (eg, because they are more attractive to the elderly).
- The 'local' level data was obtained via special request to the statistical division of Scottish Executive for housing stock levels (by type) for Census Intermediate

* www.hbosplc.com

Zones, with the lower level data zones being unavailable in a usable fashion. The results are therefore modelled at a coarser scale than in England and Wales.

The other point of note is that the post town data available from HBOS are predominately located in the central belt of Scotland where the majority of the population live.

B7 DATA SUPPLIED IN THE ACCOMPANYING FILE

The accompanying file holds land use data, housing data and GVA data. Additional data on agricultural production are available from EDINA* and on daytime and special populations from the National Population Database (HSE, 2005). These data sets must be obtained separately due to licence restrictions†. The file also holds a copy of this report together with copies of Tables 15, 17, 21, C2 and C3 in spreadsheet format for the convenience of the user.

B7.1 Land Use

The Generalised Land Use Database (GLUD) was derived from OS data by DCLG and placed on a regular grid by HSL. The database is associated with files that allow the content to be displayed as a regular grid on a GIS. GLUD data is not available for Scotland or Wales.

Table B1 GLUD Land Use Data

Field Heading	Units	Description
EASTINGS	1m resolution	British National Grid Easting of the centre point of the grid cell
NORTHINGS	1m resolution	British National Grid Northing of the centre point of the grid cell
DOMESTI	1000 m² per km²	Area of land taken up by domestic buildings
NONDOMESTI	1000 m² per km²	Area of land taken up by non-domestic buildings
ROAD	1000 m² per km²	Area of land taken up by roads
PATH	1000 m² per km²	Area of land taken up by paths
RAIL	1000 m² per km²	Area of land taken up by railways
GARDENS	1000 m² per km²	Area of land taken up by gardens
GREENSPACE	1000 m² per km²	Area of land taken up by green space
WATER	1000 m² per km²	Area of land taken up by water
OTHER	1000 m² per km²	Area of land taken up by other land uses
UNCLASSIFI	1000 m² per km²	Area of land taken up by unclassified land uses

* EDINA national data centre Edinburgh (www.edina.ac.uk)

† A version of the National Population Database appropriate for use in COCO-2 has been prepared by HSL.

B7.2 Housing

Census housing data for England, Scotland and Wales are provided together with the total value of the housing stock and rental value prepared on a regular grid by HSL. The database is associated with files that allow the content to be displayed as a regular grid on a GIS.

Table B2 Housing Data

Field Heading	Units	Description
EASTINGS	1m resolution	British National Grid Easting of the centre point of the grid cell
NORTHINGS	1m resolution	British National Grid Northing of the centre point of the grid cell
TOTALVALUE	£(m) per km^2	Total value of housing stock
RENTRETURN	£(m) per km^2	Rental return
ALLHOUSES	Number per km^2	All household spaces in the area at the time of the 2001 Census
UNSHAREDDW	Number per km^2	All household spaces that were in an unshared dwelling
UDHOUSBUNG	Number per km^2	All household spaces that were a house or bungalow
HBDETACHED	Number per km^2	All household spaces that were a detached house or bungalow
HBSEMIDET	Number per km^2	All household spaces that were a semi-detached house or bungalow
HBTERRACED	Number per km^2	All household spaces that were a terraced house or bungalow
FLATMAISAP	Number per km^2	All household spaces that were a flat, maisonette or an apartment in an unshared dwelling
FMAPURBUIL	Number per km^2	All household spaces that were a flat, maisonette or an apartment in a purpose built block of flats, in an unshared dwelling
FMACONVERT	Number per km^2	All household spaces that were a flat, maisonette or an apartment in part of a converted or shared house, in an unshared dwelling
FMACOMBUIL	Number per km^2	All household spaces that were a flat, maisonette or an apartment in a commercial building, in an unshared dwelling
MOBILETEMP	Number per km^2	All household spaces that were a caravan or other mobile or temporary structure, in an unshared dwelling
SHAREDDWEL	Number per km^2	All household spaces that were in a shared dwelling

B7.3 GVA and building capital

General economic data in the form of the GVA generated annually together with the capital value of commercial and industrial buildings has been prepared on a regular grid by HSL. The database is associated with files that allow the content to be displayed as a regular grid on a GIS.

Table B4 GVA and Building Capital

Field Heading	Units	Description
EASTINGS	1m resolution	British National Grid Easting of the centre point of the grid cell
NORTHINGS	1m resolution	British National Grid Northing of the centre point of the grid cell
TOURISM	£(m) per km^2	Gross Value added from tourism
INDUSTRY	£(m) per km^2	Gross Value added from all industries
A	£(m) per km^2	Gross Value added from agriculture (part), hunting & forestry
B	£(m) per km^2	Gross Value added from fishing
C	£(m) per km^2	Gross Value added from mining & quarrying
DA	£(m) per km^2	Gross Value added from food, beverage & tobacco
DB	£(m) per km^2	Gross Value added from textiles
DC	£(m) per km^2	Gross Value added from leather
DD	£(m) per km^2	Gross Value added from wood
DE	£(m) per km^2	Gross Value added from pulp, paper & publishing
DF	£(m) per km^2	Gross Value added from coke, petrol & nuclear
DG	£(m) per km^2	Gross Value added from chemicals
DH	£(m) per km^2	Gross Value added from rubber & plastic
DI	£(m) per km^2	Gross Value added from non-metallic minerals
DJ	£(m) per km^2	Gross Value added from basic fabricated metals
DK	£(m) per km^2	Gross Value added from machinery nec
DL	£(m) per km^2	Gross Value added from electrical & optical
DM	£(m) per km^2	Gross Value added from transport equipment
DN	£(m) per km^2	Gross Value added from manufacturing nec
E	£(m) per km^2	Gross Value added from electricity, gas & water
F	£(m) per km^2	Gross Value added from construction
G	£(m) per km^2	Gross Value added from wholesale & retail trade
H	£(m) per km^2	Gross Value added from hotels & restaurants
I	£(m) per km^2	Gross Value added from transport, storage & communications
J	£(m) per km^2	Gross Value added from financial intermediation
K	£(m) per km^2	Gross Value added from real estate, renting & business activities
L	£(m) per km^2	Gross Value added from public administration & defence
M	£(m) per km^2	Gross Value added from education
N	£(m) per km^2	Gross Value added from health & social work
O	£(m) per km^2	Gross Value added from other community, social & personal service activities
CAPVALIND	£(m) per km^2	Capital values Industry
CAPVALRET	£(m) per km^2	Capital values Retail
CAPVALWARE	£(m) per km^2	Capital values Warehousing
CAPVALOFF	£(m) per km^2	Capital values Offices

B8 REFERENCES

HSE (2005). A National Population Database for Major Accident Hazard Modelling, Report 297. http://www.hse.gov.uk/research/rrhtm/index.htm.

ODPM (2005). Generalised Land Use Database Statistics for England.

Utley JI, Shorrock LD and Bown JHF (2001). Domestic energy fact file: England, Scotland, Wales and Northern Ireland. BR 427. www.BREbookshop.com

.

APPENDIX C Agriculture

C1 INTRODUCTION

This appendix provides the Output and GVA data required by COCO-2 to calculate agricultural losses. It also provides references to the information used to derive the recommended costs, examples of how loss estimates might be applied for different crops, derivation details for some of the equations and considers agricultural waste costs.

The seasonal adjustment factors, introduced as an optional refinement of the equations of Section 9, are also derived. However, the background details introduced to estimate these factors are not strictly part of COCO-2, which is not intended as a model of agricultural production but of the economic loss associated with any restrictions imposed on production. The details are considered only to the extent required to enable seasonal adjustment factors to be produced. An alternative scheme could be developed which would nevertheless fit with the agricultural loss equations of Section 9. Thus, as the assumptions are not necessarily unique, care should always be taken to make sure that any seasonal assumptions introduced to improve loss estimation when implementing COCO-2 are consistent with the modelling assumptions used by the models supplying the COCO-2 implementation with information.

When considering what level of detail may be appropriate, it should be borne in mind that COCO-2 will form part of a PRA calculation and the inherent uncertainties in the inputs to any cost estimate from such a complex calculation may obscure small refinements in cost estimation. In particular, there are two general sources of uncertainty related to agricultural data. Firstly, future production trends cannot be easily predicted, as they are a consequence of the complex economic environment of the agricultural sector influenced by the effects of climate change and any actions taken to mitigate such effects[*]. Analogous effects apply to industry losses but there is no link in this case between the product and the extent of any restrictions. The use of up to date data will minimise the effect of this longer-term drift in the production mix. Secondly, the exact planting and harvesting times of any particular crop will depend on the particular variety being planted, where in the country the planting is taking place and the vagaries of the weather, while the location of the crop on the farm will depend on the particular rotation scheme employed. The assumption of continuity, that the same thing will be grown this year as surveyed in the previous year, will still imply some uncertainty over the identity of a crop that might be affected at a particular location by the passage of a contaminant plume. However, within the resolution of the available data it is likely that areas growing major crops such as cereals and potatoes will continue to do so.

To calculate agricultural losses, information on the crops restricted following an accidental release will be required. This can be provided by a PRA code used in combination with appropriate agricultural production data. The latter can be obtained

[*] For example, the increased interest in the production of biofuels.

from the survey carried out by Defra in June each year. The survey information is processed by EDINA* in conjunction with other data to produce a spatial distribution of crop and animal production in the UK. The PRA code is therefore assumed to provide estimates of, eg, how many hectares of a particular crop are restricted and how long the restrictions will last. This information is sufficient for a simple COCO-2 estimate of loss.

Following the presentation of output and GVA values in Section C2 there is a discussion in Section C3 of how the losses accruing from restrictions on periodically produced agricultural output may be modelled either as a seasonally dependent loss or as an annual average. Section C4 then considers losses for continuously produced commodities with the remaining sections discussing agricultural countermeasure costs and the costs of disposing of agricultural wastes.

C2 OUTPUT AND GVA ESTIMATION

The Output and GVA estimates required by COCO-2 were derived by combining data from various sources. To allow the model to be easily maintained the sections below identify the data sources, illustrate how the estimates were made for each generic food category and discuss the limitations of the analysis.

To calculate the value of output on either a per hectare or per animal basis as appropriate, figures for the output at market prices and the production area were taken from ‘Agriculture in the United Kingdom 2005’ (AUK, 2005).

Output at market prices has been used, instead of basic prices, to avoid the inclusion of subsidies. As these are transfer payments, they do not represent an economic loss and so should not be included in the calculation of costs to the economy as a whole. There will remain other distortions in the estimates, such as those from import tariffs, which are not accounted for. In addition, three-year averages for 2003 to 2005 were calculated in an attempt to remove some of the year-on-year variation that is common in agriculture.

The agricultural products considered are those of Table 4 in the main text and Table C1 where the latter provides lists the sources used to establish the appropriate output and GVA data. The subsections below provide details of the particular assumptions used in the estimation of the output and GVA values provided in Tables C2 and C3.

---

*EDINA (http://edina.ac.uk/) is a JISC-funded national data centre based at Edinburgh University. Agricultural data are available on a regular 2 km grid compatible with other data used by COCO-2. It should be noted that the production of crops (animals) is provided in hectares (numbers) of product per grid cell or per 4 square kilometres. EDINA data must be licensed and should be sourced directly.

Table C1 Data sources for agricultural costs

Produce	Output/Value of production	Area/animals	Enterprise output & gross margin
Grain	[1]Table 8.1 Output of cereals Wheat, rye, barley, oats and summer cereals mixtures, other cereals	[1]Table 5.1 Production Area	[4]FBS, [5]FMP
Potatoes	[1]Table 8.1 Output of potatoes (including seeds)	[1]Table 5.11 Production Area	[4]FBS
Sugar Beet	[1]Table 8.1 Output of sugar beet	[1]Table 5.7 Sugar beet Area	[4]FBS
Fruit	[1]Table 8.1 Output of fruit	[1]Table 5.12 Production Area	[5] Table: Fruit
Cow meat	[1]Table 8.1 Output of livestock, primarily for meat, cattle	[3] Table 4 Total other cattle and calves	[4]FBS
Cow milk	[1]Table 8.1 Output of livestock products, milk	[3]Table 4 Dairy categories	[4]FBS
Sheep meat	[1]Table 8.2 Output of livestock, primarily for meat, sheep	[3]Table 6 Total other sheep + 96% of lambs < 1yr	[4]FBS
Vegetables Root Green Legumes	[2]Table 13 Field vegetables: value of home production	[2]Table 5.9 Area grown in the open	[5]Table: Field-Scale Vegetables

[1]*Agriculture in the United Kingdom, http://statistics.defra.gov.uk/esg/publications/auk/default.asp*

[2]*Basic Horticultural Statistics, 2006, http://statistics.defra.gov.uk/esg/publications/bhs/default.asp*

[3]*Agricultural and Horticultural Survey – June http://statistics.defra.gov.uk/esg/statnot/june_uk.pdf*

[4]*Farm Business Survey (FBS), http://statistics.defra.gov.uk/esg/asd/fbs/default.htm*

[5]*Farm Management Pocketbook (FMP)(Nix,2007)*

C2.1 Vegetable output

The statistics in AUK (2005) are not given at a sufficient level of disaggregation for the three vegetable categories considered by COCO-2: root vegetables, green vegetables and legumes. Area and output data were therefore taken from 'Basic Horticultural Statistics 2006' where information on field vegetables is split into four categories: roots and onions, brassicas, legumes and others (including celery, rhubarb and watercress). It is assumed that green vegetables are represented by the 'Brassicas' and 'others' categories while the generic term root vegetables includes both root and onion categories. This division then allows these generic vegetable categories to be represented within the June Survey classifications and output value assigned.

C2.2 Cattle output

The total value of output was taken from AUK (2005). To derive the value of output per animal, figures from the 2006 June Survey were used.

The categories used were:

a) other cattle two years old and over

b) other cattle one year old and under two years old

c) other cattle and calves under 1 year (78%).

These cover survey codes K13-16 and 78% of K17-19. For cattle under one year old, separate categories for animals for slaughter and for replacement are not available and therefore had to be estimated.

The proportion of 78% was taken from the estimate used in livestock statistics of the number of cattle under 1 year that will be used for meat. The proportion is derived by comparing the total number of cattle under one year old to the total number of cattle for slaughter that are one year old but less than two years old in the following year.

The above estimate encompasses all extant cattle that are likely to be subsequently slaughtered, ie, from those to be killed as calves, to those that will be more than two years old when killed. It is not known which animals of each age category will be killed in any particular area and it is thought impractical and inappropriate to attempt to differentiate between the GVA values of cattle killed at different ages. COCO-2 therefore assumes that the animals to be slaughtered are drawn from the mixed age stock described above with about 50% of stock animals being replaced every year. The output and GVA values per head given in Tables C2 and C3 are therefore based on the total stock of animals for slaughter and not the number likely to be slaughtered in a year.

C2.3 Cow milk output

The total value of the output was taken from AUK (2005) while the animal numbers for dairy cows was calculated from the June Survey 2006 categories. This includes dairy cows and dairy heifers in first calf covering June Survey codes K1-3.

C2.4 Sheep output

The total value of the output was taken from AUK (2005) while the number of sheep that value represented was given by the June Survey categories of total other sheep 1 year old and 96% of lambs younger than 1 year using the June Survey codes M9, 13, 14 and 96% of M17. The estimate that the residual 4% of lambs younger than 1 year are put to the ram to provide replacement stock was provided by Defra livestock statistics. Unlike the situation for cattle discussed in Section C2.2 the vast majority of sheep are killed as lambs and it is therefore the number of lambs that dominate the stock to be slaughtered.

C2.5 Gross value added (GVA) per hectare/animal

GVA data are not directly available at the required level of detail because there is not enough information available at this level to allocate costs to the different commodities. Therefore, micro level data from the Farm Business Survey were used to estimate GVA. It is assumed that the relationship between total output and gross value added in the aggregated agricultural accounts is similar to the relationship between gross margin and output in business level accounts from the Farm Business Survey.

Data for enterprise output and gross margin were taken from the Farm Business Survey, for 2004-6 for cereals and 2003-5 for the other commodities. These data were used to calculate the percentage of output that represents gross margin, with this percentage then applied to the output values for each category taken from AUK with three-year averages used to lessen the effect of the large year-on-year variation.

For crops represented by aggregate categories, eg, cereals, fruit and vegetables, each commodity was weighted according to the area grown (from the Basic Horticultural Statistics, 2006 or AUK (2005) in the case of cereals) to derive one figure for gross margin as a proportion of output. In particular, to estimate the gross margin for vegetables information from The Farm Management Pocketbook (NIX, 2007) was used. Again, the root and green vegetable split had to be estimated, this time by aggregating data on individual commodities. The vegetables used depended simply on the data available, and included:

a) Root – carrots, onions, parsnips, leeks

b) Green – Brussels sprouts, cabbage, cauliflower, calabrese and lettuce

Due to the limitations of the data available, it is not possible to do a separate calculation for legumes, so it has been assumed that legumes and green vegetables have the same GVA. It was found that the gross margin varied widely between different vegetables but on aggregating the results similar estimates were obtained for root and green vegetables, which implies that the assumption made for legumes is reasonable.

Table C2 Output per hectare, for first year values

	Cereals	Potatoes	Sugar Beet	Root vegetables	Green vegetables	Legumes	Orchard Fruit	Soft Fruit		Cattle	Cow milk	Sheep
2005												
Total output £ million	1389	482	263	315	373	60	103	213	Total output £ million	1328	2602	654
Hectares 000 hectares	2928	137	148	28	47	47	17	9	Animals 000 head	4550	2509	17781
Output per hectare	£474.39	£3,518.25	£1,777.03	£11,250.00	£7,936.17	£1,276.60	£6,058.82	£23,666.67	Output per animal	£291.87	£1,037.07	£36.78
2004												
Total output £ million	1675	633	278	258	368	67	105	173	Total output £ million	1252	2615	715
Hectares 000 hectares	3133	149	154	26	42	48	18	8	Animals 000 head	4561	2589	17497
Output per hectare	£534.63	£4,248.32	£1,805.19	£9,923.08	£8,761.90	£1,395.83	£5,833.33	£21,625.00	Output per animal	£274.50	£1,010.04	£40.86
2003												
Total output £ million	1602	517	280	270	377	73	102	175	Total output £ million	1221	2629	689
Hectares 000 hectares	3059	145	162	28	48	48	19	8	Animals 000 head	4503	2633	17553
Output per hectare	£523.70	£3,565.52	£1,728.40	£9,642.86	£7,854.17	£1,520.83	£5,368.42	£21,875.00	Output per animal	£271.15	£998.48	£39.25
3 year average												
Total output £ million	4666	1632	821	843	1118	200	310	561	Total output £ million	3801	7846	2058
Hectares 000 hectares	9120	431	464	82	137	143	54	25	Animals 000 head	13614	7731	52831
Output per hectare	£511.62	£3,786.54	£1,769.40	£10,280.49	£8,160.58	£1,398.60	£5,740.74	£22,440.00	Output per animal	£279.20	£1,014.88	£38.95

Table C3 GVA per hectare, for subsequent years

3 year average	Cereals	Potatoes	Sugar Beet	Root vegetables	Green vegetables	Legumes	Orchard Fruit	Soft Fruit	3 year average	Cattle	Cow milk	Sheep
Output per hectare £	511.62	3786.54	1769.40	10280.49	8160.58	1398.60	5740.74	22440.00	Output per animal £	279.20	1014.88	38.95
Gross margin %	50.54	65.40	57.18	35.28	37.49	37.49	53.78	51.28	Gross margin %	17.57	53.63	57.13
GVA per hectare £	£258.56	£2,476.27	£1,011.78	£3,626.70	£3,059.40	£524.34	£3,087.15	£11,508.16	GVA per animal £	£49.06	£544.28	£22.25

C2.6 Regional considerations

Data have not been calculated on a regional basis for any of the commodities. After examining regional data from the regional accounts for agriculture and the Farm Business Survey for 7 areas of England, the differences found between regions were not great for most categories.

For fruit and vegetables, a second set of data split into different regions calculated from the Farm Business Survey was considered and large variations between the two data sets were found. However, it was decided not to calculate data on a regional basis.

The Farm Business Survey can only produce regional data for England split into three regions; North, East and West, and not into the 7 areas discussed above, due to the small number of farm businesses included in each survey. For fruit, it was not even possible to calculate regional data for the North, as there were fewer than 15 farm businesses in the sample. In addition, the differences cannot be easily explained. They would add unnecessary uncertainty to the model and generally, the variation between regions for one year was smaller than the variation in the figures year-on-year for the same region.

In using data for the UK, Northern Ireland has been included. The error should be small as the contribution to the total by Northern Ireland is generally small and in addition, values per animal or hectare are used.

Output values for cattle and sheep are taken from output primarily for meat, ignoring gross fixed capital formation, as breeding animals counted in this investment category will not be directly affected by food restrictions.

For animal numbers, June Survey figures have been used rather than annual average figures from Agriculture UK as these should fit in with the EDINA data used elsewhere in the model to estimate the number of animals affected.

C3 PERIODIC PRODUCTION

This section explains how the unit costs of Section C2 should be applied to calculate losses, for agricultural production that follows an annual cycle, such that the estimated costs are either dependent (seasonally or biannually) or independent of when in the year the accident occurs.

Crops, such as cereals, are harvested once a year over a very short period while others such as potatoes are harvested over a period of a few months. Both potatoes and cereals are normally stored following harvest. The default assumption made by COCO-2 is that even if a crop is usually stored after harvest, the economic loss is determined at harvest, ie, COCO-2 does not consider any effects due to storage on crop value[*]. The argument is firstly, that if a crop, eg, grain at harvest, is contaminated above accepted levels then it may remain unacceptable to the public even if it were to subsequently fall

[*] Theoretically, some crops could be sold into intervention storage and only released for sale years later.

below those levels after a suitable storage period. In this case, the harvested amount will be subject to the economic loss. Secondly, even if it were likely to be acceptable, complex arrangements would have to be put in place at harvest to ensure that only crops from designated areas with comparable concentrations were stored together to avoid any controversy over the mixing of contaminated and uncontaminated grain.

However, if storage is part of the normal marketing of a crop and there are no impediments to the identification, segregation and sale of the crop after a normal period of storage, then there will be no economic loss except for some minor administrative costs*. In COCO-2, this situation can be accounted for by excluding the material sold from storage in the calculation of economic losses.

The sections below provide simple estimates of the loss likely to be incurred from an accident occurring at different times of the year. The general assumption is that production, and thus use of variable inputs, would stop if it was clear that the crop could not be sold on harvest.

To avoid claims of excessive accuracy the loss is estimated for each quarter and is independent of the exact timing of the accident within the three month period. However, this introduces an arbitrary component into the assessed loss. The division of the year into four parts can be based on a calendar year, which has a natural connection to the annualised accounting of output and GVA, or on a year based on the seasons with the latter representing a more natural partitioning of the growing cycle. It may be expected that the rate output value accumulates throughout the year will be better represented by the more natural division. However, the important determinant of the representation is the harvest boundary, ie, the latest month harvest occurs. This ensures that the highest loss will occur in the three months preceding harvest and the lowest in the three months following harvest. Unfortunately, this makes the division of the year crop dependent. The tables representing periodic production in the subsections below give loss factors for a fixed calendar division and a harvest dependent division when there is a difference and indicate which is the most appropriate to use.

Thus, for periodic production the losses that arise directly from not being able to sell a crop in the first year are given by Equation 9.1 where QF(s) is the loss fraction for the season the accident occurs (see, for example Table C5). As stated previously, output is the annual average output value in £ per hectare and the GVA is the gross value added in £ per hectare. It is assumed that harvest occurs at the latest practical date that does not jeopardise the value of the crop, if a delay is likely to reduce the amount of produce exceeding the CFIL criterion.

C3.1 Cereals

The composite category of cereals represents the production of wheat, oats, barley, etc, including crops not destined directly or indirectly for human consumption. For example,

* If the crop were to be stored for several years, in addition to the storage costs, it is likely that the value of the crop would differ from estimates derived using the values of Table C3. COCO-2 does not attempt to model this change in value.

increasing amounts of UK wheat are likely to be used to produce biofuels. Therefore, not all cereals exceeding the CFIL criteria or the related restrictions on animal feed will necessarily be subject to a FEPA order restricting the sale of foods*. However, although it is recommended that such market factors be kept under review, COCO-2 assumes that cereals that are predicted to exceed the permitted CFIL activity concentrations will not be sold, ie, COCO-2 does not attempt to model the effect of product substitution on the loss incurred†. However, as the COCO-2 model assumes that the numbers of hectares restricted are supplied by other modules of the PRA model within which it has been implemented the net effect is to assume that no costs are incurred if some nominally restricted production is diverted to other uses.

Cereals have a simple cropping regime represented by a single annual harvest that takes place over a short period. Planting begins in October for winter-sown crops and continues through until the spring. Harvest occurs in the third quarter (Q3) from July to September, at which point all inputs have been used and the full output value will be lost if restrictions are then applied following an accident.

The fourth quarter (Q4) is the beginning of a new crop year, and the time when an accident would have the least effect on production. However, during this quarter, seeds and sprays will be used, and these inputs will therefore be lost, if following an accident in Q4, it is predicted that restrictions will be applied to the crop at harvest. Throughout the first (Q1) and second quarters (Q2) the rest of the inputs are applied, increasing the seasonal multiplier.

The composition of variable inputs (Output - GVA) is given in Table C4 with the cumulative input loss fraction for each quarter shown in Table C5‡.

TABLE C4 Component cereal inputs %(output - GVA)[1]

Inputs	Component Input	Duration
Seed	15%	October to March
Fertiliser	45%	February to June
Sprays	40%	October to September

[1]Private communication Defra agricultural advisor

As harvesting is assumed to end in September no alternative partitioning of the year is considered in Table C5.

*More specifically a farmer may apply for consent to sell a restricted crop for non-food use (Spindura, 2006).

† The value of grain to sectors prepared to accept a ‘contaminated’ product that cannot otherwise be sold may be less than the COCO-2 estimated values.

‡ Variable costs are consumables such as seed, fertiliser, sprays and casual labour. It excludes fixed labour costs and capital depreciation.

TABLE C5 Fraction of (output - GVA) lost from cereal restrictions at harvest for an accident in a given season[1]

Period	Cumulative Input Terms[3]	Value	QF(s)[2] Standard quarters[4]	Standard Biannual[5]
January	[Dec]+0.15/6+0.4/12	0.23		
February	[Jan]+0.15/6+0.4/12+0.45/5	0.38		
March	[Feb]+0.15/6+0.4/12+0.45/5	0.53	0.38	0.25
April	[Mar]+0.45/5+0.4/12	0.65		
May	[Apr]+0.45/5+0.4/12	0.78		
June	[May+0.45/5+0.4/12	0.90	0.78	
July	[Jun]+0.4/12	0.93		
August	[Jul]+0.4/12	0.97		
September	[Aug]+0.4/12	1.00	0.97	0.87
October	0.15/6+0.4/12	0.06		
November	[Oct]+0.15/6+0.4/12	0.12		
December	[Nov]+0.15/6+0.4/12	0.18	0.12	
Annual average <QF>		0.56		

[1]Fraction of inputs associated with each activity taken from Table C4

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into two as follows: Summer (April – September), Winter (October – March)

The losses incurred from restrictions placed on the sale of cereals can therefore be calculated using Equations 9.1 and 9.2, the appropriate output and GVA values from Tables C2 and C3 and the seasonal loss fraction QF(s) or weighted average seasonal loss fraction ‹QF› of Table C5.

C3.2 Potatoes

Depending on the particular crop, ie, early potatoes, second early potatoes or main crop potatoes, planting will take place from late February until early June with the majority taking place in March and the first three weeks of April. The exact timing will depend on where in the country the potatoes are being grown. However, although the planting and cropping times are distinct it would be misleading to try to include details of the exact proportion of each type of potato grown in an area as this would imply greater accuracy than can be practically achieved. Thus, for simplicity, no differentiation is made between early and main crop potatoes, with planting assumed to take place from March through to May and harvest taking place from July to October. No planting takes place in Q4, and it is assumed that no seed potatoes have been purchased in anticipation of planting in the first quarter of the following year. However, some spraying will take place over the winter. This information is summarised in Table C6.

Most potatoes go into storage and only if they are above the CFIL at the end of this period will a loss be realised. However, affected potatoes would have to be stored separately from any uncontaminated crop to maintain public confidence and minimise the expense of testing their activity concentration before they were released for sale. This practical consideration will not affect early potatoes sold as harvested, but it may influence the modelling of the amount of crop predicted by an ACA code to be restricted and therefore the loss to be costed by COCO-2. Unlike other crops, potatoes that are not sold cannot be ploughed in but will need to be lifted to clear the affected fields. It is assumed that this will cost only a small fraction of the amount required to lift the potatoes for sale, in particular because there will be no requirement for the potatoes to be sorted, graded and packed. This cost is not specifically considered by COCO-2 as it is assumed part of the cost of applying countermeasures (HPA-RPD, 2005).

TABLE C6 Component potato inputs %(output - GVA)[1]

Inputs	Component Input	Duration
Casual harvest labour	30	July to October
Seed potatoes	14	March to May[2]
Fertilisers	28	March to July
Sprays	28	January to December

[1]The last three inputs are simple divisions (20%, 40%, and 40%) of the output-GVA value, remaining after casual labour has been accounted for and are not meant to imply excessive accuracy.

[2]Nix (2007) and Caunce (2007) suggest March as the start date but potatoes may be sown earlier in the extreme south, eg, Cornwall and the Channel Islands. There is some ambiguity over the end of the planting season but truncating it to May is conservative in terms of loss estimates.

The losses from an accident occurring in any particular season are shown in Table C7a and Table C7b. The former table assumes that either seed potatoes will not be purchased before planting, or any potatoes already in store can be kept for later planting or sold. The advantage of this assumption is that the expense of planting potatoes occurs uniformly over the planting period, which is the same as saying that there is an equal likelihood of the potatoes being planted at any time in the period. However, as seed potatoes do not keep well it can alternatively be assumed that the entire cost occurs in March the consequences of which are illustrated in Table C7b.

Table C7a Fraction of (output - GVA) lost for potato restrictions at harvest for accident in given season[1]

Period	Cumulative input		QF(S)[2]			
	Terms[3]	Value	Standard quarters[4]	Harvest Quarters[5]	Standard biannual[6]	Harvest biannual[7]
January	[Dec]+0.28*1/12	0.07		0.047		
February	[Jan]+0.28*1/12	0.09				
March	[Feb]+0.28*1/12+0.14*1/3+0.28*0.2	0.22	0.13		0.24	
April	[Mar]+0.28*1/12+0.14*1/3+0.28*0.2	0.35		0.22		0.13
May	[Apr]+0.28*1/12+0.14*1/3+0.28*0.2	0.47				
June	[Jun]+0.28*1/12+0.28*0.2	0.55	0.46			
July	[Jul]+0.28*1/12+0.28*0.2+0.3*0.25	0.70		0.58		
August	[Aug]+0.28*1/12+0.3*0.25	0.80				
September	[Sep]+0.28*1/12+0.3*0.25	0.90	0.80		0.63	
October	[Oct]+0.28*1/12+0.3*0.25	1.00		0.90		0.74
November	0.28*1/12	0.02				
December	[Nov]+0.28*1/12	0.05	0.36			
Annual average <QF>		0.44				

[1]Fraction of inputs associated with each activity taken from Table C6.

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into quarters as follows: Q1(November – January), Q2(February – April), Q3 (May – July), Q4(August – October). This is the recommended four season division.

[6] The year is divided into two as follows: Summer (April – September), Winter (October – March)

[7] The year is divided into two as follows: Summer (May – October), Winter (November – April) This is the recommended two season division.

Table C7b Fraction of (output - GVA) lost for potato restrictions at harvest for accident in given season[1]

	Cumulative input		QF(S)[2]			
Month	Terms[3]	Value	Standard quarters[4]	Harvest Quarters[5]	Biannual Standard[6]	Biannual Harvest[7]
January	[Dec]+0.28*1/12	0.07		0.047		
February	[Jan]+0.28*1/12	0.09				
March	[Feb]+0.28*1/12+0.14+0.28*0.2	0.31	0.16		0.26	
April	[Mar]+0.28*1/12+0.28*0.2	0.39		0.27		0.16
May	[Apr]+0.28*1/12+0.28*0.2	0.47				
June	[May]+0.28*1/12+0.28*0.2	0.55	0.47			
July	[Jun]+0.28*1/12+0.28*0.2+0.3*0.25	0.70		0.58		
August	[Jul]+0.28*1/12+0.3*0.25	0.80				
September	[Aug]+0.28*1/12+0.3*0.25	0.90	0.80		0.64	
October	[Sep]+0.28*1/12+0.3*0.25	1.00		0.90		0.74
November	0.28*1/12	0.02				
December	[Nov]+0.28*1/12	0.05	0.36			
Annual average <QF>		0.45				

[1]Fraction of inputs associated with each activity taken from Table C6.

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into quarters as follows: Q1(November – January), Q2(February – April), Q3 (May – July), Q4(August – October). This is the recommended four season division.

[6] The year is divided into two as follows: Summer (April – September), Winter (October – March)

[7] The year is divided into two as follows: Summer (May – October), Winter (November – April) This is the recommended two season division.

Thus, the first year loss for potatoes can be estimated using Equation 9.1 where V is the loss from not being able to sell the crop, F is the hectares of food exceeding the criteria at harvest (or after normal storage if deemed appropriate) and QF(s) is the loss fraction, for the season the accident occurs, given in Table C7. If restrictions are likely to continue until harvest in the following year, the loss will be given by Equation 9.3. Note if subsequent restrictions were only likely to affect early crop potatoes, ie, later planting would result in lower uptake, there would be an argument for assuming that main crop potatoes would be planted so that no loss would be realised. As no distinction is being made between late and early varieties and there may be other reasons why this would be impractical this option is not pursued. The quarterly or biannual harvest based loss fractions provide a better representation of the seasonal loss, and should therefore be used unless inconvenient for the PRA code implementing COCO-2.

C3.3 Sugar beet

This crop is agriculturally important and although, from a dose perspective, it is less likely than other foods to be a major contributor to the dose received due to the extensive processing and inherent delay involved in producing sugar it may still be subject to CFIL restrictions. Planting begins in March and continues until early April with harvest occurring between September and February.

For sugar beet, it is assumed that the crop year starts in Q1, when some sprays are applied and planting begins. The majority of inputs are used in Q2, with some fertiliser and sprays still used in Q3, and harvest takes place in Q4. This information is summarised in Table C8. Two alternative viewpoints can be adopted for the standard division of the year shown in Table C9. Firstly, the assumption can be made that as a root crop any sugar beet, which was still in the ground awaiting harvest in January and February, would not be immediately affected by an accident in January or February and could be harvested without loss if this occurred promptly. This effectively curtails the harvest period to the end of the year. Alternatively, the loss quoted for the first quarter will only apply if planting has begun while a seasonal loss fraction of 1 will apply if the crop remains to be lifted[*]. Note this assumption is not made when quarter year divisions based on the last date of harvest are used because there are then distinct planting and harvesting periods.

TABLE C8 Component sugar beet inputs %(output - GVA)

Inputs	Component Inputs	Duration
Seed	20%	March to April
Fertiliser	40%	March to July
Sprays	40%	January to December

Given the pattern of expenditure shown in Table C8 the seasonal loss fractions can be calculated as shown in Table C9.

[*]It is assumed that a crop will always be harvested before a successor crop is planted so that the Output loss is always less than or equal to 1.

TABLE C9 Fraction of (output - GVA) lost for sugar beet restrictions at harvest for accident in given season[1]

Period	Cumulative Inputs		QF(s)[2]			
	Terms[3]	Value	Standard quarters[4]	Harvest quarters[5]	Standard biannual[6]	Harvest biannual[7]
January	[Dec]+0.4/12	0.97				
February	[Jan]+0.4/12	1.00		0.97		0.92
March	0.4/5+0.2/2+0.4/12	0.21	0.73		0.81	
April	[Mar]+0.4/5+0.2/2+0.4/12	0.43				
May	[Apr]+0.4/5+0.4/12	0.54		0.39		
June	[May]+0.4/5+0.4/12	0.65	0.54			
July	[Jun]+0.4/5+0.4/12	0.77				
August	[Jul]+0.4/12	0.80		0.74		0.57
September	[Aug]+0.4/12	0.83	0.80		0.67	
October	[Sep]+0.4/12	0.87				
November	[Oct]+0.4/12	0.90		0.87		
December	[Nov]+0.4/12	0.93	0.90			
Annual average <QF>		0.74				

[1]Fraction of inputs associated with each activity taken from Table C8.

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into quarters as follows: Q1(December – February), Q2(March – May), Q3 (June – August), Q4(September – November). This is the recommended four season division.

[6] The year is divided into two as follows: Summer (April – September), Winter (October – March)

[7] The year is divided into two as follows: Summer (March – August), Winter (September – February) This is the recommended two season division.

The economic loss from sugar beet restrictions will be given by Equations 9.1 and 9.2 using the factors of Table C9. As with potatoes the quarterly or biannual averaged harvest based seasonality factors provide a better representation of the seasonal loss, and should therefore be used unless inconvenient for the PRA code implementing COCO-2 due to the change in seasonal periods.

C3.4 Legumes

The component costs for legumes production are shown in Table C10. The ‘legumes’ included in this calculation are broad, runner and dwarf beans, green peas and peas harvested dry. Vining peas are sowed from mid February to April and generally harvested from June to August. Dried peas are harvested in August and September. Field beans are grown for animal feed and are not considered in COCO-2. As the harvest is assumed to end in September, no separate harvest dependent division of the loss fractions is required.

TABLE C10 Component legumes inputs %(output - GVA)

Inputs	Component inputs	Duration
Casual labour	77	June to September
Seed	4.6	February to April
Fertilisers	9.2	March to July
Sprays	9.2	January to September

Table C11 gives the seasonal adjustment factors derived from Table C10.

TABLE C11 Fraction of (output-GVA) lost for legumes restrictions for accident in given season[1]

Period	Cumulative inputs		QF(s)[2]	
	Term[3]	Value	Standard quarters[4]	Standard biannual[5]
January	0.092/9	0.01		
February	[Jan]+0.092/9+0.046/3	0.04		
March	[Feb]+0.092/9+0.092/5+0.046/3	0.08	0.04	0.02
April	[Mar]+0.092/9+0.046/3+0.092/5	0.12		
May	[Apr]+0.092/9+0.092/5	0.15		
June	[May]+0.092/9+0.092/5+0.77/4	0.37	0.22	
July	[Jun]+0.092/9+0.092/5+0.77/4	0.59		
August	[Jul]+0.092/9+0.77/4	0.80		
September	[Aug]+0.092/9+0.77/4	1.00	0.80	0.51
October	0.0000	0.00		
November	0.0000	0.00		
December	0.0000	0.00	0.00	
Annual average <QF>		0.26		

[1]Fraction of inputs associated with each activity taken from Table C10.

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into two as follows: Summer (April – September), Winter (October – March)

C3.5 Fruit

Foliage begins to appear on orchard fruit in March, with harvesting occurring during September and October. The casual labour employed for picking makes up 59% of variable costs. Soft fruit grows much more quickly with growth beginning in April and harvest occurring between June and August. However, similar casual labour costs (64%) are incurred for soft fruit picking. Orchard fruit may be stored and both forms are preserved through their use in manufactured products. However, the timing of harvest is the important factor from the perspective of COCO-2. To resolve when the largest losses are likely to occur it is therefore necessary to treat soft and orchard fruits as distinct crops. As with other crops the quarterly or biannual averaged harvest based seasonality factors, provide a better representation of the seasonal loss, and should therefore be used unless inconvenient for the PRA code implementing COCO-2 due to the change in seasonal periods.

C3.6 Orchard fruit

As indicated in Table C12 there are no significant inputs in Q1, with the main input, spraying, occurring from April through to September. Harvest occurs in the relatively short period between September and October.

TABLE C12 Component orchard fruit inputs %(output - GVA)

Inputs	Component inputs	Duration
Casual labour	59%	September to October
Sprays	41%	April to September

It can be argued that if an accident occurs in July or August the casual labour required to pick the fruit would not be hired and the predicted loss of Table C13 would not be realised. If this were thought to be a significant issue, eg, the accident had affected a large fruit growing area, the seasonal adjustments can be easily derived on a monthly basis.

TABLE C13 Fraction of (output - GVA) lost for orchard fruit restrictions at harvest for accident in given season[1]

Period	Cumulative inputs		QF(s)[2]			
	Term[3]	Value	Standard quarters[4]	Harvest quarters[5]	Standard biannual[6]	Harvest biannual[7]
January	0.0000	0.00		0.00		
February	0.0000	0.00				
March	0.0000	0.00	0.00		0.17	
April	0.41/6	0.07		0.02		0.01
May	[Apr]+0.41/6	0.14				
June	[May]+0.41/6	0.21	0.14			
July	[Jun]+0.41/6	0.27		0.21		
August	[Jul]+0.41/6	0.34				
September	[Aug]+0.41/6+0.59/2	0.71	0.44		0.29	
October	[Sep]+0.59/2	1.00		0.68		0.44
November	0.0000	0.00				
December	0.0000	0.00	0.33			
Annual average <QF>		0.23				

[1]Fraction of inputs associated with each activity taken from Table C12.

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into quarters as follows: Q1(November – January), Q2(February – April), Q3 (May – July), Q4(August – October). This is the recommended four season division.

[6] The year is divided into two as follows: Summer (April – September), Winter (October – March)

[7] The year is divided into two as follows: Summer (May – October), Winter (November – April) This is the recommended two season division.

C3.7 Soft fruit

Again, as shown in Table C14, there is no input in Q1. In the case of soft fruit, sprays are used for a shorter period between April and June, with harvest occurring between June and August (Q3).

TABLE C14 Component soft fruit inputs %(output - GVA)

Inputs	Component inputs	Duration
Casual labour	64%	June to August
Sprays	36%	April to June

The predicted loss fractions for calendar and harvest times are shown in Table C15.

TABLE C15 Fraction of (output - GVA) lost for soft fruit restrictions at harvest for accident in given season[1]

Period	Cumulative inputs		QF(s)[2]			
	Term[3]	Value	Standard quarters[4]	Harvest Quarters[5]	Standard biannual[6]	Harvest biannual[7]
January	0.0000	0.00				
February	0.0000	0.00		0.00		0.00
March	0.0000	0.00	0.00		0.00	
April	0.36/3	0.12				
May	[Apr]+0.36/3	0.24		0.12		
June	[May]+0.36/3+0.64/3	0.57	0.31			
July	[Jun]+0.64/3	0.79				
August	[Jul]+0.64/3	1.00		0.79		0.45
September	0.0000	0.00	0.60		0.45	
October	0.0000	0.00				
November	0.0000	0.00		0.00		
December	0.0000	0.00	0.00			
Annual average <QF>		0.23				

[1]Fraction of inputs associated with each activity taken from Table C12.

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into quarters as follows: Q1(December – February), Q2(March – May), Q3 (June – August), Q4(September – November). This is the recommended four season division.

[6] The year is divided into two as follows: Summer (April – September), Winter (October – March)

[7] The year is divided into two as follows: Summer (March – August), Winter (September – February) This gives same loss fraction as the standard biannual division of t he year.

C3.8 Sheep

Lambing occurs between February and May, with slaughtering starting in June and continuing right through until the following February. The input timings are summarised in Table C16 below. In most circumstances if it is forecast that the sale of lambs is likely to be restricted, then the lambs may be sold early or provision may be made to provide them with clean feed*. In the event that the lambs are contaminated, providing access to clean feed for a few weeks prior to sale may be sufficient to reduce their activity levels to below the CFIL threshold. In most cases, altering the time lambs are sold will not result in a substantial direct loss or one that it is reasonable to resolve within the COCO-2 framework given expected annual and regional variations (excluding the cost of providing clean feed). However, in rare circumstances the length of time the lambs would need to be kept out of the food chain might result in them losing sufficient value that it was thought appropriate for them to be culled, eg, they could no longer be sold as lambs.

* The supply of clean feed should be costed as a countermeasure (HPA-RPD, 2005)

TABLE C16 Component sheep inputs %(output - GVA)

Inputs	Component inputs	Duration
Feed	40%	February to April
Vet & Med	20%	October to August
Fertiliser	20%	February to June
Misc. costs	20%	All year

Although as discussed above a complete loss of value is unlikely, following the approach adopted for other crops the seasonal loss factors from restrictions placed on the sale of that year's lambs, which may not yet have been born at the time of the accident (sheep have a 5 month gestation) can be estimated, as shown in Table C17 below. As with crops the quarterly or biannual averaged harvest based loss fractions provide a better representation of the seasonal loss, and should therefore be used unless inconvenient for the PRA code implementing COCO-2 due to the change in seasonal periods

Ewes sold for mutton are not specifically included within this scheme firstly, because a delay in selling is likely to be less significant and secondly, because the market is dominated by the sale of lambs (more than 87%). However, they are valued implicitly because to simplify the output and GVA calculations the total UK output and gross value added (which includes some proportion of meat from discarded breeding animals) is divided by the number of slaughtered animals (which excludes discarded breeding animals) to give a value per animal slaughtered. Thus, the value of the individual slaughtered animal is slightly overestimated.

TABLE C17 Fraction of (output-GVA) lost for long term sheep restrictions for an accident in the given season[1]

Period	Cumulative inputs		QF(s)[2]			
	Terms[3]	Values	Standard quarters[4]	Harvest Quarters[5]	Standard biannual[6]	Harvest biannual[7]
January	[Dec]+0.2/12+0.2/11	0.79				
February	[Jan]+0.2/12+0.2/11+0.2/5+0.4/3	1.00		0.85		0.77
March	0.2/12+0.2/5+0.2/11+0.4/3	0.21	0.67		0.69	
April	[Mar]+0.4/3+0.2/12+0.2/5+0.2/11	0.42				
May	[Apr]+0.2/12+0.2/5+0.2/11	0.49		0.37		
June	[May]+0.2/12+0.2/5+0.2/11	0.57	0.49			
July	[Jun]+0.2/12+0.2/11	0.60				
August	[Jul]+0.2/11+0.2/12	0.64		0.60		0.49
September	[Aug]+0.2/12	0.65	0.63		0.56	
October	[Sep]+0.2/12+0.2/11	0.69				
November	[Oct]+0.2/12+0.2/11	0.72		0.69		
December	[Nov]+0.2/12+0.2/11	0.76	0.72			
Annual average <QF>		0.63				

[1]Fraction of inputs associated with each activity taken from Table C16.

[2]s represents the season of the year the accident occurs and QF is the mean loss fraction for an accident that can occur at any time within that season.

[3]The shorthand notation [Month] indicates that the term for that month should add to the terms given explicitly.

[4] The year is divided into quarters as follows: Q1(January – March), Q2(April – June), Q3 (July – September), Q4(October – December)

[5] The year is divided into quarters as follows: Q1(December – February), Q2(March – May), Q3 (June – August), Q4(September – November). This is the recommended four season division.

[6] The year is divided into two as follows: Summer (April – September), Winter (October – March)

[7] The year is divided into two as follows: Summer (March – August), Winter (September – February) This is the recommended two season division.

Farms operate early, mid and late lambing systems influenced by geography, climate and market opportunities with the latter providing a limiting time for the expected sale of that season's lambs. Thus, if no sale can be achieved by February then there will be a loss of annual income. Equation C1 is a slight variation in the conventional approach of this section that can be applied to the sale of lambs. The loss estimate V of Equation C1 represents the loss from not being able to sell F lambs before they lose value and will only be realised if inputs are stopped following the accident. This is likely to result in welfare problems for the lambs and therefore has the implication that the lambs are culled.

$$V = F \times (QF(s) \times (output - GVA) + GVA)\theta(\Delta T - BT)$$

$$\theta(x) = \begin{Bmatrix} 1 \,\forall x > 0 \\ 0 \,\forall x \le 0 \end{Bmatrix} \quad \text{(C1)}$$

where QF(s) is given in Table C17 and θ is a step function determined by the length in days of any required restrictions (ΔT) and the buffer time (BT) in days between the start of any restrictions and the end of the sale season. Thus, θ and hence V=0 if restrictions on the sale of lambs end before the end of the normal sale period. The sale period will depend on whether an early, mid or late lambing system is being operated but for simplicity it is assumed that no loss occurs if lambs can be sold between the months of June and February following the accident.

A FEPA order placed on the sheep will restrict their movement, sale and slaughter but a licence may be obtained for movement, which would curtail the need for culling, if the lambs were likely to be saleable after a few weeks on clean pasture.

C4 RESTRICTION COSTS FOR CONTINUOUS PRODUCTION

The assumption of continuous production is true for some commodities such as milk and a reasonable approximation for others such as root and leafy green vegetables, which as generic categories are available all year. Thus, it is assumed that root vegetables, cow milk and cattle production and leafy green vegetables are not subject to seasonal variation but are instead produced continuously and uniformly throughout the year*. On that basis, it is possible to derive a simple set of equations representing the loss that would result from short and longer-term restrictions for each of these categories. Before proceeding to develop the model, Section C4.1 considers the effect on the value of a crop of restrictions that only last a few days. As farming is weather dependent and likely to suffer minor delays regularly, it can be envisaged that a short duration restriction may not be economically significant.

C4.1 Harvest delay tolerance

Following an accident, a large area might be subject to restrictions on the sale of vegetables for a short period (eg, 30 days), while a smaller area might be restricted for longer (eg, 90 days). The COCO-2 model needs to establish how long the restriction period has to be before an economic loss is likely to materialise. The effect of delay on the harvest of vegetables was sought from the horticultural industry and the information shown in Table C18 was obtained.

* For simplicity, the root vegetable category includes both root vegetables such as turnips, carrots, swedes, parsnips, beetroot, etc, as well as bulbs such as onions but excludes potato tubers, as data on potatoes are available separately.

TABLE C18 Losses from harvesting delays*

Vegetable	Cope with 7 day delay	Harvest period
Root crops	Minimal loss possibly cope with 10 to 14 days if required	All year round
Cabbage and Brussels sprouts	Losses would be minimal	All year round
Cauliflower	50% loss of crop	All year round
Broccoli	Possible 100% loss of crop	June to November
Salad crops (lettuce, spinach)	Possible 100% loss of crop	May to October
Legumes	Possible 100% loss of crop	June to September

**Phillip Effingham Technical & Development Director Marshalls, The Mill, Butterwick, Boston*

The simple assumption made in Table C18 is that nothing within an affected area will be harvested for sale while a FEPA restriction is in force even if it will be saleable at the end of the restriction. This is simpler to manage than short-term storage and likely to be more acceptable. For crops that cannot cope with a delay of a week the next harvest is of crops that are ready the day after the last day of the restrictions. This conservative assumption implies that crops due to be harvested on the last day of the restrictions are still written off even if they might cope with such a short delay.

When modelling the activity concentration likely in agricultural produce, assumptions such as the generic sowing and cropping times are generally made. For COCO-2, it is appropriate to consider general modelling constraints when assessing which costs to consider although the exact details of the modelling approach are not relevant to the economic model, which assumes that an estimate of crop contamination can be made. National data are available on the hectares of different families of crops grown and in the absence of more detailed information, it is assumed, eg, that any area of leafy green vegetables is composed of the national proportions of the various sub-types. This assumption is implicit in the use, by COCO-2, of a single value for the Output and GVA of vegetables per hectare grown anywhere in the country (see Section C2). Without knowing exactly what crop was affected, if information were available on the relative value of different vegetable types, an estimate could be made of the temporal variation in lost value from a short period of restriction at different times of year. Although there may be some merit in using this approximation to derive a winter and summer loss within a continuous cropping model this approach has not been pursued in COCO-2 due to lack of data and the additional sources of uncertainty that would be introduced into any estimated loss.

C4.2 Estimation of continuous cropping losses

Assuming that any area of land has an equal mixture of crops at all stages of development then the amount at any stage is F/GP where F is the area and GP is the average growth period of the crops. Thus, the loss over a period of time t is Ft/GP and the whole area will be cropped in the growth period. One aspect of this approach that should be noted is that the Defra agricultural survey provides the number of hectares per square kilometre of a crop but continuous cropping allows multiple crops to be recovered from the same area over the space of a year. If a generic crop type is being used, eg, root vegetables, the hectares for each component crop are simply combined and no problem arises but if multiple harvests of a single crop occur, the hectares allocated to that crop will reflect the short growth period and this should be taken into account when estimating the average growth period.

The assumption is made that inputs occur daily in line with daily cropping but that these will cease for those crops that are predicted to exceed the limits for sale when they are eventually harvested. This assumption may not be practical in all cases as sprays may be required to protect saleable crop in other fields from the spread of pests and diseases. However, to minimise the disposal problem it is assumed that any waste crop will be dealt with quickly and that therefore the stopping of inputs will be an appropriate assumption in most cases.

Thus, the lost value V on the first day of restrictions will be the output loss as all inputs have been committed as shown in Equation C2 where in addition to the annual output value F is the area and GP the average growth period of the crops.

$$V = \frac{F \cdot 1}{GP}\left(\frac{GP}{365} output\right) \tag{C2}$$

In Equation C2, the annual output, which is assumed to be produced uniformly throughout the year, has been normalised to the output expected over a single growing period. The loss on the second day of restrictions will be nearly as great except that the inputs scheduled for the first day of restrictions will not have occurred. Similarly, the crop due to be harvested on the third day of restrictions will have missed two days inputs. The general term is shown in Equation C3 where t is the number of days since the imposition of restrictions.

$$V = \frac{F \cdot 1}{GP}\frac{GP}{365}\left[\frac{GP-(t-1)}{GP}(output - GVA) + GVA\right] \tag{C3}$$

In Equation C3, the output and GVA costs have been normalised to give the value lost in a day. Thus, the loss is the sum of the general term for the length of the restrictions provided the restrictions are less than the growth period. If the restrictions are longer than the growth period there will be no output loss as planting will not have occurred but a GVA loss will continue for that additional period. Considering losses within the growth period the sum of terms of the form of Equation (C3) is given by Equation (C4):

$$\sum_{t=1}^{t=\Delta T}\frac{F \cdot 1}{365}\left[\frac{GP-(t-1)}{GP}(output - GVA) + GVA\right] = \frac{FT}{365}\left[\frac{2GP+1-\Delta T}{2GP}(output - GVA) + GVA\right] \tag{C4}$$

where ΔT is the total length of the restrictions in days. For restrictions that continue beyond the growth period there will be a loss from the sum of the daily GVA contributions forgone. Thus, for ΔT>GP the additional loss is given by Equation (C5).

$$V = \frac{F}{365}(\Delta T - GP)GVA \tag{C5}$$

The total loss for restrictions extending beyond the growth period is therefore given by Equation (C6).

$$V = \frac{F}{365}\left[\frac{GP+1}{2}(output - GVA) + GVA \times GP\right] + \frac{F}{365}(\Delta T - GP)GVA \tag{C6}$$

This becomes Equation (C7) below.

$$V = \frac{F}{365}\left[\frac{GP+1}{2}(output - GVA) + GVA \times \Delta T\right] \tag{C7}$$

C4.3 Root vegetables

Considering root vegetables, the simplest assumption that can be made is that an amount of the annual output proportional to the restriction period is lost in the first year and if the effect of the accident extends into the second year, the amount of GVA proportional to the second year restriction period is lost. However, these assumptions are not very satisfactory as they implicitly assume that root crops take a year to grow and that inputs continue to be made to crops with no sale value on harvest. A more realistic model of the loss will apply the considerations of Section C4.2 and introduce the assumption of an average time from planting to harvest. Strictly, this average time will subsume many factors that depend on the particular crop and for crops that are actually planted throughout the year, the particular planting season. For example, winter planted crops may take longed to mature than those planted in the spring. Nevertheless, if a representative growth period is selected and if fallow periods are neglected, then assuming that inputs are supplied continuously, the output loss following restrictions that last for less than the growth period can be represented by Equation C4[*].

If the restrictions are predicted to last longer than the growth period, the additional losses will be proportional to the GVA to give the total loss shown in Equation C7. The growth period is a modelling input that should be consistent with the parameterisation of the PRA model supplying the timing and extent of agricultural restrictions to COCO-2. In general, there will be a series of losses representing areas subject to restrictions of different lengths T_n reflecting the variation in the amount of radioactive material deposited by the dispersing plume in different areas[†].

The continuous production model assumes that plants are available for cropping in a sequence in which each term of the sequence is a day further from harvest. The growth period indicates how long an area of ground is being used by a crop before it can be re-sown. In addition, as shown in Table C18, it is assumed that root vegetables will not lose value if the restriction on their sale is limited to 7 days or less. Strictly, as well as there being no loss if the restrictions last for 7 days or less there will be no loss associated with crops sown up to 7 days before the start of the restrictions if the restrictions last for the entire growth period or less. If the restrictions are longer than the growth period plus 7 days there will be a GVA loss from the planting that does not occur.

[*]Strictly fallow periods are implicitly included in the output and GVA values and in the averaging of the production over each EDINA grid cell.

[†]Deposition will vary, for example, with distance from the source, because of the underlying terrain and because of variations in rainfall during the passage of the plume.

Thus, the total loss from restricting the sale of root vegetables for various lengths of time is given by Equation C8.

$$V = \sum_n \frac{F_n(\Delta T_n - 7)}{365}\left[\frac{2GP + 6 - \Delta T_n)}{2GP}(output - GVA) + GVA\right]$$
$$\times [\theta(GP - (\Delta T_n - 7)) - \delta(\Delta T_n - 7 - GP)] \qquad \text{(C8)}$$
$$+ \frac{F_n}{365}\left[\frac{GP + 1}{2}(output - GVA) + GVA(\Delta T_n - 7)\right]\theta(\Delta T_n - 7 - GP) \; \forall \Delta T_n > 7$$

$$where \;\; \theta(x) = \begin{cases} 1 \; \forall x \geq 0 \\ 0 \; \forall x < 0, \end{cases} \quad \delta(x) = \begin{cases} 1 \; x = 0 \\ 0 \; \forall x \neq 0 \end{cases} \quad and \;\; \Delta T_n = \min(\Delta T_n, 730)$$

In evaluating Equation C8, it is likely that in peripheral areas or, more accurately areas of low deposition, the first term will apply because the required restriction period is short. However, nearer to the source of the release and in particular areas of high deposition the restrictions required may be long enough to trigger the use of the second term of the equation. After 2 years, it is assumed by COCO-2 that production elsewhere will replace any production lost through continuing local restrictions.

C4.4 Leafy green vegetables

Leafy green vegetables are a composite class representing open field vegetables with edible leaves or florets. Members of the class are available all year and the continuous cropping expressions previously derived can therefore be used to model the loss from any restrictions imposed. The distinction from the results derived for root crops is that some leafy green vegetables are sensitive to short delays as shown in Table C18. As discussed in Section C4.1 In the absence of a detailed breakdown of the seasonal variation of costs for the different crops included in the category of leafy green vegetable it is appropriate simply to assume that the category of leafy green vegetables cannot support any delays without a loss, as shown by Equation C9.

$$V = \sum_n \frac{F_n \Delta T_n}{365}\left[\frac{2GP + 1 - \Delta T_n)}{2GP}(output - GVA) + GVA\right][\theta(GP - \Delta T_n) - \delta(\Delta T_n - GP)]$$
$$+ \frac{F_n}{365}\left[\frac{GP + 1}{2}(output - GVA) + GVA \times \Delta T_n\right]\theta(\Delta T_n - GP) \qquad \text{(C9)}$$

$$where \;\; \theta(x) = \begin{cases} 1 \; \forall x \geq 0 \\ 0 \; \forall x < 0, \end{cases} \quad \delta(x) = \begin{cases} 1 \; x = 0 \\ 0 \; \forall x \neq 0 \end{cases} \quad and \;\; \Delta T_n = \min(\Delta T_n, 730)$$

The terms of Equation C9 have exactly the same meaning as those of Equation C8 except that the output and GVA values are those appropriate to leafy green vegetables (see Section C2).

C4.5 Milk

The production requirements of milk will not permit any delay in the delivery of the product with, in any event, very little or no storage capacity on farms for any milk produced and not sent to a dairy as part of the regular delivery. In addition, unlike root vegetables, inputs must be maintained for animal welfare reasons. Thus, milk production is not only continuous but must be maintained as continuous until a specific decision is made to either stop production or to allow the sale of milk to be resumed. Any decision to dry-off, or in extremis cull, cows to end milk production will be treated as a countermeasure in COCO-2 and costed separately (HPA-RPD, 2005). The loss from restricting the sale of milk is therefore the lost output value until countermeasures are put in place, which stop production or allow sales to be resumed, the cost of the countermeasures applied including the cost of disposal (see Section C6), and if production then ceases the lost GVA from the sale of milk. The lost output costs are given by Equation C10 for continuing production that cannot be sold.

$$V = \sum_n F_n \times \frac{output}{365} \times \Delta T_n \qquad \text{(C10)}$$

Where $\Delta T_n = \min(\Delta T_n, 730)$

In Equation C10 F_n is the number of cows grazing pasture in a particular location that will have their milk restricted, eg, above the CFIL criteria, for a period of ΔT_n days (eg, 7, 14, 30) after the accident and output is expressed in £ per animal per year. Equation C10 will also apply if the cows are dried-off but maintained on the farm. However, the disposal cost for waste milk will be reduced as it will only apply until a time $T_p < \Delta T_n$ when milk production stops.

The time taken to dry-off cows will depend on the method adopted but can take up to 2 weeks with a greater potential for animal welfare problems to occur if the pace is forced. The stage of lactation and pregnancy of the cows should also be considered. There is a continuous entry and exit of cows from the annual production cycle with lactation lasting approximately 10 months in parallel with a gestation period of 9 months. As stated in HPA-RPD (2005), further research is required to establish the most appropriate methods of drying off dairy cattle at different stages of lactation. As drying off is normally undertaken in preparation for calving and the next lactation cycle, an artificial dry period would make the initiation of the next lactation cycle difficult. Thus, the UK Recovery Handbook (HPA-RPD, 2005) suggests that suppression of lactation should only be considered if it is to be followed by slaughter.

If it is thought appropriate to end production quickly by culling the cows T_p days after the introduction of restrictions on the sale of milk, the loss from actual and potential milk sales will be given by Equation C11 where the GVA is in £ per animal per year and F_n is the number of cows affected.

$$V = \sum_n \frac{F_n}{365} \times (output \times T_p + GVA \times (\Delta T_n - T_p)) \ \forall \Delta T_n > T_p \qquad \text{(C11)}$$

where $\Delta T_n = \min(\Delta T_n, 730)$

This approach, although reducing milk disposal costs, will incur the additional cost of disposing of the dead animals (see Section C6).

If a cull is instigated, there will also be a capital loss, which can be approximated using information from Nix (2007)* on the cost of replacements and the effective depreciation rate. A replacement down-calving heifer costs £750, a cull cow is worth £300 and 25% of a herd is replaced every year, which implies that on average the cows culled to end milk production will be worth £525 each.

C4.6 Cattle

Cattle production can be modelled as a continuous process with the growth period representing the lead-time from insemination until the calf is sent to market. Although it is assumed that calves can be retained for a short period, without losing relative market value as they gain weight, limitations of space may limit the length of time cattle can be kept on a farm†. Thus, for COCO-2, it is assumed that without restrictions cattle are continuously produced and sold at the optimum age; accounting for factors such as quality, and rate of return and conservatively that the imposition of restrictions on the sale of cattle will produce a daily output loss proportional to the length of the restriction. This is composed of the GVA loss from the break in continuous production and the cost of inputs over the period of the restrictions. There are many rearing schemes, which may affect losses, but as these are unknown, the COCO-2 assumptions are simple, robust and defensible. Thus, an output loss will be realised that is proportional to the entire period of the restrictions if these are less than or equal to two years. If restrictions are estimated to continue beyond two years COCO-2 assumes alternative arrangements will have been put in place to allow output to be restored either in the affected area or elsewhere in the country.

The loss from restrictions imposed on cattle sales is therefore given by Equation C10 where the output value is representative of all cattle routinely sent for slaughter, ie, retired dairy cows as well as beef cattle. If countermeasures are introduced and the cattle are culled, the loss will be given by Equation C12 where T_p is the time delay after the start of the restrictions before any cull takes place.

$$V = \sum_n \frac{F_n}{365} \times (output \times T_p + GVA \times (\Delta T_n - T_p)) \; \forall \Delta T_n > T_p \qquad \text{(C12)}$$

$$where \; \Delta T_n = \min(\Delta T_{n,} \; 730)$$

*A cull cow was worth a little more (£310) according to Nix (2004) with all other values unchanged to give an essentially identical average value of £530.

†Strictly, once cattle reach the minimum weight for slaughter the decision on when to sell would be taken on finish ie the fat cover as they continue to put on weight.

C5 AGRICULTURAL COUNTERMEASURE COSTS

A large and diverse number of additional costs may arise depending on the mechanism chosen to implement any restrictions imposed following an accident. Most obviously restricting the sale of foodstuffs may create a waste disposal problem with many possible solutions. For example, the crop could be ploughed in or harvested and composted. Particular options could lead to reduced fertility of soils and reduced yields in the years following intervention. Alternatively, land could be taken out of food production and alternative crops grown which would require investment in alternative seed stocks, expertise, new markets (eg, a processing industry) and marketing.

The costs incurred by the various alternative routes for disposing of agricultural wastes are discussed below. In addition to the waste problem, there are a panoply of countermeasures that can be implemented to reduce the uptake of radioactivity into crops and animals and the amount likely to end up in animal products. Information on the range of countermeasures available including estimates of costs has been collected as part of the UK Recovery Handbook (HPA-RPD, 2005). This maintained set of reference information discusses the merits and problems of a range of countermeasures. In any application of COCO-2, the particular options selected could have a significant effect on the cost of the recovery actions.

C6 COSTING THE DISPOSAL OF AGRICULTURAL WASTE

The five waste producing agricultural countermeasures considered by the UK Recovery Handbook (HPA-RPD, 2005) are listed in Table C19 and the corresponding waste disposal options applicable in Table C20.

TABLE C19 Waste producing agricultural countermeasures

Countermeasure	Comment
Clean feeding	Livestock may be fenced in or housed to prevent grazing on contaminated pasture. Existing fences or farm buildings could be used although some may need modification. New purpose built sheds could also be considered. Slurry produced by the fenced in animals can be stored and spread on the land at a suitable time. While livestock are fenced in, a programme of grassland management should be implemented to allow the livestock to return to free grazing. For example, contaminated grass can be ensiled and fed to non-critical stock or stored to allow for radioactive decay. The grass can also be disposed of via composting, incineration or landfill.
Restrictions on the sale of foods exceeding EU criteria[1]	Following the imposition of food restrictions, animal carcasses, crops and milk will require disposal[2]. This will be achieved using one of the disposal options discussed later.
Alternative land use	Crops or animals for the production of non-edible crops are selected. This can include cotton/flax for fibre; rapeseed for bio-diesel; sugar beet for bio-ethanol or butanol; perennial grasses or coppice for bio-fuel. Agricultural land may also be used for production of leather and wool and in extreme situations forestry. The original animals and crops will be disposed of via composting, incineration, landfill or rendering. The products of this countermeasure should have activity levels below regulatory levels or there would be little point in making the change. However, If not they will have to be disposed of using composting, incineration, landfill or rendering.
Slaughtering Dairy Cows	Dairy cow carcasses will be sent for disposal via incineration, landfill or rendering.
Topsoil Removal	This remediation procedure is only likely to be considered for very small volumes of waste. If it were used, the contaminated soil will probably go directly to landfill but incineration could be considered as an intermediate treatment.

[1]The loss of output from this restriction is discussed in earlier sections

[2]Depending on the size of the accident Burial and Burning could be used to dispose of animal carcasses but would be a last option following the experience of the FMD outbreak of 2001

The waste disposal options in the UK Recovery Handbook (HPA-RPD, 2005) that are not considered in detail in COCO-2 are the land spreading of milk and the ploughing-in of a standing crop because the equipment to carry out these options will be readily available on farms and should not incur significant costs except that of the farmer’s time. The processing and storage of milk for disposal, although considered in the UK Recovery Handbook (HPA-RPD, 2005) is not considered in COCO-2 as the Agriculture and Food Countermeasures Working Group (Alexander et al, 2005) thought that the processing of milk was likely to be unacceptable to dairies due to the potential contamination of plant and equipment (HPA-RPD, 2005).

Costs are not available within the UK Recovery Handbook for the waste disposal options of Table C20 and are therefore provided in the following sections.

TABLE C20 Waste Disposal Options considered in COCO-2

Option	Comment
Biological Treatment (digestion) of Milk	At Sewage Treatment Works
Burial of Carcasses	
Burning of Carcasses	
Composting – crops	
Disposal of Milk to Sea	
Incineration – animal carcasses and crops	
Landfill – animal carcasses and crops	
Rendering	

C6.1 Cost of biological treatment (digestion) of milk

The biological treatment of milk would be carried out at one or more sewage treatment works (STW) as dairy plants would be unlikely to accept contaminated milk. However, STWs have a very low capacity to treat raw milk due to its high chemical oxygen demand (COD) and concentration of suspended solids, 210,000 mg l^{-1} and 5000 mg l^{-1} respectively.

The unit charge for treating waste effluent, in pence per cubic metre is calculated using Equation C13 (Southern Water, 2006) and the parameters of Table C21.

$$\left[R + V + \frac{Ot \times B}{Os} + \frac{St \times S}{Ss} + M \right] \quad \text{(C13)}$$

TABLE C21 Biological treatment charging rates and parameters

Cost Parameters £ m^{-3}	Symbol	Southern	Wessex
Reception and conveyance	R	0.3476	0.4733
Volumetric primary or preliminary treatment	V	0.295	0.1956
Biological treatment	B	0.3349	0.3314
Sludge treatment and disposal	S	0.2291	0.1567
Long sea outfall	M	0.0444	
Sewage Parameters mg l^{-1}			
Sewage suspended solids	Ss	512	313
Sewage COD[1]	Os	452	802
Milk Parameters mg l^{-1}			
Milk suspended solids	St	5000	
Milk COD	Ot	210,000	

[1]Chemical Oxygen Demand

Using the above parameters the unit charge is ~ £160 m^{-3} for southern water and slightly less ~ £90 m^{-3} for Wessex water. A representative charge for the biological treatment (digestion) of milk is therefore ~ £125 m^{-3}.

C6.2 Burial of Carcasses

Data on the cost of burying carcasses is available from the FMD report by the National Accounting Office (NAO, 2002). It was reported to have cost £79 million to purchase the land and construct the burial sites. With an estimated further cost of £35 million for the management and restoration of the sites over the next 15 years to give a total cost neglecting discounting of £114 million.

Approximately 1.3 million carcasses were buried in mass burial sites with the great majority of these being sheep. Assuming sheep weigh 50kg each (Halley, 1982 and Brown et al, 2002) then the total weight buried is approximate 65,000 tonnes giving a cost for mass burial ≅ £1750 per tonne.

C6.3 Burning of Carcasses

Table C22 provides a list of requirements for constructing a pyre to burn 300 cows or equivalent (150 tonnes).

Table C22 Burning Carcasses

Inputs	Cost £ FMD[1] 2001	Cost £ 2006
175 tonnes of coal	≤130 per tonne	40 per tonne
380 railway sleepers	5 to 20	10 to 50
250 pallets	10	10
4 tonnes of straw	40 per tonne	30 per tonne
2250 litres of diesel	0.15	0.15
Total cost	33,500	29,000

[1]Foot and Mouth Disease

In 2001, 100,000 tonnes of pyre ash had to be collected and disposed of to landfill at a cost of £38 million. The ash could also be sent for incineration at an estimated cost of £500 per tonne, including collection and subsequent landfill. Thus,

cost of mass burning (ash to landfill) ~ £600 per tonne,

cost of mass burning (ash to incineration) ~ £700 per tonne.

C6.4 Composting

The cost of composting at a centralised composting facility is estimated to be £90 to £200 per tonne (DETR, 2000), and includes the cost of collection, transfer, gate fees, disposal/recovery, and operating and capital costs. The costs do not include any returns from the sale of compost.

The collection and transfer costs for kerbside collection from residential homes are expensive and estimated to cost £100 per tonne (ECOTEC, 2000). Transporting contaminated crops from a farm to a centralised composting site should be much cheaper. In addition, there will be no separation costs as there are with municipal waste.

ECOTEC (2000) estimates the cost of composting to be between £20 and £130 per tonne, but does not include collection and separation costs. Therefore, for COCO-2 the cost of composting crops has been estimated as £150 per tonne.

Centralised composting normally is carried out indoors using a range of techniques (windrow, aerated pile, in-vessel, etc) and usually takes 3 to 12 months before the final compost is produced. In a recent study, it was found that for a number of radionuclides the vast majority of activity remained in the compost (Shaw et al, 2001). Therefore, it is unlikely to be sold and will have to be disposed of by incineration and/or landfill. As composting reduces the mass of the original crops by 50% the cost of landfill and incineration become £35 and £65 per tonne of crop respectively, based on the information given in Sections C6.7 and C6.8.

In addition to this, it is estimated that 5% of the original mass of crops is converted to leachate, which needs to be collected and disposed of. It can be used as a liquid fertiliser or sent for treatment at conventional STWs. Using the information given in Section C6.1 the cost will be in the region of £2 per tonne of crop. To summarise:

Cost of centralised composting (landfill) ≅ £190 per tonne.

Cost of centralised composting (incineration) ≅ £220 per tonne.

Windrow composting can be carried out on farm fields with standard farming equipment used to shred and turn material. In 1999 there were 65 on-farm sites processing $6.6\ 10^4$ t y^{-1} (Slater et al, 2001). This is an average of 1000 t y^{-1} per farm and assuming the density of crops is about 1 t m^{-3} then the volume composted is 1000 m^3 y^{-1} per farm.

Using information from an Environment Agency Report (EA, 2001) it can be calculated that, if on-farm composting were to be established following an accident, the cost for the average throughput with the provision of a lagoon would be £26,325 or, with a storage tank, £36,185 (ie, equivalent to £26 and £36 per tonne of compost respectively).

As with centralised composting, the majority of activity will remain in the compost but the exact proportion will depend on the radionuclide. Therefore, the compost will probably be disposed of to landfill or incineration, and the leachate treated at STWs at the same cost as those given for a centralised facility. This gives the following total cost:

Cost of on-farm composting (lagoon) ≅ £65 per tonne (landfill) or £95 per tonne (incineration).

Cost of on-farm composting (storage tanks) ≅ £75 per tonne (landfill) or £105 per tonne (incineration).

C6.5 Disposal of Milk to Sea

The costs assume the disposal of milk via the long sea outfalls at coastal STW's. Disposal can also be achieved using the outfalls at nuclear facilities but some of the costs are difficult to establish and would probably only be available at the time of an accident, eg, nuclear facility charges, vehicle hire, etc.

The unit charge for discharging waste effluent, in pence per cubic metre is calculated using Equation C13 assuming no treatments are applied (B=0, S=0). This gives a unit charge ≅ £0.57 m^{-3}.

C6.6 Incineration of carcasses

The estimated costs of disposing of sheep by incineration during FMD in 2001 were £25 per carcass (TSO, 2002). Assuming sheep weigh ~50 kg (Halley, 1982, Brown et al, 2002 and Nix 2007) each then the total cost is £500 per tonne.

Defra (2002) estimated that the cost for disposing of seals infected with 'Phocine Distemper Virus' by incineration to be £125 per tonne. However this did not include the transportation costs, estimated to cost £70 for one animal plus £10 for every extra animal. Assuming cattle weigh ~500 kg (Halley, 1982 and Nisbet et al, 1998, Nix 2007) each and sheep weigh ~50 kg each gives transportation costs of £80 to £260 per tonne respectively. The total costs are therefore between £205 to £385 per tonne but this is not likely to be applicable to a large scale event when costs may be expected to be higher. Therefore, the values estimated during the FMD outbreak are recommended for use in COCO-2.

Cost of incineration (animal carcasses) ≅ £500 per tonne.

C6.7 Incineration of crops

DETR (2000) estimated that the cost of incineration of mixed municipal waste would be £60 to £80 per tonne. This includes the cost of collection, transfer, gate fees, disposal/recovery, and operating and capital costs. These figures do not include the cost of disposal of incinerator ash to landfill, which is estimated to be £60 to £70 per tonne of ash. Assuming incineration reduces the mass of waste by 75% the cost of landfill will be £15 to £20 per tonne of crop. Thus, the overall cost is £75 to £100 per tonne of crop. Independent of the above estimate Gedge and Fitz-Gibbon (2002) have estimated that the cost of incinerating mixed municipal waste in the UK is £90 to £190 per tonne. Settling on the mean of the range suggests that the appropriate cost for COCO-2 is:

Cost of incineration (crops) ≅ £130 per tonne.

C6.8 Landfill

During the FMD outbreak in 2001, about 95,000 tonnes of carcasses were disposed of to landfill of which 69,000 were in Cumbria at a cost of £17.5 million (NAO, 2002). This cost included disposal, transportation and landfill costs. These figures equate to £250 per tonne. A similar estimate of the cost of landfilling carcasses, of £200 per tonne is given by a report on lessons to be learned from the FMD outbreak (TSO, 2002).

Cost of landfill (animal carcasses) ≅ £250 per tonne.

Under landfill regulations, crops would be classified as 'active waste'. This includes all wastes except those classified 'inert', which include waste materials from building sites such as earth and rubble. DETR (2000) estimated landfill costs of £40 to £50 per tonne, which includes the cost of collection, transfer, gate fees, disposal/recovery, and operating and capital costs. It does not include landfill tax, which in 2006 was set at £21 per tonne. Therefore, landfill costs are £60 to £70 per tonne.

The cost of landfill for mixed municipal waste in the UK has also been estimated at £30 to £50 per tonne (Gedge and Fitz-Gibbon, 2002) but again this does not include landfill tax. Including landfill tax, this would equate to £50 to £70 per tonne. Thus:

Cost of landfill (crops) ≅ £70 per tonne.

C6.9 Rendering

Defra (2002) estimated that the cost for disposing of seals infected with ‘Phocine Distemper Virus’ by rendering was £100 per tonne, which include transportation costs and routine cleaning.

The products of rendering, MBM, greaves and tallow, will be contaminated with radioactivity and will have to be sent to landfill or incineration for disposal.

Rendering reduces mass by 60% (BSE Inquiry, 1998) and so the cost of sending the rendering products to landfill is ~ £30 per tonne of carcasses.

The cost of sending the rendering products to incineration per tonne of carcasses is £25 to £30. The cost of disposing of incinerator ash is then added to this. As incineration reduces the mass of material by 75% only 10% of the original (carcasses) material is left so the cost of landfill is £6 to £7 per tonne of carcasses. This gives a cost of rendering followed by incineration of £140 per tonne. Thus:

Cost of rendering (landfill) ≅ £130 per tonne.

Cost of rendering (incineration) ≅ £140 per tonne.

C7 REFERENCES

Alexander C, Burt R and Nisbet AF (2005). Stakeholder involvement facilitates decision making for UK nuclear accident recovery. *J Environ Radioact*, **83**(3), 297-303.

AUK (2005). Agriculture in the United Kingdom 2004. ISBN 0 11 243086 4.

Brown J, Wilkins BT and Nisbet AF (2002). Management options for food production systems affected by a nuclear accident. Task 3: Diversion of crops grown for human consumption to animal feed. Chilton, NRPB-W18.

BSE Inquiry (1998). The rendering industry prior to the identification of bovine spongiform encephalopathy (BSE). Statement by Brian Rogers on behalf of the United Kingdom Renderers’ Association (UKRA). The BSE Inquiry/Statement No 33. Mr Brian Rogers (scheduled to give evidence 29/04/98). Viewed at http://www.bseinquiry.gov.uk/files/ws/s033.pdf on 23rd June 2002.

Caunce M (2007). Personal communication Brow Farm Ltd, Smithy Lane, Holmeswood, Ormskirk, Lancashire. http://www.browfarm.co.uk/.

Defra (2002). Phocine Distemper Virus in Seals: Suggested Disposal Options for Seal Carcasses. Defra, London. In UK Phocine Distemper Virus Epizootic Investigation Report 2002/2003 www.defra.gov.uk/science/Project_Data/DocumentLibrary/WM0301/WM0301_5242_FRP.pdf

DETR (2000). Waste Strategy 2000: England and Wales (Part 2). TSO, Norwich.

EA (2001). Technical guidance on composting operations-version 3. Draft for external consultation. Bristol.

ECOTEC (2000). Beyond the Bin: The Economics of Waste Management Options. ECOTEC Research and Consulting Limited.

Gedge G and Fitz-Gibbon S (2002). Laying Waste to Britain: Why the UK Needs a Zero Waste Strategy. Green Party of England & Wales, London.

Halley RJ, (1982). The agricultural notebook (17th edition). Butterworths, London

HPA-RPD (2005). UK Recovery Handbook for Radiation Incidents: 2005. Chilton, HPA-RPD-002.

NAO (2002). The 2001 Outbreak of Foot and Mouth Disease. National Audit Office TSO, London.

Nisbet AF, Woodman RFM, Brown J, Smith JG and Wilkins BT (1998). Derivation of working levels for animal feedstuffs for use in the event of a future nuclear accident. Chilton, NRPB-R299.

Nix J (2007). Farm management pocketbook 37th edition. Ashford, Wye College Press.

Nix J (2004). Farm management pocketbook 34th edition. Ashford, Wye College Press.

Shaw S, Green N, Hammond DJB and Woodman RFM (2001). Management options for food production systems affected by a nuclear accident. Task 1: Radionuclide behaviour during composting. Chilton, NRPB-R328.

Slater RA, Frederickson J and Gilbert EJ (2001). The state of composting 1999: Results of the Composting Association's survey of UK composting facilities and collection systems in 1999. The Composting Association, Wellingborough, UK.

Southern Water (2006). Trade effluent charges 2006/2007. Worthing.

Spindura J (2006). Food Standards Agency personal communication.

TSO (2002). A report on the concept, construction and effect of Ash Moor barrows at Meeth and Petrockstow, Devon, 2001. Ash Moor Joint Report September 2001. In Foot and Mouth Disease: Lessons to be Learned Inquiry. Report HC888 Annex A: Submissions. The Stationary Office, Norwich.

Wessex Water (2006). Trade effluent charges 2006/2007. Bath.

APPENDIX D A relationship between WTP and QALY measures

D1 INTRODUCTION

Following the discussion of Section 7.3 and the inherent difficulty of resolving the relationship between a WTP approach and the use of QALY measures it is appropriate to consider the approach of Jones-Lee et al (2007). On grounds of equity, neither the VPF of the DfT nor the QALY of NICE is age dependent*. However, as discussed in Jones-Lee et al (2007) both theory and empirical evidence suggests that the VPF, or strictly the dominant WTP component, will be a decreasing function of age for those of middle age and above and an increasing function of income†.

The VPF and QALY conventions cannot be easily reconciled by, for example, assuming that the value of a life year (VOLY) for an individual is given by the VPF divided by the remaining life expectancy. A VOLY calculated in this simple way for a constant VPF for someone with eight years of remaining life expectancy, will be five times as large as the VOLY for someone with forty years of life expectancy. 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 with eight years of life expectancy is one fifth of the VPF for a forty year-old.

To resolve these difficulties the approach and assumptions of Jones-Lee et al (2007) has been followed. Thus although not empirically demonstrated it is assumed 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. Considering an extension of life expectancy by a day to have no value, the assumptions are met by an expression with the simple functional form shown in Equation D.1 where D represents the number of days of extra life expectancy.

* A QALY of 1 should be interpreted as living at full health as appropriate for the age of the subject for a year. However, QALYs for subjects at different ages have the same weight, ie, the Value of a Life Year (VOLY) is constant.

† For young adults survey evidence suggests that WTP for a reduction in the risk of death is again less than for those of middle age. Although immediately interpretable with simplistic psychology that assumes that the young discount the benefits of a long life in comparison to immediate benefits, it does imply, absurdly, that a year of extra life can have negative value, see Jones-Lee et al (2007).

$$WTP = \alpha D^{\beta} \text{ where } D > 1, \alpha > 0 \text{ and } 0 < \beta < 1 \qquad (D.1)$$

From Table 11 the WTP valuation of VPF is approximately £1.4m and the average prevented road fatality would entail about 40 years (14610 days) of extra life expectancy, so that $\alpha.14610^{\beta}$ should equal approximately £1.4m. If additionally it is assumed 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 then (starting from the 40 year value), the results of Table D1 follow for a range of increases in life expectancies, ε.

Table D1 WTP for an increase in life expectancy of ε

ε, years	WTP, £
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

Jones-Lee et al (2007) reports that setting α = 675 and β = 0.80 gives a non-linear relationship which is well represented by the above linear approximation for $\varepsilon > 10$. These values of α and β give the best fit to the figures above and generate the (rounded) numbers shown in Table D2.

The right-hand column of Table D2 the 'VOLY equivalent' is calculated for the purposes of that table by taking the difference between the WTPs for any two entries and dividing that figure by the difference in the remaining life expectancy. So, for example, the difference between the WTP for those with ε = 40 years (that is, £1,450,000) and the WTP for those with ε = 30 years (that is, £1,150,000) is £300,000, and that figure, if divided by the 10 years difference in remaining life expectancy, generates a VOLY of £30,000.

The functional form is such that the VOLY rises as ε 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 WTP for ε = 1 and the WTP for ε = 2. In Table D2, the relevant figure, shown in the right-hand column, is the difference between £132,000 and £76,000, ie, 56,000. The difference between the WTP for two months and the WTP for one month is £7,700 for that extra month, which when multiplied by 12 (and rounded) gives 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 D2 WTP and implied VOLY for various levels of remaining life expectancy

ε (years unless otherwise stated)	WTP (£)	VOLY equivalent (average implied by difference between successive WTPs)* (£)
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 (ie, D in days or ε in years), rather than age and for general convenience the results derived for the VOLY (and the underlying WTP from which the VOLY is derived) could be re-expressed as functions of age. The variation in life expectancy with age is shown graphically in Jones-Lee et al (2007). However, for application in COCO-2, life expectancy is acceptable as epidemiological models of cancer induction estimate the number of years of life lost through cancer.

Before calculating the cost of fatal health effects from this approach it is worth noting that Jones-Lee et al (2007) refer to the VPF in the corresponding discussion and not the WTP. As the uncertainties in the relationship and valuation are large, and the WTP term is by far the dominant contribution, this is unlikely to make a significant difference. However, it is thought important not to loose sight of the other contributory terms.

In COCO-2, the discounted cost of fatal health effects HF_c is given in the main text by Equation 10.3, which on substituting for the WTP gives equation D.2.

$$HFc = \sum_n \frac{(\alpha\varepsilon_n^{\beta} + NetOutput_n + Medical_n)}{(1+r)^{l_n}} \qquad \text{(D.2)}$$

Where the sum is over all n that die, with I_n representing the delay in years between the accident occurring and the death of each of the n individuals where r is the pure discount rate of 1.5%.

Strictly, a term accounting for QALY loss during morbidity should be included. This is not considered for fatal outcomes, as the VOLY cost will dominate health costs when the outcome is fatal. However, when patients recover any ongoing QALY reduction is, in many cases unlikely to be a dominant factor. This is clearly dependent on the health effects experienced for example the most likely potential health effects occurring sometime after an accident are cancers*. Any ongoing health impairment following treatment for cancer will depend on the cancer and the treatment regime, for example, after treatment for thyroid cancer, some patients may require the thyroxine hormone for the remainder of their life but as this is administered in tablet form, it is unlikely to be a major detriment. However, in some cases there will be a more significant detriment, eg, when surgery for lung cancer has reduced lung function or a patient has been given a colostomy following colon cancer, etc. Unfortunately, to arrive at an appropriate valuation it would be necessary to know the proportion of patients undergoing particular treatments and the likely prognosis and end state having received this treatment. As previously discussed, this information is not currently available in a suitable form.

The health cost of morbidity HM_C is therefore estimated using Equation 10.4 (reproduced here as Equation D.3) with a VOLY valuation of £30,000 for a life year at full health and the QALY term indicating how many VOLY equivalents have been lost†:

$$HMc = \sum_{n=1}^{n=N} \frac{((1 - QALY_n) \times VOLY \times T_n + NetOutput_n + Medical_n)}{(1+r)^{l_n}} \qquad \text{(D.3)}$$

The health status of a patient undergoing cancer treatment is clearly larger than zero and as the patient is likely to recover within a few years with no assumed ongoing problems a QALY of 0.5 is adopted as the characteristic health state during the illness. This value is consistent with the estimate of Stouthard et al (2000) for the diagnosis and primary therapy phase of colorectal cancer.

As noted by Jones-Lee et al (2007) there is no guarantee that the amounts derived by this approach will match those from a direct elicitation, but equally there is doubt over the reliability of responses to WTP / WTA questions (Olsen et al, 2004).

D2 REFERENCES

Jones-Lee M, Loomes G and Spackman M (2007). Human Costs of a Nuclear Accident. HSE. http://www.hse.gov.uk/economics/research/humancost.pdf.

Olsen JA, Donaldson C and Pereira J (2004). The insensitivity of ‘willingness-to-pay’ to the size of the good: New evidence for health care. *J Economic Psychology*, **25**, 445-460.

Stouthard MEA, Essink-Bot M-L and Bonsel GJ (2000). Disability weights for diseases A modified protocol and results for a Western European region. *Euro J Public Health*, **10**(1), 24-30.

*For severe accidents, members of the public may be exposed to sufficient radiation to cause deterministic effects, which for those that survive may impose ongoing care requirements and a long-term reduction in their quality of life.

† Note the VOLY and other costs are not discounted over the period of treatment as the preference is for them to be incurred over as short a period as possible.

APPENDIX E Model Application Considerations

E1 INTRODUCTION

Any model implementing the COCO-2 methodology will expect to receive a number of inputs, generated for example by an Accident Consequence assessment (ACA) code. The ACA model will predict the physical consequences of an accident and this appendix discusses points that should be borne in mind when deriving accident specific data for use in COCO-2.

As stated in Section 8 COCO-2 needs to be supplied with information on the area, people and production affected. This can be achieved by mapping the introduced countermeasure zones to identify the people and type of production directly affected by the accidental release and countermeasure response. The simplest way of viewing countermeasures, from an economic perspective, is as tasks that do not generate a value added contribution to the economy but instead attempt to restore the economy to its previous state. Countermeasures may on occasion restore the economy to a new state and particular care must be exercised in determining the costs in this case.

COCO-2 is not concerned with the details of any accident consequence modelling except in as far as it will affect the estimated losses. For example, beyond the emergency phase, decontamination procedures may be introduced to restore affected areas and the loss of GVA in such an area is assumed proportional to the restoration time. Thus, although COCO-2 does not try to estimate the resources available for such work, which is regarded as a modelling input, it will have a major effect on the cost.

E2 TRANSIENT EFFECTS

The cost to the economy of advising people to shelter will depend on the area affected. Short periods of sheltering in residential areas can probably occur at negligible cost. However, small businesses will be adversely affected and industrial and commercial areas may experience more economically significant effects. The main effect on small businesses is likely to be caused by delaying production and deferring sales until restrictions are lifted. It may be postulated that the loss to local businesses will be small if no additional countermeasure actions are taken and people are therefore able to move around freely after some hours.

As previously stated in the main text, within the conceptual model of COCO-2, the effects of sheltering are modelled by assuming that businesses stop working for the day that sheltering is in force. If sheltering were to last into a second day, it is assumed that output is lost for the whole of that day. This overestimates the consequences as some businesses will be able to carry on production, eg, office related activities that do not have a particular need for ventilation will not be seriously affected. However, some factories and all shops will be affected and although shops could be expected to make up most lost trade the following day, their annual income is likely to fall as they will have had staff and other running costs that will not be recouped.

The more disruptive countermeasure of short-term evacuation may be introduced as an alternative to, or following on from, a period of sheltering in certain sectors. This may then be subsequently extended, for example to allow for monitoring to take place before people return to their homes. It may be expected that under such circumstances those affected would be put up in local hotels. However, if the accident were large or affected a densely populated area it may be impractical to assume that this could occur in a short period of time as thousands of bed spaces would be required that were not too far from the homes the people had left and were expected to return to shortly. The procedure may therefore be staggered, effectively increasing the time some areas will remain restricted and the consequent costs that will be incurred.

The economic effects of short-term countermeasures are likely to be more influenced by the time of day the accident occurs than will be the case for their longer-term counterparts. Information from the National Population Database (NPD) developed for the HSE (HSE, 2005) has been made available for COCO-2 by HSL, see Section 11 and Appendix B. This database in conjunction with other information can be used to provide the numbers and ages of those most likely to be directly affected by an accident at different times of day or year, eg, during term time when children are likely to be in school. This information is approximate and averaged. However, it will give a much more realistic assessment of the numbers likely to be directly affected by a daytime release than the use of the midnight census count. The use of these data will require that the parameters used in the economic model do not assume data features that are only consistent with Census data representing the distribution of the nighttime population. It also implies that the model should have sufficient resolution to differentiate between accidents occurring at night and during the day. The significance of accident timing is likely to depend on the size and duration of the release. Differentiation between accidents that occur during the day and those at night already occurs to some extent because particular weather conditions are more prevalent at night than during the day. However, as well as being more consistent on this topic it may also be important to distinguish conditions that might occur when people are travelling to or from work and thereby take advantage of the information in the HSL database on transport. The specific difficulties of an accident during morning or evening commuting times has not been considered in developing COCO-2 as this is not central to the aims of COCO-2.

One confounding factor that could affect the availability of beds for an evacuated population would be the intense media interest likely to occur in the aftermath of an accident. Even without evacuation the intense media interest that is likely to arise following an accident, in what could be a predominately rural area, would provide a short-term stimulus to the hotel trade before the negative effects of the accident then took hold with a potential reduction in tourist numbers to the area. Similar economic benefits may arise following recovery work although in both cases the local blip in spending is generally a transfer of spending that would otherwise occur elsewhere in the country. COCO-2 is not a dynamic model and therefore misses transient effects, which are assumed to be washed out when averaged over time and the whole country.

E2.1 Evacuation accommodation cost

The cost of accommodating those evacuated is considered in Section 8.3.2. To calculate the cost of the accommodation Census information can be used to find the number of people living in the evacuation zone and the number of houses evacuated. This may be very different from the number evacuated from the zone, as employees of local companies and visitors will probably be able to return to their own homes outside the evacuation zone from the reception centre. Generally, the daytime population may be evacuated but the nighttime population would require accommodation.

In COCO-2 the cost of accommodating those evacuated is estimated as the Imputed rental value of housing per day times the number of days that the houses are vacated, where the imputed rent is a function of the house price. Various methods have been used to calculate the imputed rent (IR) for example, Guðnason, (2003) proposed the formula of Equation E.1:

$$IR = P_H \left[\frac{r}{1-(1+r)^{-N}} \right] \quad \text{(E.1)}$$

where P_H is the house price, r the real interest rate and N is the lifetime of the property. The lifetime of property is difficult to estimate but Guðnason (2003) used a depreciation rate of 1.5% for buildings or approximately 1.25% of the total price as the value of land is not easily separated out. This gives an effective lifetime of 67 years and with an average real interest rate of approximately 4% the imputed daily rent can be estimated as: 1.2×10^{-4} P_H. This value is in good agreement with the number given in the main text.

E3 LONG-TERM COSTS

The population of an area might undergo temporary relocation if it was thought appropriate to remove people while decontamination work went ahead. This could consist of extended evacuation where the population are kept out of the area following evacuation until decontamination work has been completed or alternatively allowing people to return (if they were evacuated in the first place) at the end of the emergency phase and then removing them to allow decontamination work to proceed. The variety of possible relocation scenarios are not of direct interest to COCO-2 except to the extent that they need to be accommodated by the model framework, eg, the costs of transporting people given in Section 8.3.1 can be adapted to fit any appropriate scenario.

It is assumed in general that business will resume when all areas are appropriately decontaminated. However, there are likely to be two exceptions to this rule. Firstly, if a very large area is being remediated it may be expected that if resources were not available to decontaminate it all quickly it would be zoned and areas would then be brought back into use sequentially. Secondly, particular industries, because of the complex nature of the plant in use, could take very much longer to decontaminate than surrounding sites. If suitable reassurances can be made about resuspended radioactivity and direct irradiation from these facilities, then it is reasonable to assume that they could continue to be out of action for a period while the rest of the area resumes normal operations. These distinctions do not affect the COCO-2 methodology, but they should be considered when the methodology is implemented as part of a software application.

E4 RESTORATION TIME

It can be envisaged that the ACA code will provide information on the extent of areas of each particular type that require one or more decontamination techniques to be applied. The UK Recovery Handbook (HPA-RPD, 2005) and related publications provide cost estimates for the application of particular techniques, and the work rate of each team employed to carry out the procedures. The effectiveness of these procedures is also available and the effect on doses of applying the techniques can therefore be calculated. What remains to be determined is how many teams are likely to be committed to the application of any particular technique. The assumption within the UK Recovery Handbook (HPA-RPD, 2005) is that, although some techniques are appropriate for large contiguous spaces while others are more appropriate for small plots, the costs of applying each technique vary linearly and scale as the number of teams employed increases. The time taken is also assumed to fall in proportion to the number of teams employed. Thus, without further constraints, the approach would be to employ as many teams as possible, as the cost of applying the decontamination procedures would be the same but the area would be restored much more quickly. Unfortunately, this makes it impossible to work out the economic consequences of an accident, which are critically dependant on the length of time industry and business are out of action.

To provide additional insight on how long an area might be out of action information on past disasters has been reviewed. The type of nuclear accidents under consideration by COCO-2 have not affected a modern market economy and it would be unsafe to draw inferences from the Chernobyl accident, the aftermath of which was yet another contributory factor in the collapse of the planned economy of the USSR. Similarly, the accident at Three Mile Island, although resulting in the loss of the reactor, had only a very limited release of radioactivity, which did not require decontamination to be considered. Although not an airborne release from a reactor, the accident at Goiania did result in an extensive clean up operation being undertaken to remove caesium, which is likely to be a major contributor to any long-term problem following a reactor accident (IAEA, 1988). The event became known at the end of September 1987 with major decontamination work beginning in mid-November and ending shortly before Christmas. This phase of the work employed 550 workers and 12 hour shifts sometimes in adverse weather conditions to ensure that work in the affected area of approximately 1 km^2 was completed on schedule. After this intense effort decontamination work continued at a lower level in peripheral areas until March 1988.

Other disasters are generally of a very distinct nature and cause considerable physical damage, which necessarily takes time to repair. The most similar and potentially appropriate in terms of a need to decontaminate but not repair is the Seveso accident (the Bhopal accident, which was much more serious, is not applicable because of the difficulty of drawing inferences from India). Unfortunately, although within the EU where economic inferences are likely to be more easily transferable to the UK economy, only a small area of open land was decontaminated. Further, the decontamination work that did occur took a considerable time to organise and resulted in a political scandal when 41 barrels of dioxin-contaminated waste from Seveso were discovered dumped in an unused abattoir in Anguilcourt-le-Sart, a village in northern France[*].

The principal distinguishing factors between conventional accidents and a nuclear accident are the role of insurance and the recruitment of the restoration workers. For example, following a flood, a business might well contact a company to do the repairs after a loss adjustor or surveyor has inspected the premises. Generally, the cost of restoring business premises following radioactive contamination is unlikely to be covered by insurance although there may, exceptionally, be some payments on other grounds such as compensation for loss of business. Similar or less support may be available in the household insurance sector. There is also no provision in UK emergency planning for the Local Authority to let the contracts for the clean-up of premises. Thus, assuming a source of funds can be drawn on and that the Local Authority through the advice that it receives can support businesses and private individuals in the selection of appropriately skilled contractors to do the work, the remaining restrictions on rapid cleanup are likely to be the limited number of companies with the skills required to do remediation work and the need for a number of different Government Departments/regulators to be satisfied that the work meets relevant regulations and criteria. There may be additional delays if staff from an affected company were required to oversee operations for health and safety or security reasons. Finally, companies may want to have their own monitoring carried out to decide if it is appropriate to resume operations and as part of their duty of care to their employees and the public.

The consequence of the above discussion is that no clear advice can be given on the length of time decontamination procedures are likely to take. Before such advice could be developed, the experience of the work force would need to be matched to the techniques employed and the likely radiation levels. If experienced radiation workers were not required and the work could be carried out by council employees or contractors it is likely to be able to proceed quickly provided the workforce were fully aware of and accepting of the risks. It is recommended (see Section 13) that further work is done in this area to extend the information held by the UK Recovery Handbook (HPA-RPD, 2005) into a set of rules that take account of the likely capacity to undertake particular tasks of councils, specialist contractors and the military. This information may then be used to provide estimated time scales for various combinations of decontamination techniques. This could be used directly as expert estimations or, when COCO-2 is used as part of a PRA assessment, included as part of the probabilistic analysis[†].

[*] http://www.roche.com (Seveso - 30 Years After A chronology of events)

[†] PRA models normally only consider weather sequences probabilistically.

E5 REFERENCES

Guðnason R (2003). Owner Occupied Housing: Market Price Approach to User Cost. Statistical Commission and United Nations Economic Commission for Europe (UNECE), International Labour Organisation (ILO). Conference of European Statisticians, Joint UNECE/ILO Meeting On Consumer Price Indices, Geneva, 4-5 December.

HPA-RPD (2005). UK Recovery Handbook for Radiation Incidents: 2005. Chilton, HPA-RPD-002.

HSE (2005). A National Population Database for Major Accident Hazard Modelling, Report 297. http://www.hse.gov.uk/research/rrhtm/index.htm.

IAEA (1988). The radiological accident in Goiania. VIENNA, STI/PUB/815. ISBN 92-0-129088-8.

APPENDIX F Additional features of the example calculation

This appendix highlights some additional aspects of the example calculation discussed in Section 12. There are two main sources of cost, agriculture and health, which are discussed in turn. However, to set the scene Table F1 provides some background information on the area and number of people assumed to be affected by the emergency and recovery countermeasures applied.

TABLE F1 Background Information on the inhabited area affected

Property	Value
Number of people sheltered	9,803
Area of Zone A sq km (population away for 7 days)[1]	4.28
Area of Zone B sq km (population away for 1 month)[2]	0.37
No of people temporarily relocated from Zone A	7,112
No of people temporarily relocated from Zone B	505

[1]Techniques applied in Zone A fire hosing, vacuum sweeping and grass cutting

[2]Techniques applied in Zone B high pressure hosing and turf removal

F1 AGRICULTURE

The modelling of agricultural losses using the methodology described in this report (see Sections 6, 9 and Appendix C) although based on an approach that is broadly similar to that applied in COCO-1 is considerably more detailed and includes indirect effects, which were not previously considered in COCO-1. This permits a more realistic estimate of the losses in the agricultural sector to be made without greatly increasing the data requirements. The consequent increase in the reliability of the loss estimate likely to be afforded by the COCO-2 approach is an important consideration as nuclear sites are generally in predominately rural areas where agriculture is likely to be the most affected economic sector. The more realistic modelling of agricultural losses does however raise new issues as shown by the examples below.

F2 EFFECTIVE MULTIPLIERS

Many of the costs associated with the scenario discussed in Section 12 have both direct and indirect contributions. Table F2 illustrates the relative importance of the two types of cost. The ratio between them (the effective multiplier) illustrates how the local and temporal modelling used in COCO-2 has effectively modified the multipliers of Table 17. The effective business multiplier is a weighted average of the multipliers of Table 17 that takes into account the mix of industries present within the affected areas. The multipliers for the different industries range from 1.41 to 2.14. However, for agriculture the effective multiplier arises from a single multiplier 1.91, modified by the variation in seasonal cost commitments in the production processes and weighted to take into account agricultural practices within the affected areas.

TABLE F2 Direct and Indirect COCO-2 costs

Loss	Direct £000	Indirect £000	Effective multiplier[1]
Business	1,866	1,281	1.69
Tourism	139	88	1.63
Agriculture	142,965	108,426	1.76

[1]The ratio of (Direct + Indirect) costs to Direct costs. This is a function of the local mix of industries and of local agricultural practice, corrected for seasonal effects.

Table F2 illustrates the importance of agricultural seasonal corrections to the agricultural multiplier used in the estimate of the indirect contribution. The interplay between seasonal effects acting on the direct and indirect costs is complex but if the model had failed to consider them (ie, omitting even the annual average correction factors of Appendix C) then naively the indirect effect might be 15% larger, ie, a sum greater than the total inhabited area costs of Table 26.

It is unfortunate that there is currently only a single multiplier available for agriculture. The use of a single agricultural multiplier is likely to distort the result of the calculation as different farm production systems, eg, beef; dairy or arable are unlikely to have the same multiplier effect on the economy. In addition, the definition of the multiplier includes the effect of activities other than farming. Establishing improved agricultural multipliers is raised as an area for future work in Section 13.2

F3 HEALTH COSTS

From an epidemiological perspective, health costs should be based on the consequences for each ‘individual’, ie, the expected result if a cohort of identical people were exposed to an identical pattern of dose. Such a calculation is impractical but indicative calculations may be carried out to establish costs for particular groups if the use of the generic cancer costs of Section 10.5 were not thought adequate. Particular examples where the use of more detailed calculations may be justified are, if the exposed group had a particular age distribution, or were subject to relatively high doses in the nonlinear dose response regime or if a more complex age dependent costing such as discussed in Appendix D were thought appropriate. Although such a calculation would not present particular difficulties it would have the disadvantage of more or less tightly coupling the doses received by the population, the age profile of the population, the way the cost attenuates with the elapsed time before the on set of the illness and the age of those affected when they become ill. The two obvious ways of handling this problem would be to have either this particular cost calculation at an earlier stage of PRA modelling or to repeat part the health effects calculation within the COCO-2 module purely for the generation of health costs. If, for example, it were anticipated that the flexibility of being able to use a more complex cost model such as that discussed in Appendix D were desirable it would be appropriate to consider carefully the advantages and disadvantages of different design options when implementing COCO-2 within a PRA model.

To give an approximate example of the complexity that might ensue from calculating health costs directly from the doses received consider an alternative evaluation of the health costs for the example scenario of Section 12. This rough and ready calculation has the advantage of providing illustrative health effect costs that are likely to be more broadly consistent with estimated agricultural and inhabited area costs of Section 12.5 by avoiding any artefacts introduced through the mixing of regular and polar grids.

In this example, ingestion is the dominant dose pathway and as food produced at a particular location is likely to be widely distributed throughout the country a collective dose calculation that makes use of the cost of cancer estimates of Section 10.5 is likely to be both the simplest and most robust approach. PC Cosyma (Jones et al, 1996) calculates the collective dose from ingestion from the amount of activity deposited in each grid element, the concentration of radioactive material in foods from unit deposition, the amount of food produced for human consumption in each grid element, and the dose per unit activity ingested. Except for a possible allowance for wastage this calculation is based on the assumption that all food produced in the area of interest is consumed somewhere; the collective dose is independent of where the food is consumed. Nominal individual food doses within PC Cosyma are calculated on the assumption that all food is produced at the point of consumption. The deposition density is multiplied by the concentration in food per unit deposition, the individual consumption rate and the dose per unit intake. PC Cosyma states that the assumption that all food is produced at the point of consumption will lead to reasonable predictions for individual doses at large distances from the site, where it is likely to be true on average. However, it is unlikely to be true close to the site, and these doses calculated by PC COSYMA are likely to over-estimate the true dose due to food being sourced from around the country.

For those under the plume the population weighted nominal organ doses as a function of time from all exposure pathways, taking into consideration all the applied countermeasures, were calculated*. The temporal behaviour of this nominal dose over 50 years was used to select the appropriate cancer costs used in Section 12.6.3 where the conservative assumption was made that all of the dose was received in the first year. It was also noted that all the doses received were within the low dose regime where a linear dose response is assumed and only one population needs to be assessed. However, as noted, if there are any groups for which this is not true, the costs of Section 10.5 could not be used and consideration should be given to splitting the analysis into separate subgroups. In the example of Section 12, the vast majority of the doses received are from food and the predicted individual doses will overestimate the doses likely to be received by those under the plume, as the food grown in the area and

* PC Cosyma only calculates adult doses and these were used for all age groups in the population.

not subject to restrictions will be distributed throughout the country*. However, this dose can be used to estimate an upper bound on the likely cost of cancers in the UK with the assumption that sufficient food is grown with this level of contamination to meet everyone's needs.

Using the methodology of Section 10.5 the number of radiation induced fatal cancers expected in the years following the accident, and the reduced life expectancy of those that die in each exposed age cohort was estimated using the nominal colon and bone marrow doses†. The epidemiological calculation was applied separately to each 5 year age cohort to allow the loss of life expectancy to be estimated and appropriately costed. The health cost results are displayed graphically as a function of age at exposure in Figure F1 and the costs of cancer deaths shown Table F.3. The basic procedure was then repeated to provide estimates of the cost of cancer incidence, which are shown in Figure F2 and Table F.4.

TABLE F.3 Cancer deaths

	Number of fatalities[1]	Expected life lost (years)	Expected delay[2]	Cost £m				
				COCO-1[3]	COCO-1[4]	COCO-1[5]	COCO-1[6]	COCO-2
All solid cancers	1014.1	14.9	42.6	55.0	93.0	320.9	411.5	768.6
Leukaemia	73.1	22.2	28.4	8.3	14.4	34.1	43.7	68.0
Total	1087.2	-	-	63.3	107.4	355	455.2	838.6

[1]UK 2004 population (59,845,800) from ONS multiplied by the proportion of the population likely to experience a radiation induced fatality over their lifetime, using UNSCEAR (2008).

[2]The delay before a fatality after the initiating event is weighted by the number of deaths per cohort.

[3]This human capital estimate based on Equations 16 and 18 of the COCO-1 report has not been revalorised.

[4]This human capital estimate based on Equations 16 and 18 of the COCO-1 report revalorised using the COCO-2 cost of treatment and a GDP deflator to increase the estimated average earnings

[5]This subjective estimate based on Equation 15 of the COCO-1 report has not been revalorised

[6]This subjective estimate based on Equation 15 of the COCO-1 report revalorised to use the COCO-2 WTP valuation and treatment costs together with the COCO-1 3% adjusted discount rate.

The cost spike displayed in Figure F2 for leukaemia due to exposure in early childhood assumes a loss of net output during a period of illness, which as shown in Table F.4, may occur in later childhood. In this case, although not attributable to the child, it is reasonable to assume an equivalent loss of parental output during the period of illness.

Although Table F.4 provides an estimate of the number of people that get cancer but eventually recover, the cost of cancer incidence quoted includes the costs incurred during the initial period of treatment of those that eventually die. This is a reasonable cost to include but is also present on grounds of tractability. The variable time delay

* Note settlements are in valleys, near river crossings, etc, and not in wilderness areas remote from agriculture. Thus, for a large-scale event, estimating the concentration of radioactivity in locally grown food where the people are will be broadly similar to estimating it where the food is grown.

† For minor technical reasons PC Cosyma used an approximation of the 2001 census population to estimate the numbers exposed in each sector and distance band although the age distribution used in the epidemiological model was representative of 2003.

between getting cancer and subsequently dying prevents any simple relationship being established between the number of patients being treated in any incidence cohort and the number dying in the corresponding fatal cancer cohort.

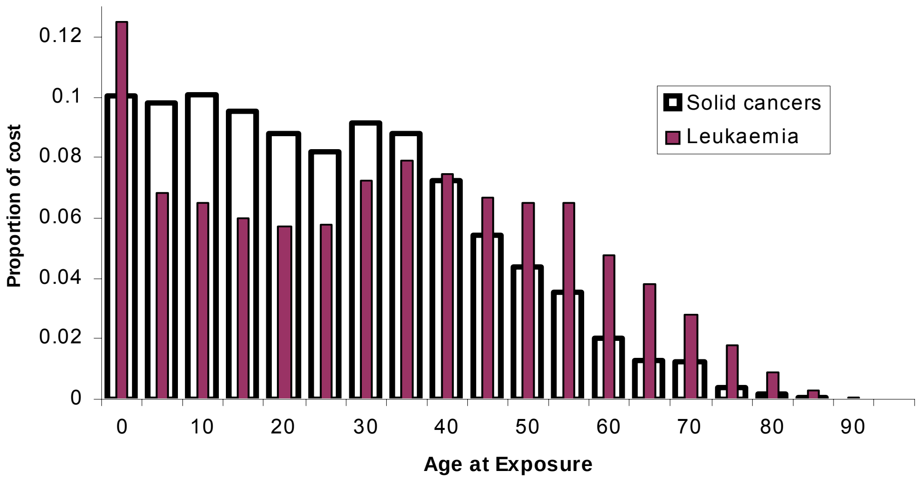

Figure F1 Proportion of cost per age group for all solid cancers and leukaemia respectively

TABLE F.4 Cancer incidence

	Number non-fatally affected[1]	COCO-2 treatment period years	Expected delay[2]	Cost £m				
				COCO-1[3]	COCO-1[4]	COCO-1[5]	COCO-1[6]	COCO-2
All solid cancers	2030.9	5	37.6	41.9	82.0	73.3	115.9	124.3
Leukaemia	108.4	5	19.2	3.7	7.3	6.5	10.3	8.7
Total	2139.3	5	-	45.6	89.3	79.8	126.2	133

[1]UK 2004 population (59,845,800) from ONS multiplied by the proportion of the population likely to experience a radiation induced cancer over their lifetime using UNSCEAR (2008).

[2]The delay before the onset of illness after the initiating event is weighted by the number of instances per cohort including those that do not recover.

[3]This human capital estimate based on Equations 16 and 18 of the COCO-1 report has not been revalorised.

[4]This human capital estimate based on Equations 16 and 18 of the COCO-1 report revalorised using the COCO-2 cost of treatment and a GDP deflator to increase the estimated average earnings

[5]This subjective estimate based on Equation 15 of the COCO-1 report has not been revalorised

[6]This subjective estimate based on Equation 15 of the COCO-1 report revalorised to use the COCO-2 VOLY valuation and treatment costs together with the COCO-1 3% adjusted discount rate.

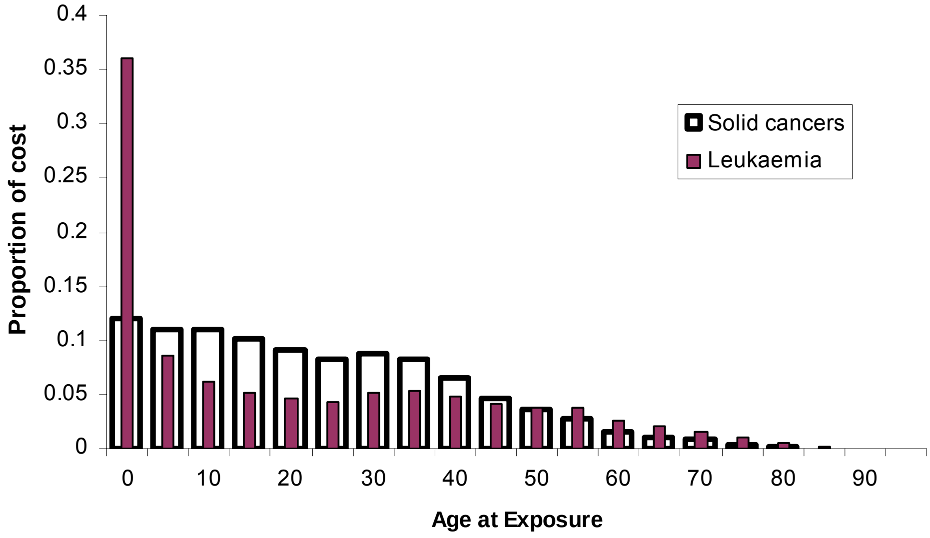

Figure F2 Proportion of cost per age group for morbidity arising from all solid cancers and leukaemia respectively.

Combining the results of Tables F.3 and F.4 gives an upper bound for the COCO-2 cost of cancers for the particular example accident of Section 12 of approximately £ 970 m.

F4 REFERENCES

Jones JA, Mansfield PA, Haywood SM, Hasemann I, Steinhauer C, Ehrhardt J and Faude D (1996). PC Cosyma (Version 2): An accident consequence assessment package for use on a PC. European Commission, EUR 16239.

ONS (2004). Office for National Statistics. Mortality Statistics Cause. Review of the Registrar General on Deaths by Cause, Sex and Age, in England and Wales, 2003. Series DH2 no 30. Stationery Office, London, 2004.

UNSCEAR (2008). United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). *Effects of Ionizing Radiation*. UNSCEAR 2006 Report to the General Assembly, with scientific annexes. New York, United Nations (in press).

APPENDIX G Glossary

ABI1	The Annual Business Inquiry type1 is a business survey of numbers of people employed.
ABI2	The Annual Business Inquiry type 2 is a business survey of accounting data.
Analytical Tables	Also known as Derived Tables, Symmetric Input-Output Tables, or Input-Output Tables, and are derived from I-O Supply and Use Tables. The Analytical Tables represent the theoretical side of I-O work. They are produced by ONS approximately every five years, most recently for the year 1995. Data that are more recent have been produced for Scotland by the Office of the Chief Economic Advisor. These tables include the Imports Use and Domestic Use matrices, industry-by-industry and product-by-product matrices plus the Leontief inverse, multipliers and other analyses of their structure.
Annual Business Inquiry	This is an annual ONS survey of businesses covering employment and financial information such as turnover, gross fixed capital formation, inventories, purchases of goods and services, taxes and subsidies, and employment costs.
Backward linked indirect loss	Damage to production facilities reduces their demand for inputs from other producers.
Basic price (bp)	This price is the preferred method of valuing output and value added. This reflects the amount received by the producer for a unit of goods or services excluding any taxes on products and including any subsidies on products. This price includes only taxes on production (for example, business rates) and excludes any subsidies on production (for example, agricultural set-aside). It excludes any transport charges invoiced separately by the producer.
Blue Book	The common name for the annual UK National Accounts: it has a blue cover in the shops.
Capital goods	These are goods, other than material inputs and fuel, used for the production of other goods and/or services. They include factory buildings, machinery, locomotives, lorries and tractors. Land is not usually regarded as a capital good.
Capital service price	The capital service price is the unit cost for the use of a capital asset for one period that is, the price for employing or obtaining one unit of capital services. The service price is also referred to as the "rental price" of a capital good, or the "user cost of capital".
Capital services	Capital services are the productive inputs, per period, that flow to production from a capital asset. The value of capital services is the quantity of services provided by the asset multiplied by the price of those services.
Capture rate	The percentage of spending that accrues to the region's economy as direct sales or final demand. Tourist spending on services within the region is captured; however, tourist purchases of goods are generally not all treated as final demand to the region. For imported goods bought at retail establishments, typically only the retail (and possibly wholesale) margins will accrue to the local economy.
CBA	See cost benefit analysis.
CEA	See cost effectiveness analysis
Chained volume measure (CVM)	The terminology used to refer to the volume data obtained via chain linking.
Chain-linking	Technique now adopted by the ONS to construct volume data. Under previous methods, volume data was constructed by measuring activity in the price of a specific year (the price reference base) that was updated about every five years. Under chain linking the price reference base is updated annually. The technique better reflects changing patterns of output and expenditure.
Classification of individual consumption by purpose (COICOP)	This is a classification used to identify the objectives of both individual consumption expenditure and actual individual consumption.
Combined Use matrix	Each column in the matrix analyses, by product group, the inputs of a particular industry group or sector of final demand, whether from domestic production or imported. It shows the inputs used by each industry to produce their total output, separating intermediate consumption of goods and services from its primary inputs. The intermediate consumption and final demand estimates by type of product in this matrix are valued at purchasers' prices.
Commodity	A transportable good that may be exchanged. It may be one of a run from a production line, a unique item (Mona Lisa) or the material medium for a service (software diskette). This is the concept used for customs classifications.

Compensation of employees (CoE)	This is the total remuneration, in cash or kind, payable by enterprises to employees for work done. This covers all wages and salaries including certain forms of payments made-in-kind and the pay and allowances in cash and kind of HM Forces. It also includes payments by employers regarded as supplements to wages and salaries, such as contributions to the National Insurance Scheme, employers' contributions to other pension schemes together with redundancy payments and compensation payments covering, for example, injury. It excludes certain specific expenses of employment such as travel expenses or cost of special clothing needed exclusively for work.
Compensating variation	For a 'proposed welfare gain' due to provision of public good, the compensating variation refers to the amount of money income that has to be given up by the consumer to attain increased level of utility (ie, WTP measure).
Constant prices	A stock of assets is expressed at constant prices when all members of the stock are valued at the prices of a single base period.
Consumption of fixed capital	This is a measure of the amount of fixed capital assets used up in the process of production during the year resulting from physical deterioration, normal obsolescence or normal accidental damage. For the purposes of national accounts, capital consumption is valued on a current cost basis whereas company accounts usually record depreciation on a historical cost basis.
Contingent valuation	Determination of willingness to pay, through use of structured questionnaire in which respondents answer yes/no to suggested prices (dichotomous choice) or provide a willingness to pay number themselves (open ended).
Cost benefit analysis	A term used to describe an analysis which seeks to quantify in money terms as many of the costs and benefits of a proposal as possible, including items for which the market does not provide a satisfactory measure of economic value, ie, an analysis of all the welfare costs and benefits. However, the expression is sometimes confined to monetary costs and benefits alone.
Cost effectiveness analysis	A technique, which seeks to identify how to meet a particular objective at least cost. It enables prioritisation between options, but ultimately cannot assess whether an option is economically worthwhile.
Cost of variability in outcomes	This is the most a person is willing to pay to have a benefit that is certain, rather than one that is uncertain.
Costs	Section 56 of the Environment Act defines costs as including 'costs to any person and costs to the environment'. Costs include any environmental, human health or other social impacts, which are detrimental in nature, any capital and recurrent expenditure, administrative costs, monitoring and enforcement costs, and research and development costs.
Cultivated assets	These assets are livestock for breeding (including fish and poultry), dairy, etc, and vineyards, orchards and other plantations of trees yielding repeat products.
Current prices	A stock of assets is expressed at current prices when all members of the stock are valued at the prices of the year in question.
DALY	Disability-adjusted life years
Deflation	This is the technique used to change values from nominal terms (current prices) into real terms (constant prices or volume), expressing the production (or consumption) of goods and services in the prices of a common year.
Depreciation	See Consumption of fixed capital.
Derived tables	See Analytical Tables.
Diminishing marginal utility	The tendency as extra units of any commodity or service are used up or 'consumed', for the satisfaction provided by those extra units to decline.
Discount rate	The discount rate is an interest rate used to convert a future income stream to its present value.
Discounting	A method used to convert future costs or benefits to present values using a discount rate.
Domestic Use matrix (I-O Analytical Tables)	Each column in this matrix analyses by product group the purchases of domestically produced goods and services used up in the production process. This matrix separates the purchases of imported goods and services from intermediate purchases (as shown in the Combined Use matrix), and shows these imports as a separate row. The Domestic Use matrix is shown at basic prices.
Economic cost (or opportunity cost)	The value of the most valuable of alternative uses

Economic efficiency	Describes a situation where the total value of the end uses, to which the resources are put, is maximised. A consequence is that all resources will be put to their highest value uses.
Economic value	The monetary measure of the wellbeing associated with the change in the provision of some good. It is not to be confused with monetary value, unless the latter is explicitly designed to measure the change in wellbeing, nor with financial value, which may reflect market value or an accounting convention. As Freeman (1993) notes, the terms 'economic value' and 'welfare change' can be used interchangeably.
EQ-5D	A European quality of life questionnaire containing five physical and psychological dimensions
Equivalent variation	The equivalent variation refers to the amount of compensation required to be provided to the individual so that she could attain an improved utility level in case the provision of the public good does not take place (ie, WTA)
European System of Accounts 1995 (ESA 95)	The European System of National and Regional Accounts is the integrated system of economic accounts, which is the European version of the United Nations System of National Accounts 1993 (SNA 93).
Existence value	The value placed by people on the continued existence of an asset for the benefit of present or future generations. The latter is sometimes referred to as the bequest value. See also Use value.
Externality costs or benefits	The non-market impact of an intervention or activity which are not borne by those who generate them.
Final buyers	Expenditure by final buyers is comprised of HHFCe, NPISHs, general government, gross fixed capital formation, changes in inventories, valuables and exports of goods and services. Total demand by final buyers is the same as total final consumption expenditure.
Final Demand	The term for sales to final consumers, (households or government) Sales between industries are termed intermediate sales. Economic impact analysis generally estimates the regional economic impacts of final demand changes. Visitor spending is one type of final demand.
Final output	This is that part of total output of each industry sold either for final consumption by households, general government or for investment (including additions to inventories) and for export. In short, total output sold to final buyers. For the whole economy, total final output is equal to the value of goods and services (both domestically produced and imported) available for consumption, investment and export. Total final output is equal to total final consumption expenditure, which is the same as total demand by final buyers.
Financial Intermediation Services Indirectly Measured (FISIM)	This component of the National Accounts reflects the exclusion of interest payments from the measure of GDP, but their inclusion in the output of the financial services sector.
Fixed assets	Fixed assets are tangible or intangible assets produced as outputs from processes of production that are used repeatedly or continuously in other processes of production for more than one year.
Forward linked indirect loss	Direct damage to production facilities and to inventories cause shortages of inputs for firms needing supplies.
GDP deflator	An index of the general price level in the economy as a whole, measured by the ratio of gross domestic product (GDP) in nominal (ie, cash) terms to GDP at constant prices.
General government final consumption expenditure (GGFCe)	This is the final consumption expenditure by central government and local government including direct payment for goods and services and payment for the services of government employees. The figures exclude expenditure on grants, subsidies, interest payments and other transfers; expenditure on non-military fixed capital assets and inventories; loans and loan repayments. Expenditure on military weapons and equipment used to deliver them are included in this section and are not part of capital formation.
Geometric depreciation	Geometric depreciation is a depreciation profile based on a constant annual rate of capital consumption over the life of the asset.
Government Office Regions (GOR)	The English regions covered by the nine Government Offices, equivalent to NUTS1 regions and the domains of Regional Development Agencies (see NUTS, Region).
Gross	Key economic series can be shown as gross (before deduction of the consumption of fixed capital) or net (after deduction of the consumption of fixed capital). Gross has this meaning unless otherwise stated.
Gross capital formation	Gross capital formation is measured by the total value of the gross fixed capital formation, changes in inventories and acquisitions less disposals of valuables for a unit or sector.

Gross capital formation (GCF)	Gross capital formation consists of gross fixed capital formation plus changes in inventories and acquisitions less disposals of valuables. Net capital formation is estimated by deducting consumption of fixed capital from gross capital formation.
Gross domestic product at market prices (GDP mp)	This is a measure of the value of goods and services produced in the UK before providing for capital consumption. It is equal to gross value added at basic prices plus taxes (less subsidies) on products. Alternatively, it is equal to the sum of total final domestic consumption expenditures less imports of goods and services.
Gross fixed capital formation (GFCF)	This consists of resident producers' acquisitions less disposals on fixed (tangible and intangible) capital assets, for example, new buildings, vehicles, ships, aircraft and plant and machinery, either for replacing or adding to the stock of existing fixed assets. Expenditure on repairs and maintenance is excluded but improvements to land are included. The industry headings used in the I-O analyses of gross fixed capital formation are shown in Annex C.
Gross margin	The output of the distribution and service trades industries is measured on a gross margin basis. The purchases of goods for resale (without further processing) are deducted from turnover (excluding VAT) to give the gross margin earned which, after adjusting for changes in inventories of finished goods and work-in-progress and other coverage and valuation adjustments, represents total output at basic prices.
Gross profits and other trading income	This comprises the gross trading profits of companies, gross trading surplus of public corporations, self- employment income and rental income (excluding any rent earned from any land and sub-soil assets). These incomes are measured before providing for depreciation but after deducting holding gains.
Gross Value Added (GVA)	Gross Domestic Product excluding taxes (less subsidies) on products; the headline measure of regional economic activity
Gross value added at basic prices (GVA bp)	This is a measure of the contribution to GDP made by an individual producer, industry or sector. The gross value added generated by any unit engaged in production activity can be calculated as the residual of the units' total output less intermediate consumption, or as the sum of the factor incomes generated by the production process. Net value added is shown after deducting capital consumption.
Hedonic pricing	Deriving values by decomposing market prices into their constituent characteristics.
Household final consumption expenditure (HHFCe)	This is expenditure, including imputed expenditure, incurred by resident households on individual consumption of goods and services, including those not sold at economically significant prices. All business expenditure and interest payments are excluded.
Households	Households are individuals or small groups of individuals as consumers. Where the activities of entrepreneurs producing goods and market services cannot be separated, households are treated as a quasi corporation.
Human capital approach	Human skills and capabilities generated by investments in education and health. Investments of time, effort, and money spent on education, training or health that improves productivity is analogous to investment of financial capital. The human capital approach is a method of valuing lives gained in terms of the discounted productive capacity of the patients treated.
Industry (producer) technology (I-O Analytical Tables)	This is one of two types of technology assumptions used in converting I-O Supply and Use Tables into I-O Analytical (Symmetric) Tables. This assumes that all products produced by an industry are produced with the same input structure.
Industry by industry table (I-O Analytical Tables)	An industry by industry table is a Symmetric Input-Output Table with industries as the dimensions of both rows and columns. As a result, it shows which industry uses the output of which other industry.
Input-Output Annual Supply and Use Tables	These show a balanced and complete picture of the flows of goods and services in the economy for a specific year. These balances are composed of the Supply and "Combined Use" matrices produced each year as part of the annual national accounts compilation round. Total supply and demand for goods and services is valued at purchasers' prices.
Input-Output Supply and Use Tables	These provide a framework through which the three measures of GDP (production, income and expenditure) and their components can be fully reconciled. The tables are used to benchmark the annual level of UK GDP.
Input-Output Tables	See Analytical Tables.
Institutional sector	The economic accounts split the economy into institutional sectors according to their role in the economy. The main sectors are non-financial corporations (split between public and private), financial corporations (split between public and private), general government (split between local and central), households and non-profit institutions serving households (NPISHs). The rest of the world is also treated as a sector within the accounts.

Inter-Departmental Business Register (IDBR)	The IDBR is a register, maintained by the ONS, of all UK businesses (apart from some small self- employed businesses below the VAT threshold). The register is mainly generated from information on VAT registered businesses collected by HM Revenue and Customs and Pay As You Earn details also held by HM Revenue and Customs.
Intermediate consumption	This represents industries' purchases of goods and services to be used up in the production process (excluding any goods purchased for resale without any further processing), and adjusted for changes in inventories of materials and fuels. Intermediate consumption excludes fixed assets whose consumption is recorded as consumption of fixed capital.
Intermediate output	That part of the total output of each industry consumed by other industries in the production process.
International Passenger Survey (IPS)	A survey of passengers leaving and entering the UK
Inventories	Previously known as stocks, inventories consist of holdings of materials and fuels, work-in-progress, finished goods and goods bought for resale without any further processing.
Leontief inverse table (I-O Analytical Tables)	The columns of the Leontief inverse (I-O Table) show the input requirements, both direct and indirect, on all other producers that is generated by one unit of output.
Make matrix (I-O Analytical Tables)	Each column in this matrix analyses, by product group, the output of a particular industry. Each row analyses the output by industry group of a particular product group. The data relate to domestic output only and are valued at basic prices in both the I-O Analytical Tables and the I-O Annual Supply and Use Tables. In both cases, values are shown after deducting holding gains on inventories of finished goods and work-in-progress held by the industries concerned. The matrix is largely diagonal, and the off- diagonal entries are known as secondary products. As part of the process in compiling industry-by-industry or product-by-product tables, this matrix is transformed such that all the entries are on the diagonal.
Marginal utility	The increase in satisfaction gained by a consumer from a small increase in the consumption of a good or service.
Market output	This is output of goods and services produced by market or non-market producers and sold at economically significant prices.
Market prices	Those prices which purchasers pay for the goods and services they acquire or use, excluding deductible VAT. The term is usually used in the context of aggregates such as GDP, whereas purchasers' prices refer to the individual transactions.
Multiplier	The second round effects on the level of economic activity (output, income or employment) associated with a policy intervention (eg, where the employees of a new project spend their earnings and so increase consumer demand). Several types of multiplier (income, local, long run, short run and supply) are often estimated. The size of the multiplier depends on the period over which it is measured, and the geographical area considered.
NACE	General Industrial Classification of Economic Activities with the European Communities, the industrial classification adopted by countries in the EU
Net	The term net is a common means of referring to values after deducting consumption of fixed capital (for example, net capital stock or net domestic product).
Net Present Value (NPV)	This is the discounted value of a stream of either future costs or benefits. The term Net Present Value (NPV) is used to describe the difference between the present value of a stream of costs and a stream of benefits.
Net value added	See Gross value added.
Net worth	Net worth is the value of all the non-financial and financial assets owned by an institutional unit or sector less the value of all its outstanding liabilities; it is a measure of the wealth of a unit or sector at a point in time.
NOMIS (National Online Manpower Information System)	An on-line platform through which the ONS gives access to labour market statistics at national, regional and sub-regional levels
Non-market output	Output of own account production or goods and services provided free or at prices that are not economically significant. Non-market output is produced mainly by the government (central and local) and NPISH sectors.
Non-market producers	These are producers that provide most of their output to others free or at prices that are not economically significant.
NPISH	Non-profit institutions serving households include organisations such as charities, churches, trade unions and members' clubs.

NUTS (Nomenclature of Units for Territorial Statistics)	Standard classification adopted for the regions of the European Union. There are various levels of NUTS. NUTS 1 is the nine English Regions and Scotland, Wales and Northern Ireland.
Off-diagonals	See Secondary products and Make matrix.
One-hoss shay	A one-hoss shay is a colourful term taken from the poem, "The Deacon's Masterpiece", by Oliver Wendell Holmes (In nineteenth century American dialect, a "one hoss shay" is a cart drawn by a single horse.) "Shay" is a corruption of the French "chaise" or "post-chaise". The term is used to designate a capital asset that exhibits neither input decay nor output decay during its lifetime.
Operating surplus (or deficit)	This measures the surplus or deficit accruing from production before taking into account any transfer payments or receipts. For example operating surplus excludes interest, rent or similar charges payable on financial or tangible non-produced assets borrowed or rented by the enterprise.
Opportunity cost (or Economic cost)	The value of the most valuable alternative use
Option value	This is value of the availability of using an environmental or other asset at some future date. See also Use value.
Other changes in the volume of assets account	The other changes in the volume of assets account records the changes in assets, liabilities, and net worth between opening and closing balance sheets that are due neither to transactions between institutional units, as recorded in the capital and financial accounts, nor to holding gains and losses.
Other non-market output	This is output of goods and individual or collective services produced that are supplied free, or at prices that are not economically significant, by non-profit institutions serving households (NPISHs) or government (central and local) to other institutional units in the community as a whole. This is also known as final consumption expenditure. This output is one of three broad categories of output, the others being market output and output produced for own final use.
Output	The services produced for own final use this consists of those goods or services that are produced within an establishment that become available for use outside that establishment, plus any goods and
Output produced for own final use	This represents production of output for final consumption (for example, homegrown vegetables) or gross fixed capital formation (for example, a self-build house) by the producer, also known as own-account production.
Perpetual inventory method (PIM)	The perpetual inventory method (PIM) produces an estimate of the stock of fixed assets in existence and in the hands of producers by estimating how many of the fixed assets installed because of gross fixed capital formation undertaken in previous years have survived to the current period.
Pillar I and Pillar II	Pillar I within the Common Agriculture Policy subsidies production, while Pillar II supports rural development and environmental protection.
Present value	The capitalised value of a stream of future costs or benefits, the term 'net present value' (NPV) is often used to describe the difference between the present value of a stream of costs and a stream of benefits.
Primary inputs (I-O Analytical Tables)	Primary inputs are inputs that are not outputs of other industries. These are compensation of employees, gross profits and other trading income, imports of goods and services, net taxes on production and products. These are known as primary inputs because they are necessary to the production process but are not produced anywhere in the domestic economy. The total of all primary inputs equals total final output.
Producer's price	This valuation reflects the cost of the product as it leaves "the factory gate". This price will include taxes on production but excludes some taxes on products, for example, value added tax (VAT) invoiced to the purchaser, and distributors' trading margins. It excludes any transport charges invoiced separately by the producer.
Product	The outcome of economic activity, it is the generic term applied to goods and services.
Product (commodity) technology (I-O Analytical Tables)	This is one of the two types of technology assumptions used in converting I-O Supply and Use Tables into I-O Analytical (Symmetric) Tables. This assumes that a product has the same input structure in whichever industry it is produced.
Product by product table (I-O Analytical Tables)	A product-by-product table is a Symmetric Input-Output Table with products as the dimension of both rows and columns. As a result, it shows which products are used in the production of which other products.

Production	Production is an activity, carried out under the responsibility, control and management of an institutional unit, which uses inputs of labour, capital and goods and services to produce outputs of goods and services.
Production account	This account records the activity of producing goods and services as defined in the SNA 93 and ESA 95.The balancing item is gross value added, which is a measure of the contribution to the economy made by an individual producer, industry or sector.
Products	These are also called 'goods and services' and are the result of production. They are exchanged and used for various purposes, for example as inputs in the production of other goods and services, as final consumption or for investment.
Purchasers' price	This represents the price that a purchaser actually pays for the product. This price will include any transportation costs, distributors' trading margins and any taxes on products excluding any deductible VAT.
Purchasing power parity (PPP)	The rate of currency conversion that eliminates the differences in price levels between countries. Per capita volume indices based on PPP converted data reflect only differences in the volume of goods and services produced. Comparative price levels are defined as the ratios of PPPs to exchange rates. They provide measures of the differences in price levels between countries.
Pure time preference	The preference for consumption now, rather than later
QALY	Quality Adjusted Life Year, a year of life adjusted for its quality or its value. A year in perfect health is considered equal to 1.0 QALY. The value of a year in ill health would be discounted. For example, a year bedridden might have a value equal to 0.5 QALY.
Real price	The nominal (ie, cash) price deflated by a general price index, eg, RPI or GDP deflator, relative to a specified base year or base date.
Real terms	The value of expenditure at a specified general price level: that is a cash price or expenditure divided by a general price index.
Region	A distinct geographical area, which can vary depending on the context but often refers to the Government Office Regions of England or the NUTS 1 regions of the UK (see Government Office Regions, NUTS).
Regional multiple	An enterprise that operates or has local units in more than one region (see apportionment, local unit, reporting unit).
Relative price effect	The movement over time of a specific price index (such as construction prices) relative to a general price index (such as the GDP deflator).
Rent	This is the property income derived from land and sub-soil assets and is excluded from total output. It is distinguished in ESA 95 from rental income derived from buildings and other fixed assets - see Rental income.
Rental income	These are amounts payable by the user of a fixed asset to its owner for the right to use that asset in production for a specified period. It is included in the gross operating surplus and output of the owner, and in the intermediate consumption of the user. Also, the owner records rental income as gross receipts less actual expenditure on repairs, maintenance and insurance. Rental income also includes imputed rental income of owner- occupiers.
Revealed preference	The inferred willingness to pay for something that is non-marketed by examining the behaviour of consumers in a similar or related market
Secondary effects	Changes in economic activity from subsequent rounds of spending, there are two types of secondary effects: Indirect effects are the changes in sales, income, or employment within the region in backward-linked industries supplying goods and services to businesses. For example, increased sales in linen supply firms resulting from more hotel sales are an indirect effect of visitor spending. Induced effects are the increased sales within the region from household spending of the income earned from visitors and supporting industries. Employees in tourism and supporting industries spend the income they earn from tourism on housing, utilities, groceries, and other consumer goods and services. This generates sales, income, and employment throughout the region's economy.
Secondary products	The secondary products (also known as off-diagonals) of an industry are those products that are the principal products of other industries.
Standard Industrial Classification 2003 (SIC (2003))	The industrial classification applied to the collection and publication of a wide range of economic and industrial statistics. The current version, SIC (2003), is consistent with NACE Rev. 1.1. (SIC 1992 is equivalent to NACE except at the most detailed level).
Stated preference	Willingness to pay for something that is non-marketed derived from, people's responses to questions about their preferences, for various combinations of situations, and/ or controlled discussion groups.

Subsidies (I-O Annual Supply and Use Tables)	These are current unrequited payments made by central government, local government or the European Union to a producer or trader having the effect of reducing the selling price below the factor cost of production. They include the financing of deficits on public trading services deliberately run at a loss. There are two types, see subsidies on production and subsidies on products.
Subsidies on production (I-O Annual Supply and Use Tables)	These are subsidies other than subsidies on products and are based on the levels of productive activity, for example numbers employed.
Subsidies on products (I-O Annual Supply and Use Tables)	These are subsidies based on a quantity or value of goods or services sold.
Substitution	The situation in which a firm substitutes one activity for a similar activity (such as recruiting a different job applicant) to take advantage of government assistance
Supply Table (I-O Annual Supply and Use Tables)	The main body of the Supply Table shows estimates of domestic industries' output by type of product at basic prices. The columns represent the supplying industries and the rows represent the products supplied. Additional columns covering imports of goods and services, distributors' trading margins and taxes (minus subsidies) on products are added to show supply of all goods and services at purchasers' prices.
Symmetric Input-Output Tables	See Analytical Tables.
System of National Accounts 1993 (SNA 93)	This is the internationally agreed standard system for macro-economic accounts produced by the United Nations.
Taxes (I-O Annual Supply and Use Tables)	These are compulsory unrequited payments to central government, local government or the European Union. Within the I-O Annual Supply and Use Tables there are two types of taxes within the production boundary; see taxes on production and imports and taxes on products. Taxes on income and wealth such as income tax and corporation tax, and capital taxes like capital gains tax and inheritance tax are not included within the production boundary.
Time preference rate	Preference for consumption (or other costs or benefits) sooner rather than later, expressed as an annual percentage rate.
Total economic value	Total economic value of an environmental resource is made up of (i) use values and (ii) non-use values. Use values are composed of (a) direct use value, (b) indirect use values and (c) option values, whilst non-use values are made up of (a) altruistic, (b) existence values and (c) bequest values.
Total effects	The sum of direct, indirect, and induced effects
Total Factor Productivity (TFP)	Measure of the efficiency with which inputs are used to produce output; estimated as a residual in the growth accounting framework
Total final expenditure	This is the sum total of final consumption, gross capital formation and exports of goods and services. Total final expenditure is the same as total demand by final buyers and is equal to total final output.
Total intermediate consumption	The total intermediate consumption of each industry is the industry's total purchases of the outputs of other industries as well as purchases of imports of goods and services and intra-industry purchases for use in its production process. This is adjusted for the change in the inventory of materials and fuels. It excludes primary inputs.
Total output	The total output of an industry is the aggregate value of the goods and services together with the work-in-progress produced by the industry. It is equal to the value of the industry's sales plus any increase (and less any decrease) in the value of its inventories of finished products and work in progress. Output is thus measured after deducting holding gains. The outputs of the distribution and service trades industries are measured on a 'gross margin' basis.
Trade margin	A trade margin is the difference between the actual or imputed price charged on a good purchased for resale without further processing and the price that would have to be paid by the distributor to replace the good at the time it is sold. These margins can be earned by businesses in any industry but are mainly earned by the distribution industry.
Transfer payment	A transfer payment is one for which no good or service is obtained in return.
Transport margin	A transport margin consists of those transport charges paid separately by the purchaser in taking delivery of the goods at the required time and place.
Use Table (I-O Annual Supply and Use Tables)	See Combined Use matrix.

Use value	Value of something that is non-marketed derived from people's actual use of it. See also Existence value and Option value.
User cost of capital	The user cost of capital is the unit cost for the use of a capital asset for one period--that is, the price for employing or obtaining one unit of capital services. The user cost of capital is also referred to as the "rental price" of a capital good, or the "capital service price".
Uses	The term refers to transactions in the current accounts that reduce the amount of economic value of a unit or sector, for example, wages and salaries are a type of use for the unit or sector that must pay them. By convention, uses are on the left-hand side of the account as defined by ESA 95.
Valuables	These are goods of considerable value, which are not used primarily for production or consumption but are held as stores of value over time. They consist of precious metals, precious stones, jewellery, works of art, antiques, etc. As a new category in the accounts, the estimates for them are still in development though transactions are likely to have been recorded elsewhere in the accounts.
value of a fixed asset	Purchaser's price of a new asset of the same type less the cumulative value of the consumption of fixed capital accrued up to that point in time.
Value of the physical increase in inventories and work in progress	This is the increase in the quantity of inventories and work-in-progress held by trading enterprises or by the central government for strategic purposes. It is equal to the change in the book value of inventories and work-in-progress less holding gains.
VLYL	Value of Life Year Lost
Volume index of capital services	A volume index of capital services measures the flow of services into the production process from the different types of assets included in the capital stock.
VOLY	Value of a Life Year
VOSL	Value of Statistical Life
VPF	Value of prevented fatality
Willingness to Accept (WTA)	The amount that someone is willing to receive or accept to give up a good or service
Willingness to Pay (WTP)	The amount that someone is willing to give up or pay to acquire a good or service.
YLD	Years lived with disability
YOLL	Years of Life Lost

APPENDIX H List of Acronyms

ABI	Annual Business Inquiry
ACA	Accident Consequence Assessment
ARS	Acute Radiation Syndrome
AUK	Agriculture in the United Kingdom
BNFL	British Nuclear Fuels plc
CAP	Common Agricultural Policy
CB	Containment Bypass
CFIL	Community Food Intervention Levels
COD	Chemical Oxygen Demand
CV	Compensating Variation
DCLC	Department of Communities and Local Government
DCMS	Department for Culture Media and Sport
DfT	Department for Transport
EU	European Union
FBS	Farm Business Survey
FEMA	Federal Emergency Management Agency
FEPA	Food and Environment Protection Act
FMD	Foot and Mouth Disease
FMP	Farm Management Pocketbook
FTE	Full Time Equivalent
FZK	Forschungszentrum Karlsruhe
GDP	Gross Domestic Product
GLUD	Generalised Land Use Database
GOR	Government Office Region
GVA	Gross Value Added
HC	Human Capital
HHSA	Household Satellite Account
HPA	Health Protection Agency
HSA	Household Satellite Account
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
ICRP	International Commission on Radiological Protection
ILO	International Labour Organisation
IPD	Independent Property Databank
IZ	Intermediate Zones
KI	Potassium Iodate
LSOA	Lower Super Output Area
MSOA	Medium Super Output Area
NHTSA	National Highway Traffic Safety Administration
NICE	National Institute of Health and Clinical Excellence
NII	Nuclear Installations Inspectorate
NPD	National Population Database
NRPB	National Radiological Protection Board
NSCLC	Non-Small Cell Lung Cancer

OA	Output Area
ODPM	Office of Deputy Prime Minister
OECD	Organisation for Economic Cooperation and Development
ONS	Office of National Statistics
PIM	Perpetual Inventory Model
QALY	Quality Adjusted Life Year
RIMS	Regional Input-Output Modelling System
SCLC	Small Cell Lung Cancer
SIC	Standard Industrial Classification
SOA	Super Output Areas
SPS	Single Payment Scheme
STW	Sewage Treatment Works
TGVA	Tourism Gross Value Added
TSA	Tourism Satellite Account
VLA	Veterinary Laboratory Agency
VOA	Valuation Office Agency
VOLY	Value of Life Year
VOSL	Value of Statistical Life
VPF	Value of Preventable Fatality
VPF	Value of a Preventable Fatality
WERU	Welsh Economy Research Unit
WTP	Willingness To Pay