REVIEW OF INDIAN POINT SEVERE ACCIDENT OFF SITE CONSEQUENCE ANALYSIS

ISR Report 13014-01-01

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The production of this report has followed the standard review and quality control procedures of International Safety Research.

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EXECUTIVE SUMMARY

With the operating licenses of Indian Point Unit 2 (IP2) and Unit 3 (IP3) scheduled to expire in 2013 and 2015 respectively, the facilities' owner, Entergy, submitted a license renewal application (LRA) to the Nuclear Regulatory Commission (NRC) seeking to extend its operating licenses for another twenty years. NRC regulations require a site-specific analysis of actions to mitigate the environmental impacts resulting from a severe accident at the applicant's plant. As part of the LRA, Entergy was required to submit an Environmental Report (ER) that included a Severe Accident Mitigation Alternatives (SAMA) analysis. As part of the relicensing proceeding, NRC Staff completed a Final Supplemental Environmental Impact Statement (FSEIS) which evaluates, among other things, Entergy's SAMA analysis. The State of New York has intervened in the relicensing proceeding and has challenged, among other things, Entergy's and NRC Staff's SAMA analysis.

Central to the SAMA analysis is a cost-benefit analysis. The MELCOR Accident Consequence Code Systems-2 (MACCS2) code is used to estimate economic costs associated with a severe nuclear accident using site-specific inputs entered by the user. This cost is then used in the SAMA analysis to determine which SAMAs are cost-beneficial.

The NRC approved and released the FSEIS for IP in December 2010. Upon review of the FSEIS, specifically Appendix G, the New York State Office of the Attorney General (OAG) submitted Contention 12-C which asserts that NRC staff and Entergy have substantially underestimated the costs of decontamination measures required following a severe nuclear accident.[1] This underestimation is attributed primarily to the selection of inappropriate MACCS2 decontamination input parameters for the area surrounding the Indian Point station (i.e., New York City (NYC) and surrounding metropolitan areas).

Consequently, OAG requested that International Safety Research (ISR) in Ottawa, Canada:

1. examine Entergy's use of the MACCS2 code, including Entergy's input file for the long-term phase of a severe nuclear accident (i.e., CHRONC);
2. determine whether and to what extent the economic costs of a severe accident at Indian Point were underestimated due to, for example, the use of generic assumptions concerning decontamination costs that are not necessarily applicable to the densely populated area surrounding IP2 and IP3 found in the NYC metropolitan region; and
3. specifically address pertinent comments contained in US NRC's evaluation of OAG contentions (Appendix G of the FSEIS).

To focus the approach, ISR conducted a sensitivity analysis to determine which CHRONC input parameters have the greatest effect on the offsite economic cost risk (OECR), which is the per year total economic cost of a severe accident used in the SAMA analysis. For each of the sensitive parameters thus determined, ISR identified: the definition of the parameter; the input values chosen by Entergy; the explicit or implicit rationales for Entergy's selection of those values; a range of more appropriate values (where applicable) based on available data, currency and relevance to the location of Indian Point; and a re-calculation of the OECR using the more appropriate value(s).

[1] Previously, the State of New York had submitted Contentions 12, 12-A, and 12-B in response to earlier submissions by Entergy and NRC. These Contentions were consolidated as 12-C.

The results of the sensitivity analysis demonstrated that the MACCS2 output was most sensitive to variation in the following CHRONC input parameters:

- decontamination costs and times;
- value of nonfarm wealth;
- depreciation rate;
- societal discount rate of property;
- relocation costs; and
- fraction of nonfarm property due to improvements.

In its SAMA analysis, Entergy adopted all of the CHRONC input parameters, with the exception of farm and nonfarm wealth and the long-term exposure period, from MACCS2 Sample Problem A, adjusted only for the Consumer Price Index (CPI) to account for inflation. Sample Problem A is a collection of example MACCS2 input modules, developed initially for analysis of the Surry reactor in Virginia. The input parameters were based on the guidance provided in NUREG-1150. The Sample Problem A dataset was not intended to be a set of default input values for MACCS2. Instead, MACCS2 was designed so that users could define inputs based on site-specific data. ISR concluded that the use of Sample Problem A values for the cost sensitive parameters does not accurately incorporate available decontamination data, and the population and building characteristics of New York City and surrounding metropolitan areas.

ISR conducted research to determine more appropriate input values for these sensitive cost input parameters. For the decontamination cost and time input parameters, ISR utilized multiple sources to determine a more appropriate range of input values.

ISR confirmed that of the parameters considered in this report, the cost and time of decontamination were the most underestimated by Entergy.

ISR then ran the MACCS2 code using Entergy's MACCS2 input files substituted with values deemed appropriate by ISR for the sensitive decontamination parameters. The MACCS2 results indicate that the Entergy OECR cost values are underestimated by a factor ranging from four for the lowest ISR values and seven for the highest ISR values. This underestimation of the OECR could influence the cost-benefit analysis which forms the basis for the selection of alternatives.

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GLOSSARY

Term or Abbreviation	Description
ATMOS	Atmospheric Transport and Deposition. The first module in MACCS2. It calculates air and ground concentrations, plume size, and timing information for all plume segments as a function of downwind distance.
CDNFRM	The MACCS2 input that defines the nonfarmland decontamination cost.
CHRONC	Intermediate- and Long-Term-Phase Calculations. The third module in MACCS2. It calculates the consequence of the long-term effects of radiation and computes the decontamination and economic impacts incurred because of the accident.
CPI	Consumer Price Index.
CRAC2	Code Systems for Calculating Reactor Accident Consequences. It was developed in support of the Reactor Safety Study, WASH-1400 to assess the risk from potential accidents at nuclear power plants.
DPRATE	Defines the depreciation rate that applies to property improvements during a period of interdiction. This depreciation rate is intended to account for the loss of value of buildings and other structures resulting from a lack of habitation and maintenance.
DSCRLT	Defines the long-term phase dose criterion. This is the maximum allowable direct exposure dose commitment to the long-term critical organ during the long-term phase action period (TMPACT).
DSEIS	Draft Supplemental Environmental Impact Statement.
DSRATE	Defines the expected rate of return from land, buildings, equipment, etc. For example, the inflation-adjusted real mortgage rate for land and buildings could be used.
DSRFCT or Decontamination Factor (DF)	Dose Reduction Factor. An input in MACCS2, defines the effectiveness of the various decontamination levels in reducing dose. A dose reduction factor of three means that the resulting population dose at that location will be reduced to one-third of what it would be without decontamination. In MACCS2, dose reduction factor is used interchangeably with decontamination factor (DF), which often solely refers to the reduction in contamination and not necessarily reduction in dose. MACCS2 expects that the DF be entered under the variable name DSRFCT.
EARLY	Emergency-Phase Calculations. The second module in MACCS2. It calculates the consequences due to exposure to radiation in the first seven (7) days (the emergency phase) of the accident.
Entergy	Entergy Nuclear Indian Point 2, LLC, Entergy Nuclear Indian Point 3, LLC, and Entergy Operations, Inc., the owner of Indian Point Energy Center containing two operating nuclear reactors.

Term or Abbreviation	Description
ER	Environmental Report submitted by Entergy as part of its License Renewal Application (LRA).
Farmability	A measure of how appropriate the land is for farming, mainly due to the deposition of radionuclides onto that land.
FRNFIM	Defines the fraction of nonfarm wealth in the region due to improvements. This value includes buildings and infrastructure such as roads and utilities, as well as any nonrecoverable equipment or machinery.
FSEIS	Final Supplemental Environmental Impact Statement.
Gaussian	A mathematical probability distribution function, the "normal distribution."
GCP	Gross County Product. GCP refers to the market value of all final goods and services produced within a county in a given period.
GDP	Gross Domestic Product. GDP refers to the market value of all final goods and services produced within a country in a given period.
GMP	Gross Metro Product. GMP refers to the market value of all final goods and services produced within a metropolitan area in a given period.
Groundshine	A term describing the dose from contamination deposited on the ground.
Habitability	A measure of how habitable the land is, mainly due to the radiation dose rate in the area.
Habitability Criterion	The decision on which mitigative action to implement hinges on the habitability criterion (HC). The HC is dependent on and calculated from the long-term projected dose (DSCRLT) that a person would get if they continued to live in the contaminated area for the specified time (TMPACT).
Interdiction	In MACCS2, the prevention of people residing in an area due to higher than acceptable levels of radioactive contamination. It is a mitigative action to reduce to the total radiation dose to affected members of the public.
IP2	Indian Point Unit 2.
IP3	Indian Point Unit 3.
IPEC	Indian Point Energy Center. This is Entergy's term for the location of the Indian Point reactors, spent fuel pools, and related facilities.
LRA	License renewal application.
MACCS2	The MELCOR Accident Consequence Code Systems-2.
MELCOR	Methods for Estimation of Leakages and Consequences of Releases.
NRPB	National Radiological Protection Board (United Kingdom)

Term or Abbreviation	Description
NRC	The US Nuclear Regulatory Commission. The NRC regulates commercial nuclear power plants and other uses of nuclear materials.
NUREG-1150	An NRC Report titled “Severe Accident Risks: An Assessment for Five US Nuclear Power Plants”. The study contains analysis and example values for five nuclear power stations in the US: Surry, Peach Bottom, Sequoyah, Grand Gulf and Zion.
NYS	New York State.
OAG	New York State Office of the Attorney General.
OECR	Offsite Economic Cost Risk. The OECR is a frequency-averaged cost, on a per year basis. It is an actuarial assessment of the cost that takes into account the low frequency of severe accidents. It is the most relevant output value for the cost-benefit evaluation in SAMA analysis.
POPCST	Defines the per capita removal cost for temporary or permanent relocation of population and businesses in a region rendered uninhabitable during the long-term phase time period. This cost is assessed if any of the following actions are required: decontamination alone, decontamination followed by interdiction, or condemnation. The MACCS2 User Guide recommends that this value be derived in a way that takes account of both personal and corporate income losses for a transitional period as well as moving expenses.
PSA	Probabilistic Safety Assessment. A systematic methodology to evaluate risks associated with a complex engineered entity. Probabilities of events occurring and their consequences are important products of a PSA.
Resuspension	A term describing what fraction of the radioactive particles deposited on the ground are kicked back (resuspended) into the air. This is important when discussing the inhalation of radioactive particles.
RTW	Reproducible Tangible Wealth. A value last calculated by the US Bureau of Economic Analysis in 1995. It represents total tangible wealth of a region, i.e. buildings, land, equipment, etc.
SAMA	Severe Accident Mitigation Alternative.
Sample Problem A	Sample Problem A is one of 14 example problems provided with the MACCS2 code that incorporates input data specific to the Surry reactor consequence analysis.
Sensitivity Analysis	Measuring how much an output changes by varying an input.
Sandia	Sandia National Laboratories.
TGWHLF	Groundshine weathering half-lives (seconds)
TIMDEC	Defines the time required for completion of each of the decontamination levels. The user must define a decontamination time for each of the decontamination levels. Decontamination begins at the end of the intermediate phase.

Term or Abbreviation	Description
TMPACT	Defines the long-term dose projection period. Protective actions such as decontamination, or decontamination followed by interdiction are evaluated to determine if the exposure of an individual during this period can be reduced so that it does not exceed the long-term phase allowable dose.
VALWNF	Defines the value of the nonfarm wealth in the region. Nonfarm wealth includes all public and private property not associated with farming that would be unusable if the region was rendered either temporarily or permanently uninhabitable. This value should include the cost of land, buildings, infrastructure, and the cost of any nonrecoverable equipment or machinery.
WASH-1400	The Reactor Safety Study was a report produced in 1975 for the NRC.

1. INTRODUCTION

1.1 Background

The Indian Point Nuclear Generating Station is a three-unit nuclear power plant station located in Buchanan, New York, approximately 24 miles north of the New York City boundary (the Bronx county) and 38 miles north of the Wall Street area in Manhattan. The plant is owned and operated by Entergy Nuclear Indian Point 2, LLC, Entergy Nuclear Indian Point 3, LLC, and Entergy Operations, Inc. (Entergy). Unit 1 was shut down in 1974. Units 2 and 3 (IP2 and IP3) were commissioned in the mid 1970s, with their licenses set to expire in 2013 and 2015, respectively. Both IP2 and IP3 are pressurized water reactors manufactured by Westinghouse, each with approximately a 1,000 MW generating capacity.

Entergy has submitted a license renewal application (LRA) to the Nuclear Regulatory Commission (NRC) seeking to extend its operating licenses for another twenty years. As part of the LRA, Entergy was required to submit an Environmental Report (ER) that included a Severe Accident Mitigation Alternatives (SAMA) analysis. As part of the relicensing proceeding, NRC Staff completed a Final Supplemental Environmental Impact Statement (FSEIS) which evaluates, among other things, Entergy's SAMA analysis.

The New York State Office of the Attorney General (OAG) submitted a Contention (Consolidated Contention 12-C)[2] which asserts that the submitted Environmental Report (ER), NRC Staff's Draft Supplemental Environmental Impact Statement (DSEIS), Entergy's December 2009 SAMA Reanalysis (SAMA Reanalysis), and NRC Staff's Final Supplemental Environmental Impact Statement (FSEIS) failed to address site specific assumptions and inputs related to clean-up and decontamination costs in the New York City metropolitan region in the event of a severe accident at IP2 or IP3. In Consolidated Contention 12-C, the State of New York (NYS) asserts that NRC Staff and Entergy substantially underestimate the costs of decontamination measures which must be considered in the LRA process.

The computer code used to estimate the cost of decontamination and evacuation/relocation after a severe accident at a nuclear power plant is called the MELCOR Accident Consequence Code Systems, or MACCS. The US Nuclear Regulatory Commission (NRC) has relied on the successor code, known as MACCS2, for SAMA consequence calculations in connection with applications to renew operating licenses for nuclear power plants.

1.2 Objective and scope

The objective of this report is to review and assess Entergy's use of the MACCS2 code to estimate the economic costs associated with a severe accident at IP2 or IP3 for its SAMA analysis, and NRC Staff's evaluation of Entergy's SAMA analysis as part of the FSEIS (see Annex A). This review and evaluation encompasses the assumptions inherent in the MACCS2 code, the input parameters developed and used by Entergy for its SAMA analysis, and the NRC's discussion and approval of these parameters, methodology, and results in the FSEIS. ISR's analysis is focused on the effect of the critical input parameters on the total economic cost of a severe nuclear accident.

[2] The Board consolidated Contentions 12, 12-A, 12-B, and 12-C as Consolidated Contention 12-C.

There are several major factors which contribute to the eventual costs of a severe nuclear accident (e.g. release characteristics, weather pattern, population profile, clean-up, etc.) as evaluated by the MACCS2 code. This analysis focuses on those factors directly associated with the long-term management of the nuclear accident, specifically decontamination, interdiction (i.e. relocation) and condemnation of buildings and property. The MACCS2 code contains several modules which address issues related to the consequence evaluation of severe accidents. The "CHRONC" module contains the input parameters which ISR has evaluated and which are related to Consolidated Contention 12-C, and is therefore the only module considered in this report.

1.3 Report outline

The following section (1.4) provides further detail of the technical aspects of the contention submitted by NYS regarding the SAMA analysis for IP2 and IP3.

Section 2 contains a description of the MACCS2 code, with an emphasis on the CHRONC module, the economic cost model and the mitigative actions model.

Section 3 describes the methodology and results of the sensitivity analysis used to determine which MACCS2 input parameters have the greatest effect on the total economic cost.

Section 4 contains the analysis of each input parameter determined to be sensitive in Section 3. For each sensitive parameter, the following are provided:

1. The parameter name, value assigned by Entergy and the definition from the MACCS2 user guide;
2. The fundamental source or methodology employed to determine the value;
3. A discussion of the appropriateness of the methodology or the quantities used, and ISR's conclusions regarding more applicable methodologies or inherent quantities to account for the site-specific conditions related to the Indian Point reactors, including present time, location (i.e. NYS), economy and national and international best practices.

Section 4 also includes a comparison of the input values used by Entergy to those previously used by other nuclear power plants in the US.

Section 5 presents ISR's conclusions based on the analysis conducted in Section 4.

Section 6 contains a listing of references.

Annex A contains responses to specific comments in NRC Staff Evaluation (Appendix G).

Annex B contains a listing of the CHRONC module inputs and the results of the sensitivity analysis.

Annex C contains the details of the calculations used in the determination of decontamination costs.

Annex D contains the calculation for the value of nonfarm wealth.

Annex E contains a set of flowcharts that describe the MACCS2 economic model.

Annex F contains a timeline of certain references referred to throughout this report.

1.4 Contention history related to input parameters

The following is a chronological list of key events that comprise the NYS Contention 12 history. This listing focuses on the technical aspects of the contentions, specifically those aspects that are pertinent to the review of the MACCS2 input parameters.

- In April 2007, Entergy submitted its ER to the NRC describing, among other things, its SAMA analysis.
- On November 30, 2007, NYS submitted Contention 12, which asserted that Entergy had not, in its ER, accurately modeled the cleanup and decontamination costs for a severe accident over an urban area such as the Westchester County/New York City area surrounding Indian Point.
- On December 22, 2008, NRC Staff released the DSEIS, which describes the environmental impacts of the license renewal for IP2 and IP3. The DSEIS adopted Entergy's SAMA analysis as set forth in its ER.
- In February 2009, NYS filed Contention 12-A, which was consolidated on June 1, 2009 with previous Contention 12. The salient points of the contention were:
    - The MACCS2 model assumed large-sized radionuclides (i.e. plutonium) as opposed to small-sized particles (i.e. cesium), which are likely in a severe accident and more costly to remove and clean up;
    - The analysis should incorporate the results of:
        1. D. Chanin and W. Murfin, *Site Restoration: Estimation of Attributable Costs from Plutonium-Dispersal Accidents*, SAND96-0957, Unlimited Release, UC-502, (May 1996) ("*Site Restoration*") regarding the costs of a plutonium-dispersal accident, and
        2. Studies examining the costs of a terrorist attack and spent fuel pool fire at Indian Point.
- In December 2009, Entergy submitted a revised SAMA Analysis. The revision was due to an error made by Entergy in its original analysis and subsequent correction to the meteorological data file.
- On March 11, 2010, NYS filed Contention 12-B, which asserted that Entergy's SAMA re-analysis underestimates decontamination and clean up costs associated with a severe accident in the New York Metropolitan area and, therefore, underestimates the cost of a severe accident.
- On December 3, 2010, NRC Staff released the FSEIS. In response to NYS Contentions 12, 12-A, and 12-B, NRC staff concluded that decontamination costs were reasonable, acceptable and consistent with that of other nuclear power plants.
- On February 3, 2011, NYS filed Contention 12-C. The salient points of the contention were that the FSEIS is inadequate because:
    - It uses cost data for moderate decontamination for an event that would require heavy decontamination;
    - It does not scale up the decontamination cost data from Sandia's *Site Restoration*, which was based on Albuquerque, NM, to a much higher population-density area such as the New York City Metropolitan Area; and
    - Entergy's values are based on particles of larger diameter than one would get from a reactor accident. Smaller particles are more difficult to decontaminate.
- The Board consolidated Contentions 12, 12-A, 12-B, and 12-C as Consolidated Contention 12-C.

2. MELCOR ACCIDENT CONSEQUENCE CODE SYSTEMS-2 (MACCS2)

2.1 General

MACCS2 (Chanin, 1998 [1]) is a Gaussian plume model for calculation of radiological atmospheric dispersion and consequences, developed by Sandia National Laboratories (Sandia). MACCS2 may be used for severe accident analysis, design-basis accidents and other accidents. Its development was sponsored by the United States Nuclear Regulatory Commission (NRC) as a successor to an older code, Code Systems for Calculating Reactor Accident Consequences (CRAC), for the performance of commercial nuclear industry probabilistic safety assessments (PSAs) [2]. While the underlying models of CRAC and MACCS/MACCS2 are largely similar, the main difference between the two is that a number of CRAC parameters are "hard-wired" and, thus, cannot be changed in the CRAC code. In MACCS and MACCS2, those same parameters are user-defined and, thus, can be derived from site-specific data.

After its verification in the early 1990s, MACCS2 was released for unrestricted use.

2.2 Code structure

MACCS2 is executed in three steps. The first module, ATMOS, calculates air and ground concentrations, plume size, and timing information for all plume segments as a function of downwind distance. The next module, EARLY, calculates the consequences due to exposure to radiation in the first seven (7) days (the emergency phase) of the accident. The last module, CHRONC, calculates the consequence of the long-term effects[3] of radiation and computes the economic impacts incurred due to the accident.

The purpose of this report is to analyze the inputs used by Entergy in its SAMA analysis that are associated with long-term economic costs. All of these inputs are contained in the CHRONC module of the code. For this reason, further discussion of the MACCS2 code will be focused on the CHRONC module only.

2.3 CHRONC module

The CHRONC module contains the input parameters that pertain to both the intermediate and long-term phases of the nuclear accident consequence management. It simulates the events that occur following the emergency-phase time period modeled by the EARLY module. CHRONC calculates both the individual health effects and the economic cost of the long-term decontamination and relocation associated with a severe accident.

Based primarily on the CHRONC input parameters, MACCS2 determines the economic cost of a severe accident. The CHRONC module contains two models: the economic cost model and mitigative actions model. As described below, these models form the framework for the determination of the output costs associated with a severe accident.

[3] MACCS2 allows the user to define the period for "long-term", but it is recommended that 30 years be used since this is consistent with the EPA in its Superfund Guidance (EPA, 1991).

2.4 Economic cost model

The economic cost model of the MACCS2 code is intended to estimate the direct offsite costs from a severe nuclear accident. The following costs are calculated by the MACCS2 code:

1. Food and lodging costs for short-term relocation of people who are evacuated or relocated during the emergency phase of the accident;
2. Decontamination costs for property that can be returned to use after decontamination;
3. Depreciation of property (farm and nonfarm) while it is temporarily interdicted following decontamination to allow for radioactive decay to reduce ground contamination to acceptable levels;
4. Costs resulting from the disposal of contaminated milk and crops; and
5. Costs due to permanent interdiction of property (i.e. condemnation).

The various factors contributing to each of these costs are depicted in the flowcharts given in Annex E.

If other indirect costs were included such as medical expenses regarding adverse health effects and the costs of disposal of contaminated wastes, the total economic cost would increase.

2.5 Mitigative actions model

In MACCS2, there are five possible mitigative strategies[4] for any given spatial sector[5]:

1. No mitigative actions (i.e. do nothing); or
2. Decontaminate areas using the first (i.e. lowest) decontamination factor (DF), DF1; or
3. Decontaminate areas using the second (i.e. highest) decontamination factor, DF2; or
4. Decontaminate areas using DF2 and implement temporary interdiction for up to 30 years; or
5. Condemn the area.

The decision on which mitigative action will be implemented hinges on the habitability criterion (HC). The HC is dependent on the long-term projected dose (MACCS2 input DSCRLT) that a person would get if they continued to live in the contaminated area for the specified time (MACCS2 input TMPACT). Long-term phase doses are the sum of the groundshine and resuspension inhalation committed (50-year) doses [1].

The HC recommended by the EPA in EPA-400 [3] is 0.04 Sv (DSCRLT) in 5 years (TMPACT). The guidelines published in EPA-400 are widely accepted and used by several states including New York, where they have been used as the basis for the NYS radiological emergency preparedness plan (2010) [4].

[4] There are five strategies assuming there are two decontamination levels.
[5] Spatial sectors are based on a polar-coordinate grid defined by a number of radial divisions (e.g. 16) and the endpoint distances.

The MACCS2 decision sequence for determining which mitigative action to implement is as follows and is depicted in Figure 1:

1. If there is no decontamination and the projected radiation dose to the public in the contaminated area is less than the HC, relocation or other mitigative actions are not required, otherwise:
2. If after decontamination using DF1, the dose is less than the HC, decontaminate to DF1 and allow return to property after the time required to decontaminate (MACCS2 input TIMDEC1), otherwise:
3. If after decontamination using DF2, the dose is less than the HC, decontaminate to DF2 and allow return to property after the time required to decontaminate (MACCS2 input TIMDEC2), otherwise:
4. If decontamination using DF2 and temporary relocation for any time up to 30 years results in a dose less than the HC, decontaminate to DF2 and move back after TIMDEC2 plus the interdiction time (governed by log-linear relationship based on radioactive decay and weathering), otherwise:
5. Condemn the property (i.e. permanent interdiction).

MACCS2 incorporates the following cost effectiveness caveat: if the cost of decontamination and interdiction up to 30 years is greater than the cost of condemning the property, then condemnation is chosen [1].

The relative costs of each possible mitigative action are shown in Figure 2.

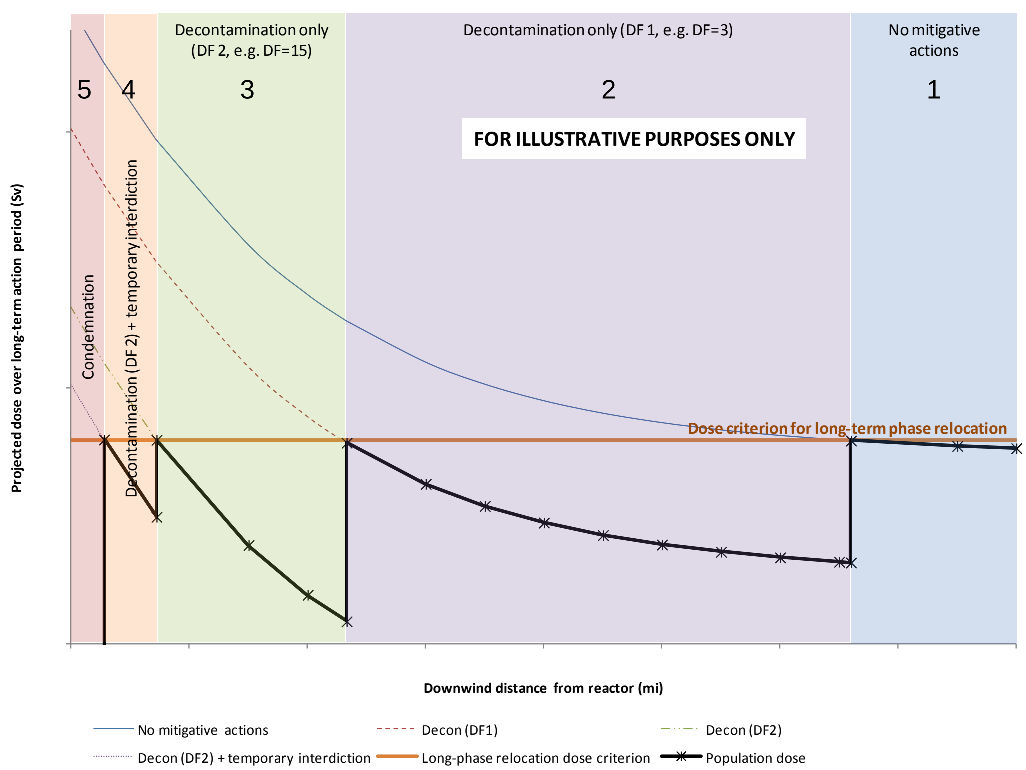

Figure 1: The population dose associated with mitigative actions

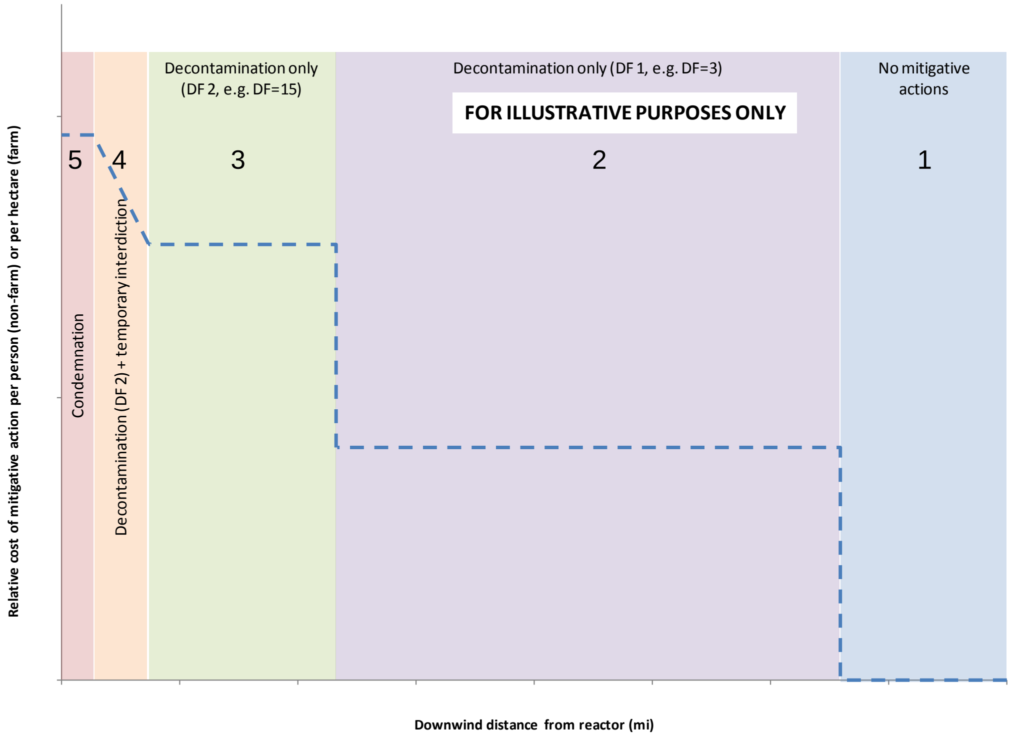

Figure 2: The relative costs associated with mitigative actions

2.6 Sample Problem A

The MACCS2 code package includes 14 sample problems containing sets of example inputs that were designed to be used to verify that the MACCS2 code was installed and running properly [1].

Sample Problem A (one of the 14 sample problems in the code package) incorporates site-specific data for the Surry site in Virginia that were obtained from NUREG-1150. The developers of MACCS2 intended that Sample Problem A be used to test the improvements that had been made to the previous version of the code. These improvements include: the capability to consider multiple source terms and emergency response assumptions in a single run; and the implementation of the new COMIDA2 food pathway model [1].

Nowhere in the MACCS or MACCS2 documentation is it suggested that the input values of the code sample problems be considered recommended or "default" values. David Chanin, the developer of the MACCS2 code, discussed the use of Sample Problem A as default values. In his 2005 paper, The Development of MACCS2: Lessons Learned [5], he stated “We also went so far as to scrupulously avoid using the common ‘default value’ in referring to the code’s provided ‘Sample Problem’ input data files. ‘Sample data’ and ‘example usage’ were the terms used to remind the analyst that they, and they alone, were responsible for reviewing MACCS and MACCS2 input data and resultant code outputs to ensure appropriateness for their application.”

All but the following three Entergy MACCS2 CHRONC input parameters were derived (i.e. taken directly or adjusted for inflation) from Sample Problem A: the value of nonfarm wealth (VALWNF), the value of farm wealth (VALWF) and the long-term exposure period (EXPTIM). As determined in the following section, of the three values, only the value of nonfarm wealth is a cost sensitive parameter.

3. SENSITIVITY ANALYSIS

3.1 Determining parameter sensitivity

ISR conducted a sensitivity analysis to determine which input parameters directly and most significantly affect the costs of mitigative actions following a severe accident.

In order to evaluate the sensitivity of each of the CHRONC input parameters, ISR varied each input parameter, one at a time, and performed a MACCS2 simulation run for Indian Point Station 2 (IP2) using Entergy's five input files (i.e., ATMOS, EARLY, CHRONC, weather file and site file). Since only the source terms contained in the ATMOS module vary between IP2 and IP3, ISR assumed that the general conclusions resulting from the sensitivity analysis are applicable to both stations.

ISR chose to quantify the effect of changing each parameter by calculating the change in the resulting total offsite economic cost risk (OECR). ISR selected the total OECR as it is the value used in the cost-benefit analysis in the SAMA analysis and therefore the most pertinent value derived from the MACCS2 output. The details of this calculation can be found in Annex B.

The OECR calculated by Entergy was $ 2.12E+05/yr in 2005 US dollars (USD) for IP2 and was used as a reference for a basis of comparison to ISR's calculated OECRs in Section 4.

3.2 Sensitivity results

To ascertain the relative sensitivity, ISR increased each input parameter by 10%[6] and the percentage increase in the total OECR was calculated. The results are listed in Annex B, Table 15. The results of ISR's sensitivity analysis indicated that the most sensitive CHRONC input parameters are (in order of decreasing sensitivity):

1) GWHLF – Long-term groundshine coefficients
2) DSCRLT – Long-term phase dose criterion (Sv)
3) VALWNF – Value of nonfarm wealth ($/person)
4) TMPACT – Time action period ends (seconds)
5) DSRATE – Societal discount rate for property (/year)
6) FRNFIM – Nonfarm wealth improvements fraction
7) TGWHLF – Groundshine weathering half-lives (seconds)
8) DPRATE – Property depreciation rate (/year)
9) POPCST – Per capita cost of long-term relocation ($/person)
10) CDNFRM – Nonfarm decontamination cost ($/person)
11) TIMDEC – Decontamination times (for all decontamination levels) (seconds)

The values for the groundshine parameters, GWHLF and TGWHLF, were adopted from the guidance published by the US NRC for the main MACCS2 input parameters [6]. Since these groundshine parameters are radionuclide-specific, calculated from first physical principles and are not time or location-dependent, there is no need for further analysis of these parameters.

[6] 10% was chosen by ISR because it is a sufficiently small increase such that the change is linear and continuous throughout the increase.

As discussed in Section 2.5, the values for the DSCRLT and TMPACT parameters are those recommended by the EPA and adopted by the state of New York. Therefore, there is no need for further analysis of these parameters.

For decontamination, the CDNFRM and TIMDEC parameters are assessed in Section 4.2. ISR assessed the remaining five sensitive parameters in Sections 4.3 to 4.7 respectively.

4. INPUT PARAMETER ANALYSIS

4.1 General

ISR carefully examined the MACCS2 CHRONC input file produced by Entergy. For each sensitive input, ISR determined the input parameter's definition, the value chosen by Entergy, the rationale or source for their value, and a discussion of what may be considered to be a more appropriate value, if required. The following sections describe and discuss the findings of this analysis.

4.2 Nonfarm decontamination costs and times

4.2.1 Parameter definition

Parameter name: CDNFRM
Entergy values: $5,184 per person, $13,824 per person (both in 2005 USD)

CDNFRM is the nonfarmland decontamination cost for each decontamination level (i.e. decontamination factor, described below). The MACCS2 User's Guide does not specify which cost components of the decontamination process should be included (e.g. characterization, decontamination, disposal, compensation, etc.); therefore it is up to the user to identify these components.

Parameter name: TIMDEC
Entergy values: 5.18E+06 s, 1.04E+07 s (60 d, 120 d)

TIMDEC is the time required for completion of each decontamination level (i.e. decontamination factor, described below).

The decontamination factor (DF) and the decontamination level are used interchangeably in MACCS2 with the dose reduction factor (MACCS2 input DSRFCT), which is defined as "the effectiveness of the various decontamination levels in reducing dose. A dose reduction factor of 3 means that the resulting population dose at that location will be reduced to one-third of what it would be without decontamination." [1]

DSRFCT = (population dose before clean-up) / (population dose after cleanup)

Usually for decontamination activities, the decontamination factor is defined as:

DF = (contamination before clean-up) / (contamination after cleanup)

It is this definition that will be used for DF in the remainder of this section.

The following table expresses DFs as decontamination efficacy in percentages.

Table 1: Reduction in contamination for each DF

DF	Reduction in contamination
2	50%
3	67%
5	80%
7	85.7%
10	90%
15	93.3%
20	95%

Decontamination factors may be classified as follows [7]:

2<DF<5 = "Light" decontamination
5<DF<10 = "Moderate" decontamination
DF>10 = "Heavy" decontamination

Some examples of the activities associated with the various values of DF are [7]:

Light decontamination – prompt vacuuming of all structural exteriors followed by detergent scrubbing. Building interiors would be decontaminated by such methods as vacuuming/shampooing. Turf/lawn areas that could not be decontaminated would be removed. Tree foliage would be hosed down, with wash water collected to avoid run-off.

Moderate decontamination - roofing would be removed and replaced. All landscape material would be replaced. Interiors of buildings would be emptied of all removable contents (e.g. desks, chairs, personal items, etc).

Heavy decontamination – A DF of 10 indicates that 90% of the radioactive contamination is removed by the decontamination technique. Based on experience following the Chernobyl accident, there is "…no method to achieve surface decontaminations of these (DF>10) levels short of completely demolishing (razing) of buildings and disposing of the material in a licensed burial facility" [7]. This is understood to mean that decontamination of an entire building to a level greater than 10 may not be possible. Other authors also come to the same conclusion [8,9].

4.2.2 Source of Entergy's values

Entergy selected DFs of 3 and 15. These DFs and their corresponding decontamination times, 60 days and 120 days respectively, were taken from Sample Problem A (see Section 4.8), which follows the assumptions made in NUREG-1150 [10].

Even though a DF of 15 is unlikely to be achievable, ISR also used these two DFs to evaluate Entergy's use of the MACCS2 model.

MACCS2 requires a user-specified nonfarm decontamination cost (in $/person) to be input for each DF. The values selected by Entergy are $5,184/person and $13,824/person for DFs of 3 and 15 respectively. Entergy obtained these values by adjusting the corresponding MACCS2

Sample Problem A values ($3,000/person and $8,000/person) by the CPI. Although many other SAMA analyses submitted to the NRC by US licensees use the same approach (see Sections 2.6 and 4.8), Entergy did not supply a rationale for this approach.

4.2.3 Discussion of CDNFRM

Decontamination costs are the dominant factor in the evaluation of the remediation cost following a severe nuclear accident. Due to the fact that there is very little data on actual severe reactor accidents in a hyper-urban area such as NYC, significant, detailed research is required to accurately determine these input parameters. As stated in NUREG-1150, one may extrapolate from other types of nuclear accidents (primarily weapon-related) or field radiological decontamination work and experiments.

Decontamination following any radioactive release will vary considerably in cost depending on the chosen DF and the radionuclide(s) involved. For the case of a severe nuclear accident, it is well documented that decontamination of small sized particles such as cesium (^{137}Cs) in urban areas represents the most significant challenge [11]. This is because cesium, with its solubility and ability to ion exchange with sodium and potassium present in the concrete, will migrate rapidly such that at 5 mm into the material, its concentration may have only dropped to 50% of that at the surface. This migration, of course, increases with time (i.e. decontamination of cesium is more difficult as time post-event passes).

Because cesium is highly soluble, it bonds to water molecules, leading to more and deeper penetration, and making it more difficult to isolate and decontaminate. This was verified by Farfan [12] who measured cesium penetration to more than 5 mm in building structures in Pripyat (near Chernobyl), some 25 years post-event. In addition, the solubility of cesium generates further problems for decontamination if it is introduced into the water cycle.

ISR acknowledges that the determination of the costs of decontamination following a severe nuclear accident is very complex. In an effort to maintain simplicity and accuracy, ISR has chosen the following methodology to calculate a realistic nonfarm decontamination cost (CDNFRM) using various sources:

1. Divide the spatial grid defined in the Entergy MACCS2 site input file into two discrete areas within the 50 mile radius of IP for the purpose of evaluation: a) the "NYC metropolitan area" and b) "the areas outside of the NYC metropolitan area";
2. For each of these two areas, calculate the cost of light and heavy decontamination using the per square kilometer decontamination cost obtained from the following sources:
   - Approach A: *Site Restoration* [7] as modified by *Survey of Costs* [13]: In these references, Sandia (Chanin) and Luna describe a methodology to estimate decontamination costs using the results from US plutonium dispersal tests as a basis;
   - Approach B: Reichmuth [14]: In this reference Reichmuth presents results from radiological dispersal device economic consequence analysis in the US and Canada;
   - Approach C: CONDO [8]: This is a decontamination cost estimation tool from the UK National Radiological Protection Board (NRPB);
   - Approach D: RISO [9]: This reference presents results from decontamination experiments carried out by RISO National Laboratory in Denmark;

3. Sum the cost of decontamination for both areas to obtain a single total cost for the 50-mile radius area surrounding the power plant for each the light and heavy decontamination;
4. Divide the total cost by the total population in the 50-mile radius surrounding the power plant (19,228,712)[7] to obtain a per capita cost for both light and heavy decontamination (i.e. CDNFRM); and
5. Update the per capita cost to 2005 costs using CPI.

A flowchart depicting ISR's methodology for calculating the CDNFRM using each of the four sources (Approaches A to D) is shown in Figure 3.

[7] This population is the sum of all sector populations as defined in the Entergy MACCS2 site input file.

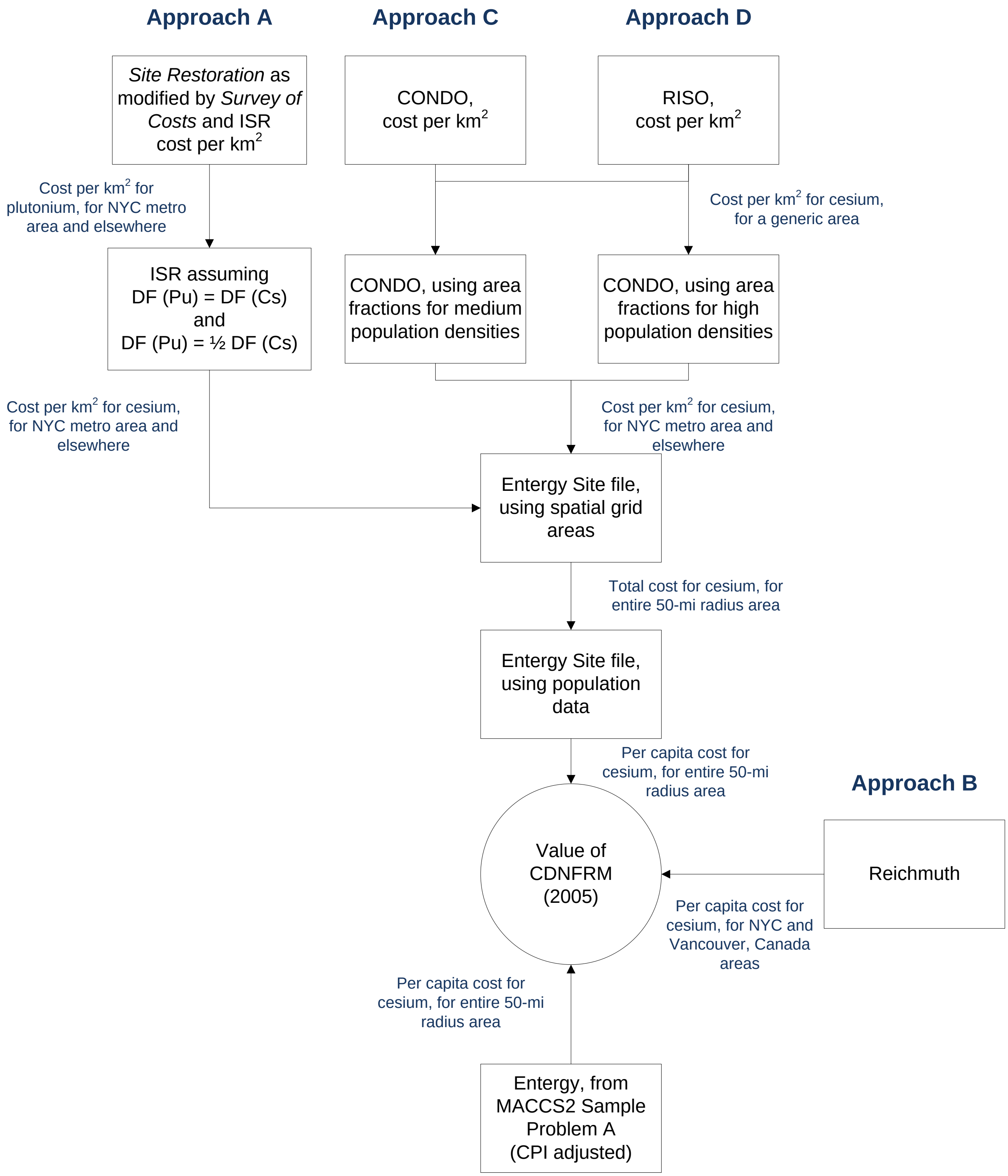

Figure 3: ISR's methodology for determining light and heavy decontamination costs (CDNFRM)

Approach A: Determining decontamination costs using current US data from Site Restoration and Survey of Costs

Site Restoration [7] used historical data (from various actual releases of plutonium and other radionuclides) to derive the costs of a cleanup following plutonium dispersal in an urban area, namely Albuquerque, N.M. In their report, Sandia specifically states that costs were not estimated for hyper-dense population[8] areas.

In *Survey of Costs*, Luna [13] subsequently used the *Site Restoration* analysis as a basis for calculating the cost of cleanup of the hyper-dense population area of interest here, NYC. To do this he:

- Used the actual area coverage (i.e. land use) percentage in NYC for *Site Restoration*'s 5 categories (e.g. residential, commercial, industrial, streets and vacant land); and
- Multiplied his results by the *population density ratio* of NYC to Albuquerque, to account for the greater structure density in NYC.

In *Survey of Costs*, Luna pre-supposes that building density is directly proportional to population density. Instead of making that assumption, ISR used the actual building densities for NYC and Albuquerque obtained from US Census data ([15], [16]) to arrive at decontamination costs, which are shown in Table 2. ISR derived the building density multiplier for residential and commercial land (i.e. 8.98) from an average of the five NYC boroughs of 13,980 buildings/mi^2 [15] versus 1,557 buildings/mi^2 for Albuquerque [16].

Table 2: Modified decontamination costs (2005 USD) for NYC using building density multiplier

	Luna, *Survey of Costs*	*Site Restoration* (Albuquerque)			ISR Using Actual Building Densities (NYC)			
Land Use	**Area Fraction in NYC**	**Light (2<DF<5) ($M/km^2)**	**Moderate (5<DF<10) ($M/km^2)**	**Heavy (DF>10) ($M/km^2)**	**Building Density Multiplier**	**Light (2<DF<5) ($M/km^2)**	**Moderate (5<DF<10) ($M/km^2)**	**Heavy (DF>10) ($M/km^2)**
Residential	0.287	$20.31	$45.99	$84.51	8.98	$182.38	$412.99	$758.90
Commercial	0.164	$32.09	$48.55	$139.84	8.98	$288.17	$435.98	$1,255.76
Industrial	0.068	$45.51	$47.55	$84.12	1.00	$45.51	$47.55	$84.12
Streets	0.250	$3.97	$4.62	$61.88	1.00	$3.97	$4.62	$61.88
Vacant land	0.238	$19.29	$20.38	$22.64	1.00	$19.29	$20.38	$22.64
Overall cost		**$121.17**	**$167.09**	**$392.99**		**$539.32**	**$921.52**	**$2,183.30**

[8] Values delineating population densities (PD in persons/km^2) to characterize regions are taken from [14], *viz*

- Rural – 0<PD<50
- Urban – 50<PD<3000
- High Density Urban – 3000<PD<10,000
- Hyper Density Urban – 10,000<PD

Decontamination of Plutonium versus Cesium

Because *Site Restoration* derived the costs of a cleanup following a plutonium dispersal, ISR determined that an appropriate multiplicative factor for the overall costs shown for plutonium in Table 2 is required to estimate the costs of the decontamination of cesium, which is the radionuclide of primary concern in a severe nuclear accident.

Plutonium dispersion accidents involve explosions that create large-sized aerosols. Outlaw et. al. [17] showed that roughly half the aerosols produced by the explosive dispersion of plutonium are larger than 30 microns. For particle sizes larger than about 30 microns, gravitational settling is important and the particles tend to deposit on the soil near the site of the explosion. This limits the size of the zone to decontaminate, increases the mass loading (g/m^2) on the surfaces to decontaminate, and limits particle mobility in the environment.

Severe reactor accidents create relatively smaller-sized aerosols [18]. Nucleation of particles from supersaturated vapors is the more important source of aerosols in reactor accidents. Particle sizes of about 3.5 – 4 microns are typical for this process, while for core debris interactions with concrete they are typically around 1 micron. The smaller particles have a lower deposition velocity and they tend to disperse further downwind. Their concentration on the surface is typically lower and the size of the zone to decontaminate is larger. In addition, severe reactor accidents disperse a wide range of fission products (e.g. cesium, rubidium, and others) and possibly some actinides (e.g. plutonium).

Soluble radionuclides such as cesium are more difficult to remove from porous surfaces than insoluble radionuclides such as plutonium. To illustrate the difference in the DF achievable for the two different radionuclides, we present the results obtained with the technique of strippable coatings. Sandia performed identical experiments attempting to remove both cesium and plutonium from concrete. The results from these tests were that the DF for cesium is 1.2 while the DF for plutonium is 5.8 [19].

This is consistent with CONDO decontamination factors, which for cesium is always less than or equal to plutonium [8] and confirms that cesium is more difficult to remove than plutonium. See Annex A for a more detailed discussion on the comparison of cesium and plutonium decontamination.

Therefore, ISR has determined that the DF for cesium may be less than or equal to plutonium, but will never be greater.

ISR considered two cases: (1) the cost of cesium decontamination equals that of plutonium; and (2) the cost of cesium decontamination is twice that of plutonium. Both cases assume that the cost of decontamination varies linearly with DF. The calculations for the nonfarm decontamination cost (CDNFRM) employ both cases for the costs determined by *Site Restoration*/Luna in Table 3 and Table 4 respectively.

Table 3: Suggested values of CDNFRM assuming cost (cesium) = cost (plutonium) (costs in 2005 USD)

	Light Decontamination (DF=3)		Heavy Decontamination (DF=15)	
	NYC metro	Area Outside NYC Metro Area	NYC metro	Area Outside NYC Metro Area
Cost per km^2 ($) from *Site Restoration*/*Survey of Costs*	5.39E+08	1.21E+08	2.18E+09	3.93E+08
Total area within 50-mi radius (km^2)	356	19986	356	19986
Total cost for the area ($)	1.92E+11	2.42E+12	7.77E+11	7.85E+12
Total cost over 50-mi radius ($)	2.61E+12		8.63E+12	
Population over 50-mi radius	19,228,712		19,228,712	
CDNFRM Per capita cost ($, 2005)	135,927		448,889	

Table 4: Suggested values of CDNFRM assuming cost (cesium) = 2 × cost (plutonium) (costs in 2005 USD)

	Light Decontamination (DF=3)		Heavy Decontamination (DF=15)	
	NYC metro	Area Outside NYC Metro Area	NYC metro	Area Outside NYC Metro Area
Cost per km^2 ($) from *Site Restoration*/*Survey of Costs*	1.08E+09	2.42E+08	4.37E+09	7.86E+08
Total area within 50-mi radius (km^2)	356	19986	356	19986
Total cost for the area ($)	3.84E+11	4.84E+12	1.55E+12	1.57E+13
Total cost over 50-mi radius ($)	5.23E+12		1.73E+13	
Population over 50-mi radius	19,228,712		19,228,712	
CDNFRM Per capita cost ($, 2005)	271,854		897,778	

The cost of light decontamination is between $136,000 and $272,000 per person, while the cost of heavy decontamination is between $449,000 and $898,000 per person.

Approach B: Determining decontamination costs using current US data from Reichmuth

US Homeland Security and EPA have recognized that cesium represents a major problem for radiological decontamination. As such they have commissioned studies such as: a) identification of the economic extent of the threat of a cesium-based radiological dispersal device (RDD) [14]; and b) determination of the efficacy of novel decontamination methods (e.g. strippable coatings as discussed above) on cesium-contaminated surfaces [20,21].

Reichmuth has conducted many studies evaluating the economic consequences of nuclear weapons and RDD effects on major metropolitan centers in the US and Canada [22]. Of particular relevance here is her work with RDDs involving cesium. While the mechanisms for dispersal differ between a reactor accident and an RDD event, the key factor in determining cost

is removal of cesium from porous substances, such as concrete, found in urban areas.

The table below summarizes two of Reichmuth's studies:

Table 5: Summary of the decontamination costs (2005 USD) based on Reichmuth's studies

Target (population density)	Cesium activity[9]	Effected Area	Total Cost of Restoration	Cost per person
NYC (10,000 persons/km^2))	1 x 10^4 Ci (3.7 x 10^{14} Bq)	10 km^2	$20 Billion	$200,000
Vancouver (5000 persons/km^2)	1 x 10^3 Ci (3.7 x 10^{13} Bq)	6 km^2	$8 Billion	$251,493

Reichmuth derived costs based on a dose rate limit for rehabitation. The data above is based on a "clean-up standard" of 500 mrem/y (5 mSv/y), which is similar to the habitability criterion used in the Entergy MACCS2 simulation: 2,000 mrem (20 mSv/y) in the first year and 500 mrem/y (5 mSv/y) for the following four years.

To verify if these costs were derived for contamination levels that are relevant to the case of a severe accident at Indian Point, we compared the cesium activity concentrations for the three scenarios in the table below.

Table 6: Comparison of cesium ground concentrations

Scenario	Cesium activity concentration
Reichmuth (NYC)	3.7 x 10^{13} Bq/km^2
Reichmuth (Vancouver)	6.2 x 10^{12} Bq/km^2
Entergy (NYC) (worst case)	1.0 x 10^{13} Bq/km^2

The cesium activity concentrations and the decontamination costs per person reported by Reichmuth are similar to those determined in this report. The decontamination techniques proposed by Reichmuth included sandblasting the exterior and completely demolishing the affected buildings, both of which correspond to heavy decontamination. Therefore using Reichmuth's results, the cost for nonfarm heavy decontamination (CDNFRM, DF=15) is between $200,000 and $252,000 per person.

Approach C: Determining decontamination costs using CONDO

The data and analysis technique reported in this section is derived from CONDO, a software tool for estimating the consequences of decontamination options developed by the NRPB in the UK [8]. CONDO is supported by a database that contains the effectiveness (i.e. DF), cost and required labour for the decontamination of cesium and plutonium using several techniques.

[9] Activity is reported here in the traditional unit of radioactivity, Curies (Ci) and the SI unit, Becquerels (Bq). 1 Ci = 3.7 x 10^{10} Bq.

CONDO prescribes the following processes for a DF of approximately 3 for cesium:

- Soil and grass - grass cutting and collection, plant and shrub removal;
- Trees/shrubs - hosing down;
- Paved surfaces - fire hosing;
- Buildings roofs - peelable coatings;
- Building walls - peelable coatings; and
- Building interiors - vacuum cleaning;

and prescribes the following processes for a DF of 10 or greater (where applicable) for cesium:

- Soil and grass - turf removal;
- Trees/shrubs - felling and replacement;
- Paved surfaces - sand blasting and waste collection;
- Buildings roofs - sandblasting with waste collection;
- Building walls - sandblasting with waste collection; and
- Building interiors - replacement.

In general, decontamination costs are calculated by CONDO using the following methodology:

1. From the CONDO database, retrieve a cost per km^2 of land for a specific area (e.g. paved surfaces) and technique (e.g. fire hosing) for both fragmented[10] and continuous[11] areas.
2. Multiply these costs by the surface fraction of the area depending on the type of population density (e.g. for semi-urban areas, the surface fraction of paved surfaces is 0.40);
3. Further multiply the costs by a factor to account for building heights or fractions of soil/grass covered by plants, trees, etc. (e.g. building interiors in a semi-urban area have a multiplicative factor of 11.55);
4. Further multiply the fragmented cost by the fragmented percentage and the continuous cost by the continuous percentage and add the two to obtain a total cost for the specific area and technique; and
5. Add the costs of all techniques to obtain a total cost of decontamination.

The NYC metropolitan area is comprised of both urban and hyper-urban population densities. To account for this, ISR performed two calculations for the total cost of decontamination to determine an appropriate range of decontamination costs using the techniques listed above for light and heavy decontamination:

- Urban calculation: assumes the NYC metropolitan area has an urban population density of greater than 1,000 persons per km^2, and everywhere else in the 50-mi radius area is semi-urban with a population density less than 1,000 persons per km^2.
- Hyper-urban calculation: assumes NYC metropolitan area has a hyper-urban population density of about 10,000 persons per km^2, and everywhere else in the 50-mi radius area

[10] Fragmented areas are those that are not relatively uniform over a large area and thus require small-scale decontamination.
[11] Continuous areas are those that are relatively uniform over a large area and thus large-scale decontamination may be used.

is urban with a population density between 1,000 and 10,000 persons per km^2.

Annex C contains the details of these calculations; the final values are summarized in the tables below. The cost of light decontamination is between \$19,000 and \$30,000 per person, while the cost of heavy decontamination is between \$90,000 and \$140,000 per person.

Table 7: Costs using CONDO values assuming the NYC metro area is classified as urban and the area outside the NYC metro area is classified as semi-urban (costs in 2005 USD)

	Light Decontamination (DF=3)		Heavy Decontamination (DF=15)	
	NYC metro	Area Outside NYC Metro Area	NYC metro	Area Outside NYC Metro Area
Cost per km^2, (\$) (Annex C)	2.78E+07	1.82E+07	1.31E+08	8.40E+07
Total area (km^2)	356	19986	356	19986
Total cost for the area (\$)	9.90E+09	3.64E+11	4.66E+10	1.68E+12
Total cost over 50-mi radius (\$)	3.74E+11		1.73E+12	
Population over 50-mi radius	19,228,712		19,228,712	
CDNFRM Per capita cost (\$, 2005)	19,431		89,734	

Table 8: Costs using CONDO values assuming the NYC metro area is classified as hyper-urban and the area outside the NYC metro area is classified as urban (costs in 2005 USD)

	Light Decontamination (DF=3)		Heavy Decontamination (DF=15)	
	NYC metro	Area Outside NYC Metro Area	NYC metro	Area Outside NYC Metro Area
Cost per km^2, (\$) (Annex C)	5.61E+07	2.78E+07	2.64E+08	1.31E+08
Total area (km^2)	356	19986	356	19986
Total cost for the area (\$)	2.00E+10	5.56E+11	9.40E+10	2.62E+12
Total cost over 50-mi radius (\$)	5.76E+11		2.71E+12	
Population over 50-mi radius	19,228,712		19,228,712	
CDNFRM Per capita cost (\$, 2005)	29,933		140,430	

Approach D: Determining decontamination costs using RISO

The methodology followed for the CONDO/NRPB decontamination costs in the preceding section was repeated using the costs per km^2 reported by the Riso National Laboratory (RISO) [9] as a starting point. ISR chose techniques from RISO that most closely correlated to those selected in the CONDO analysis; all of these techniques are used for light decontamination and therefore heavy decontamination is not considered for the RISO analysis.

The area-specific values (i.e. area and fragmented fractions) used for the CONDO analysis (Approach C) are also used here to account for semi-urban, urban and hyper-urban areas. The RISO cost rates are provided in Annex C; a summary of the results is shown in Table 9 and Table 10.

ISR determined that the cost of light decontamination is between $36,000 and $59,000 per person.

Table 9: Costs using RISO values assuming the NYC metro area is classified as urban and the area outside the NYC metro area is classified as semi-urban (costs in 2005 USD)

	Light Decontamination (DF=3)	
	NYC metro	Area Outside NYC Metro Area
Cost per km^2 ($) (Annex C)	5.46E+07	3.34E+07
Total area within 50-mi radius (km^2)	356	19985
Total cost for the area ($)	1.94E+10	6.68E+11
Total cost over 50-mi radius ($)	6.87E+11	
Population over 50-mi radius	19,228,712	
CDNFRM Per capita cost ($, 2005)	35,726	

Table 10: Costs using RISO values assuming the NYC metro area is classified as hyper-urban and the area outside the NYC metro area is classified as urban (costs in 2005 USD)

	Light Decontamination (DF=3)	
	NYC metro	Area Outside NYC Metro Area
Cost per km^2 ($)(Annex C)	1.17E+08	5.46E+07
Total area within 50-mi radius (km^2)	356	19985
Total cost for the area ($)	4.17E+10	1.09E+12
Total cost over 50-mi radius ($)	1.13E+12	
Population over 50-mi radius	19,228,712	
CDNFRM Per capita cost ($,2005)	58,916	

Summary of ISR's decontamination costs

A summary of decontamination costs obtained by ISR using Approaches A to D described above is shown in Table 11 and in Figure 4.

The MACCS2 code restricts decontamination costs (CDNFRM) to a maximum of $100,000/person; therefore, ISR modified the source code to allow for the greater decontamination costs proposed here.

The total economic cost, and therefore the OECR, reaches a maximum for decontamination costs around $200,000/person as shown in Figure 5. This is the threshold near which the cost

of decontaminating equals that of condemning and thus the total cost of condemnation, which is governed by the value of nonfarm wealth (VALWNF).

If the cost of heavy decontamination is greater than $200,000/person, the resulting OECR is $581,000/year, which is 2.74 times the OECR calculated by Entergy ($212,000/year for IP2).

Table 11: Summary of ISR's decontamination costs

Approach	Reference or Source of Data	CDNFRM ($/person, 2005)	
		Light Decontamination	Heavy Decontamination
-	Entergy (Sample Problem A)	5,184	13,824
A	*Site Restoration*/Luna	136,000 - 272,000	449,000 – 898,000
B	Reichmuth	Not available	200,000 – 252,000
C	CONDO	19,000 - 30,000	90,000 – 140,000
D	RISO	36,000 - 59,000	Not available
-	**Aggregate**	**19,000 – 272,000**	**90,000 – 898,000**

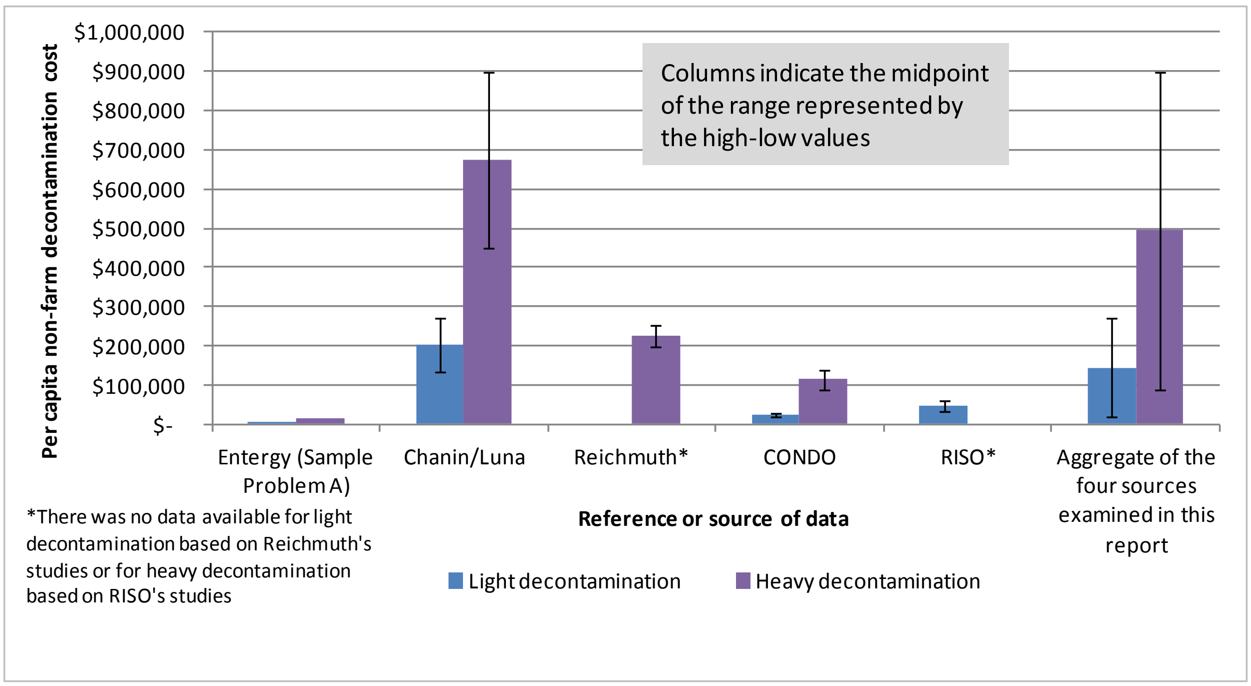

Figure 4: Graphical summary of decontamination costs (2005 USD) with ranges

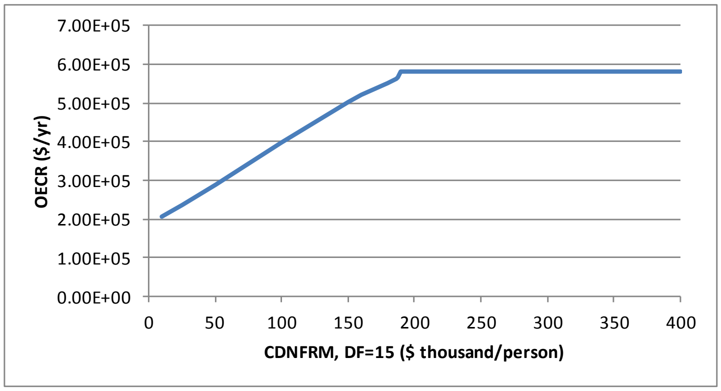

Figure 5: OECR vs heavy decontamination cost (2005 USD)

4.2.4 Discussion of TIMDEC

The decontamination times (TIMDEC) used by Entergy (i.e. 60 and 120 days for DF of 3 and 15 respectively) were taken directly from MACCS2 Sample Problem A. As stated in Section 3.2 these values were an assumption from NUREG-1150. To assess whether or not these durations are reasonable, they are compared to decontamination times of actual severe accidents.

Large-scale decontamination of the area affected by the Chernobyl accident terminated four years after the accident [23]. This included the decontamination of tens of thousands of buildings in the most contaminated cities and villages of the former USSR. Since large-scale decontamination efforts have ceased, it is not possible to estimate the total duration of clean-up for the Chernobyl accident; however, it is reasonable to expect that the decontamination time would be at least four years of continuous time (i.e. 24 h/day) for a severe accident at Indian Point.

Fukushima City is home to roughly 300,000 residents and sits 60 kilometers (35 miles) northwest of the Fukushima Daiichi nuclear plant. The decontamination efforts at Fukushima City took time to organize. After many trial decontaminations, the large-scale decontamination work may start in 2012, a full year after the accident [24],[25].

A trial decontamination of the Onami District in Fukushima City started on October 18, 2011 [26]. Originally, there was a plan to complete the decontamination of 367 households by the end of 2011, but decontamination is now expected to take much longer [27]. Many reports suggest that decontamination of the area around the nuclear plant could take decades [28] [29]. This suggests that an upper bound for the decontamination time could be approximately 30 years.

ISR calculated the effect on cost of increasing decontamination times up to 30 years as shown in Figure 6. The MACCS2 code restricts the decontamination time input to a maximum of one year; therefore, ISR modified the source code to allow for greater decontamination times. The total economic cost, and therefore the OECR, increases with decontamination time since relocation costs increase. As the OECR increases due to decontamination time, it becomes more cost-effective to condemn infrastructure and buildings and therefore the OECR plateaus.

Based on the data from Chernobyl and Fukushima, ISR believes that a reasonable range of decontamination times for the purpose of evaluation is between 4 and 30 years for heavy

decontamination and between 2 and 15 years for light decontamination[12]. For this range of possible decontamination times, ISR determined that the resulting OECR is 3.0 to 5.7 times greater than the OECR calculated by Entergy (2.12E+05 $/year for IP2).

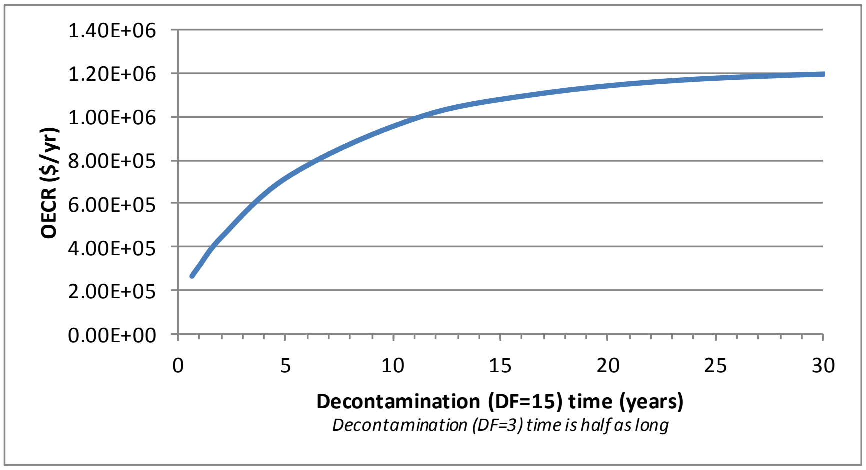

Figure 6: OECR (2005 USD) for decontamination times up to 30 years

4.3 Value of nonfarm wealth

4.3.1 Parameter definition

Parameter name: VALWNF
Entergy value: $208,838 per person, (2004 USD)

The MACCS2 manual [1] defines VALWNF as:

> VALWNF defines the value of the nonfarm wealth in the region. Nonfarm wealth includes all public and private property not associated with farming that would be unusable if the region was rendered either temporarily or permanently uninhabitable. This value should include the cost of land, buildings, infrastructure, and the cost of any non recoverable equipment or machinery.

4.3.2 Source of Entergy's value

Entergy's report details their calculation of VALWNF [30], which, along with the value of farm wealth (VALWF) and the long-term exposure period (EXPTIM)[13], was the only value not derived from Sample Problem A. Entergy's report states that VALWNF cannot be readily calculated without recent data from the US Bureau of Economic Analysis, specifically data on "reproducible tangible wealth". In the absence of this data, Entergy used SECPOP2000 [31] to generate the original VNFRM values, as originally tabulated in Entergy's report [30]. In MACCS2, the user

[12] The assumption from NUREG-1150 that the time for light decontamination is half as long as the time for heavy decontamination is adopted here.

[13] EXPTIM is the duration of the long-term exposure period considered by CHRONC [1]. Entergy selected a value of 30 y, which is the EPA standard default [1].

must enter the value of nonfarm wealth in two input files: (1) the site data input file requires a value of nonfarm wealth (VNFRM) for each economic region or in the case of NY, each county; (2) the CHRONC input file requires a value of nonfarm wealth (VALWNF) for the entire region of interest (i.e. the 50-mile radius zone) that is an aggregate of the VNFRM values. ISR determined that the OECR output value is not sensitive to changes in the VNFRM values entered in the site data input, but is sensitive to the VALWNF value entered in the CHRONC input file.

SECPOP2000 is a sector population, land fraction and economic estimation program capable of generating MACCS2 input data. Originally developed by the Environmental Protection Agency as SECPOP to calculate population estimates, Sandia National Labs was tasked to develop a new version, SECPOP2000, which would include the 2000 census population data and 1997 economic data[14] [31].

The Entergy report concludes that the SECPOP2000-provided values were not entirely adequate because the database uses 1997 economic data. In an effort to better represent the economic worth of the area, Entergy obtained the Gross County Product (GCP) (or Gross Metro Product (GMP)) values per spatial sector. Entergy divided the GCP by the population to obtain a value of GCP/person. Entergy then added this GCP/person value to the original VNFRM value to obtain a final VNFRM value which it felt better represents the economic worth of that sector. Finally, Entergy weighted these values by population to obtain a final VALWNF value for use as the MACCS2 CHRONC input.

4.3.3 Discussion

ISR concluded that Entergy's calculations of VALWNF are outdated since the values obtained from SECPOP2000 were not scaled up from 1997 values to 2004 values.

ISR scaled the SECPOP VNFRM values from 1997 to 2004 dollars by using the increase in GDP: $8,332 billion for 1997 and $11,853 billion for 2004 [32], resulting in an increase by a factor of 1.43.

All of the SECPOP VNFRM values were increased by a factor of 1.43 to better represent economic worth in 2004 dollars. To follow through with Entergy's methodology, the GCP is then added to obtain VNFRM for each county. The spreadsheet for the calculation is included in Annex D.

The population-weighted sum of all counties within the 50-mile radius around Indian Point yields a VALWNF value of $284,189 per person, which is significantly higher than the value used by Entergy, which was $208,838.

Using VALWNF of $284,189 per person would increase the final cost (OECR) by about 18%. All values in the determination of VALWNF are in 2004 USD for comparison to Entergy's value, which is also in 2004 USD.

[14] The SECPOP manual [31] states that its references for VNFRM (1997 economic data) include: 1998 and 1999 Statistical Abstract of the United States, US Dept. of Commerce, Economics and Statistics Admin., Bureau of the Census, 1999 County and City Data Book, US Dept. of Commerce, Bureau of the Census, Data User Services Div.

4.4 Property depreciation rate

4.4.1 Parameter definition

Parameter name: DPRATE
Entergy value: 0.2 per year

The MACCS2 manual defines DPRATE as:

> …the depreciation rate that applies to property improvements during a period of interdiction. This depreciation rate is intended to account for the loss of value of buildings and other structures resulting from a lack of habitation and maintenance.

In MACCS2, the loss of value of buildings and other structures is assumed to depreciate exponentially (decrease per unit time is a constant fraction of the remaining value).

4.4.2 Source of Entergy's value

There is no readily available data with respect to depreciation rates for untended property following a period of interdiction. As such, the existing value of 0.20 (or 20%) is taken from Appendix VI of Reactor Safety Study (WASH-1400). This value was assumed by the author to reflect the cost of property maintenance.

4.4.3 Discussion

It should be noted that the authors of WASH-1400 acknowledged that this depreciation rate is the "only parameter in the equation (for the present value of property following a period of interdiction) whose value could be seriously in error". However, ultimately this value was, to quote WASH-1400, "judged to be appropriate in view of the lack of maintenance during interdiction. Where property is maintained, depreciation is usually judged to be in the range of 3 to 5%." No, more specific, reasoning or calculations were provided in WASH-1400.

The values for a well maintained building quoted in WASH-1400 are consistent with the Modified Accelerated Cost Recovery System (MACRS) recommended in the Internal Revenue Service's (IRS) Publication 946, *How to Depreciate Property* [33].

It appears reasonable that a building that is not maintained would depreciate more quickly than a building that is regularly maintained. The depreciation rate of 3 to 5% is therefore accepted as a lower bound for the depreciation rate, assuming that buildings are maintained during the interdiction.

Since no other value of the depreciation rate for a building that is not maintained could be located, the value of DPRATE of 20% is accepted and the final cost (OECR) does not change.

4.5 Societal discount rate for property

4.5.1 Parameter definition

Parameter name: DSRATE
Entergy value: 0.12 per year (for 2005)

The MACCS2 manual defines DSRATE as:

> …the expected rate of return from land, buildings, equipment, etc. For example, the inflation-adjusted real mortgage rate for land and buildings could be used.

4.5.2 Source of Entergy's value

Entergy used the existing value of 0.12 (or 12%) as a representative value based on a number of measures of rate of return on debt or equity given in NUREG/CR-4551. This included the conventional mortgage rate from 1970-1986 and the return on equity of stock composites, the Standard and Poors (S&P) 500 and Fortune 500 companies. Ultimately, these values were all within 5 percentage points of 12%.

4.5.3 Discussion

Again, one of the factors used to determine DSRATE in NUREG/CR-4551 was the conventional mortgage rate at the time. This is supplemented by the fact that WASH-1400 also used mortgage rate in its determination of DSRATE. Therefore, ISR used the 2005 conventional mortgage rate in the US as the updated value of DSRATE.

From HSH Associates' national mortgage statistics, ISR determined that a representative 2005 conventional long-term mortgage rate was between 5% and 7% [34].

Using this range of values for DSRATE, the final cost (OECR) would decrease by about 8% to 12%.

4.6 Per capita cost of long-term relocation

4.6.1 Parameter definition

Parameter name: POPCST
Entergy value: $8,640 per person (2005 USD)

The MACCS2 manual defines POPCST as:

> …the per capita removal cost for temporary or permanent relocation of population and businesses in a region rendered uninhabitable during the long-term phase time period. This cost is assessed if any of the following actions are required: decontamination alone, decontamination followed by interdiction, or condemnation. This value should be derived in a way that takes account of both personal and corporate income losses for a transitional period as well as moving expenses.

4.6.2 Source of Entergy's value

Entergy's use of the value of $8,640 was based on a CPI-adjustment of a moving cost of $5,000 in 1986 found in NUREG/CR-4551 to 2005. The value was recommended based on a combination of:

- Scaling the Burke et. al. recommended moving cost of $4,000 (given in *Economic Risks of Nuclear Power Reactor Accidents*) from 1982 to 1986 to yield $4,500; and
- The moving cost based on the per capita income of 1986 of $14,600 to assume 140 days of lost wages, i.e. $5,600.

Based on these two values ($4,500 and $5,600), NUREG/CR-4551 used a value of $5,000.

It should be noted that only lost wages were considered in these values with the argument that, with the majority of personal possessions being contaminated and hence undesirable, moving costs would be extremely low in comparison to lost wages.

4.6.3 Discussion

ISR agrees that moving expenses will contribute very little to POPCST in comparison to lost wages. Therefore, ISR calculated the new value of POPCST considering two factors: (1) personal income per day; and (2) the number of days of lost wages.

Based on the most recent data from the United States Census Bureau, the average per capita income in New York State is $27,877/year or $76/day (adjusted to 2005 USD using CPI) [35].

As stated above, the interdiction duration in NUREG/CR-4551 is 140 days; in WASH-1400, it is over 6 months. Based on current unemployment benefits policies, the regular duration of state benefits is 26 weeks while the current temporary extensions of benefits bring the total to a maximum of 93 weeks [36]. It should be noted that NY state benefits do not correspond to the full amount of loss of income (it corresponds to about 50% of wages). Nevertheless, the calculation of loss of income is based on the full average income.

Therefore, based on personal income and unemployment benefit policies currently in place in NYS, the new value of POPCST is calculated to be between $10,640/person (for 140 days of lost wages) to $49,857/person (for 93 weeks of lost wages). Using the range of values, the final cost (OECR) would increase by 5% to 108%.

4.7 Nonfarm wealth improvements fraction

4.7.1 Parameter definition

<u>Parameter name</u>: FRNFIM
<u>Entergy value</u>: 0.8 (unitless)

The MACCS2 manual defines FRNFIM as:

> …the fraction of nonfarm wealth in the region due to improvements. This value includes buildings and infrastructure such as roads and utilities, as well as any non-recoverable equipment or machinery.

4.7.2 Source of Entergy's value

Entergy's value for FRNFIM was taken directly from Sample Problem A. It should be noted that the guidance provided in NUREG/CR-4551 states that this value be between 0.7 and 0.9.

4.7.3 Discussion

A fraction of 0.8 is applicable to rural or semi-urban lands. With hyper-density urban centers such as NYC, more analysis is warranted.

Recently a plot of land sold in NYC for $345 million for 3.4 acres [37]. This corresponds to \$2.5B/km^2. This plot of land was used to build the Time-Warner Centre, currently valued at (with infrastructures) about $2 Billion [38], or \$143B/km^2. So for a hyper-dense area, a FRNFIM value of close to unity would be justified.

Since the geographic region for this study includes lower population densities, we recommend using FRNFIM of 0.9. This would increase the final cost (OECR) by about 3%.

4.8 Comparison of Entergy's MACCS2 input values with those from other nuclear power plants in the US

Table 12 provides a comparison of the MACCS2 input values used by Entergy with those of other nuclear power plant license applicants. For comparison purposes:

a. only values for parameters discussed in Sections 4.2 to 4.7 of this report (i.e. the most sensitive for cost determination) are provided; and
b. all cost-parameter values were CPI-adjusted (by ISR) to 2005 values (using the US Department of Labor, Bureau of Labor Statistics), the reference year used for the Indian Point analysis.

Table 12: Comparison of sensitive parameter values for IP with other US nuclear stations (costs in 2005 USD)

Station	Year	CDNFRM (DF=3)	CDNFRM (DF=15)	TIMDEC (DF=3/ DF=15)	VALWNF	DPRATE	DSRATE	POPCST	FRNFIM
Surry [1] *	1987	$5,158	$13,754	60 d/ 120 d	$144,412	0.2	0.12	$8,596	0.8
Clinton [39]	2000	$5,172	$13,791	60 d/ 120 d	$121,265	0.2	0.12	$8,620	0.8
North Anna [40]	2000	$3,981	$10,616	60 d/ 120 d	$160,148	0.2	0.12	$8,279	0.8
Arkansas [41]	2002	$5,191	$13,846	NA	$136,903	0.2	0.12	$8,649	NA
Indian Point (Entergy)	2005	$5,184	$13,824	60 d/ 120 d	$208,838	0.2	0.12	$8,640	0.8
Levy [42]	2007	$5,415	$14,441	60 d/ 120 d	$178,217	0.2	0.12	$9,025	NA
NA – not available in public documentation *MACCS2 Sample Problem A input parameter values									

For all the stations listed in Table 12, the decontamination costs (CDNFRM) and relocation costs (POPCST) were determined by scaling up the costs in MACCS2 Sample Problem A using the difference in CPI. The value of non-farm wealth (VALWNF) appears to be site-specific, likely resulting from location census data.

The decontamination times (TIMDEC), depreciation rate (DPRATE), rate of return (DSRATE) and fraction of non-farm wealth due to improvements (FRNFIM) are all equivalent to the values used in the Surry analysis (i.e. Sample Problem A).

Table 12 shows that no matter the specific location or attributes of the facility, the input values appear to be taken from Sample Problem A. As described in the preceding sections of Section 4, ISR has concluded that reliance on Sample Problem A values (with the exception of VALWNF) has led to a significant underestimation of the costs of a severe accident at Indian Point.

5. CONCLUSION

ISR concludes that Entergy's input parameters to the MACCS2 code underestimated the total economic cost of a severe nuclear accident primarily because of the direct use of MACCS2 Sample Problem A input values for the CHRONC module. The underestimation was mostly due to costs and times for decontamination that were unrealistic given current known decontamination data and the complexities of a urban to hyper-urban area such as that surrounding IP.

ISR has derived more appropriate values and calculated the effect on the MACCS2 output. A summary of the ISR-proposed range of inputs and calculated OECR for all of the sensitive parameters is provided in Table 13. For all cases, only a single input parameter is varied, keeping all others as determined by Entergy.

If all of the ISR proposed inputs are used, the OECR is determined to be between 4 and 7 times the currently calculated Entergy value.

Table 13: Summary of ISR proposed inputs and calculated OECRs (costs in 2005 USD)

Parameter	Description	Entergy's value	ISR's proposed input value		ISR's calculated OECR ($/yr) and ratio[a]	
			Minimum	Maximum	Minimum	Maximum
CDNFRM (DF=3)	Per capita cost of nonfarm light decontamination	$5,184	$19,000	$272,000	4.21E+05 (1.99)	1.25E+06 (5.88)
CDNFRM (DF=15)	Per capita cost of nonfarm heavy decontamination	$13,824	$90,000	$898,000		
TIMDEC (DF=3)	Time required for light decontamination	60 d	2 y	15 y	6.44E+05 (3.04)	1.20E+06 (5.66)
TIMDEC (DF=15)	Time required for heavy decontamination	120 d	4 y	30 y		
VALWNF	Per capita value of nonfarm wealth (2004 USD)	$208,838	$284,189		2.51E+05 (1.18)	
DPRATE	Depreciation rate	20%	20%		2.12E+05 (1.00)	
DSRATE	Societal discount rate for property	12%	5%	7%	1.87E+05 (0.88)	1.95E+05 (0.92)
POPCST	Per capita cost of long-term relocation	$8,640	$10,640	$49,857	2.23E+05 (1.05)	4.41E+05 (2.08)
FRNFIM	Nonfarm wealth improvements fraction	80%	90%		2.19E+05 (1.03)	
Using all of ISR's proposed input values					**9.07E+05 (4.28)**	**1.47E+06 (6.96)**
Notes: [a] The ratio shown in brackets is the ratio of the ISR-calculated OECR to the Entergy-calculated OECR ($2.12E+05/yr).						

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ANNEX A Response to US NRC Staff Evaluation (Appendix G)

ISR response to "US NRC Staff Evaluation of Severe Accident Mitigation Alternatives for Indian Point Unit Nos. 2 and 3 in Support of License Renewal Application Review" (Appendix G)

Background

As part of its review of Entergy's application for renewal of the Indian Point (IP) reactor units, New York State Attorney General (NYAG) contracted ISR to review specific comments in the above-referenced document.

This is done below in a format of repeating the NRC comments verbatim, followed by ISR's response to each question or statement. The NRC report excerpts are listed in the order that they appear in Appendix G.

NRC Comments and ISR response:

1) Page G-23, lines 37 – 43

> *Sandia noted that the primary constituent in weapons grade plutonium, Pu239, is an alpha emitter, whereas the primary contaminant from an NPP accident, Cs137, is a gamma emitter. As such, Pu239 is more difficult and expensive to characterize and verify in the field than gamma emitters like Cs137. Furthermore, Pu239 is primarily an inhalation hazard with half-life of 24,000 years, whereas Cs137 is primarily an external health hazard with half-life of about 30 years. The need for evacuating the public is much greater with plutonium because if inhaled, the health consequences can be severe.*

Public evacuation and the associated costs are not part of the assessment. The SAMA analysis includes the costs of longer-term dose reduction measures such as permanent relocation and decontamination. It is the cost of these measures that should be assessed for plutonium and cesium.

From above, NRC/Sandia is implying that characterization is a major part of the costs of decontamination.

The main cost of decontamination is not radionuclide detection/characterization, but decontamination, removal, transport and storage of waste and/or building demolition. The cost fraction of urban characterization of plutonium has been calculated by Chanin in Site Restoration [7] as less that 1 % of the total and is depicted in the graph below (see Figure 7). (Note that in the graph, characterization is included in the "other costs" category).

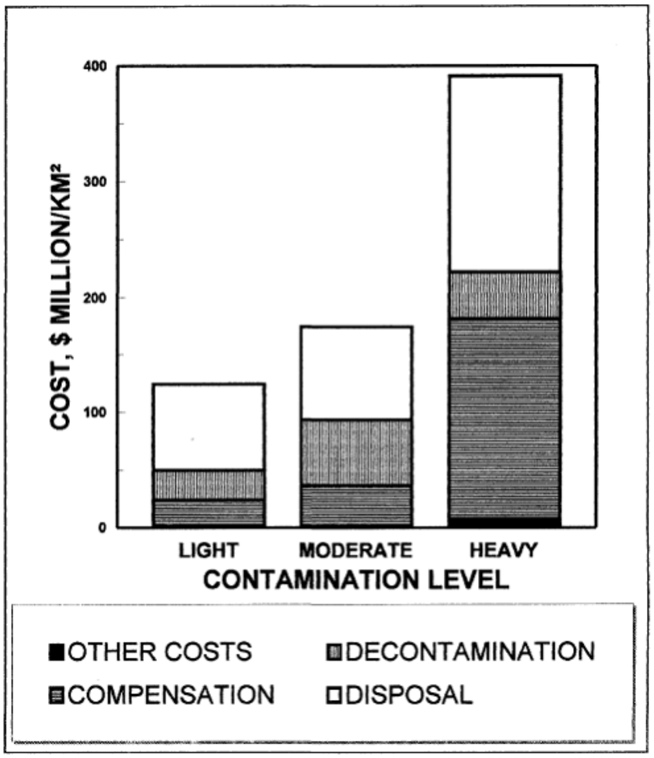

Figure 7: Composition of decontamination costs for plutonium [7]

2) Page G-24, lines 7-11

> *Sandia considered the decontamination activities described in the Site Restoration study together with the differences in health hazards posed by Pu239 versus Cs137, and concluded that the activities required to support clean-up of moderate plutonium contamination align more closely with clean-up activities for heavy cesium contamination. Sandia performed the comparison of decontamination cost values on this basis.*

NRC is quoting, almost verbatim, from the Sandia report [43], which uses the following argument to arrive at the conclusion above:

> *For decontamination of ^{137}Cs, less costly options are available rather than complete destruction and removal of infrastructure. Road surfaces contaminated with cesium could be planed or scraped just a few millimeters, using commercial equipment, to significantly reduce the radiation dose and could be sealed with asphalt. If needed a pavement overlay could be added, which is considerably cheaper than complete destruction. Such actions would reduce the dose to a low enough level to assure protection of public health and safety. ^{137}Cs does present some risk from resuspension and inhalation, but because it is primarily a dose hazard, reducing the dose through scraping and placing a cover over the remaining contamination may be expected to be sufficient. The life expectancy of an asphalt roadway is more than 30 years, providing time for the remaining ^{137}Cs to decay.*

A pavement overlay could also be used to encapsulate the ^{239}Pu to prevent disturbance or migration. However, anytime long-lived contamination is left in place, even if encapsulated, loss of control, which would result in a health hazard to the public, must be considered. It is reasonable to consider that control may be maintained for the life of pavement surface (i.e., 30 years); however, it is not practical to assume that control could be maintained for the thousands of years the ^{239}Pu would be present. Given the long term health hazard present from the ^{239}Pu, it is expected that decontamination efforts would be focused on complete removal, which is consistent with the Site Restoration study decontamination description for heavy contamination.

Considering the decontamination activities described above, the activities required to support decontamination of moderate plutonium contamination align more closely with decontamination activities for heavy decontamination of cesium.

The Sandia report [43] relies heavily on the cost of decontamination of a road to estimate the costs of decontamination of buildings, houses, soil and vegetation in urban areas. A review of the literature does not support this extrapolation.

A severe reactor accident will result in contamination containing fission products (cesium and other radionuclides) and actinides (plutonium). The choice of decontamination techniques will be based on an analysis of the exposure pathways for all these radionuclides. In some locations, the hazard from plutonium could be the driving factor while in other places the hazard from cesium could dominate. Any effective decontamination technique will result in some removal of cesium, plutonium and any other radionuclides. Therefore, using the example of road decontamination presented by Sandia, if complete removal of the road is justified for plutonium, it will also result in the full decontamination of cesium.

The concern for plutonium resuspension is due to the fact that it initially does not bind to surfaces because plutonium oxide it is not readily soluble. This property also makes it initially easy to remove. Over time plutonium settles into the surface and resuspension becomes less significant.

The airborne concentration after the passage of the plume relative to the concentration on the ground can be characterized by a resuspension coefficient $K(t)$. This resuspension coefficient varies with time as plutonium particles sink into the soil or are washed away. Reference [44] suggests the following relation for the plutonium resuspension coefficient.

$$K(t) = K_0 e^{-at} + K_\infty$$

where $K_0 = 10^{-3}\,\text{cm}^{-1}$

$K_\infty = 10^{-7}\,\text{cm}^{-1}$

$a = 5\ \text{year}^{-1}$

After 30 years, the resuspension coefficient becomes negligible and the long term health hazard from plutonium is much less than for other radionuclides.

If long-term control is disregarded and scraping and overlay is justified for plutonium decontamination, then there would be an equal if not greater percentage of plutonium removed compared to cesium. This is because unlike plutonium, cesium is soluble and can penetrate porous surfaces, making it more difficult to decontaminate[15]. In general, a greater depth of scraping would be required to achieve the same decontamination factor for cesium as for plutonium. Regardless of the depth of scraping, the ultimate cost of decontamination is still the same for both radionuclides since a single technique is used.

If long-term control and maintenance of material, infrastructure, property, etc. is of primary concern as Sandia suggests for roads, complete demolition and removal will in most cases be desired as the decontamination strategy for all areas (e.g. roads, buildings, grass, trees, etc.). Only in this case is plutonium (and other alpha emitters) the driving factor for decontamination; but demolition and removal of an entire area is a form of condemnation, not decontamination, and represents the most expensive mitigative option.

If immediate decontamination and re-habitation is preferred, despite long-term control and maintenance concerns, heavy plutonium decontamination activities are likely to align with medium cesium decontamination activities due to cesium's solubility as discussed above. This is the more realistic scenario for decontamination since condemnation of property such as that in and around NYC would be the least preferred option.

As alluded to, this discussion must be extended to include the decontamination of buildings, not just roads, as this will be the highest cost contributor. Buildings occupy greater than 50% of urban area and cost approximately 20 times more than roads to decontaminate due to interior and exterior surface areas.

Therefore NRC/Sandia's conclusion that "…the activities required to support clean-up of moderate plutonium contamination align more closely with clean-up activities for heavy cesium contamination" is simply misleading since:

- only a single activity (e.g. not scraping and removal, but scraping or removal) will be selected for decontamination of a given surface (e.g. roads) following a nuclear accident; and
- long-term control is likely to be a minor concern relative to condemning property and buildings.

Using debatable analysis of the cost of road clean-up leads to the wrong conclusion.

3) Page G-24, lines 20 – 26

> *The Site Restoration study (Table 6-2) provides an estimated cost of \$178.4 million/km^2 for clean-up of moderate plutonium contamination in urban areas, of \$14,900 per person when expressed on a per capita basis for New York City. In contrast, a cost of \$13,824 per person was used in Entergy's MACCS2 analysis*

[15] ISR has examined many references [8,21,45,46] that confirm this assertion and state that the decontamination factor for cesium is equal to or less than that for plutonium for all decontamination techniques.

> *for decontamination of heavy cesium contamination. Thus, the decontamination cost of the Site Restoration study ($14,900 per person) is not significantly different than the value used by Entergy in the SAMA analysis ($13,824 per person).*

One cannot simply divide the decontamination cost per km^2 by population density – but rather building density must be taken into account [13]. Luna proposed that the ratio of population densities of New York City to Albuquerque be used to approximate this. Entergy has questioned this assumption. Accordingly, ISR used census values of building densities in both cities to arrive at a multiplicative ratio of about 9 for residential and commercial land. As shown in Approach A in Section 4.2.3, this leads to a cost of heavy decontamination between $449,000 and $898,000 per person. If this correction is not made, then the result is that a cleanup of a contaminated area in Albuquerque would be the same as a contaminated area of equal size in New York City.

ANNEX B MACCS2 User Input Sensitivity Analysis

A listing of the MACCS2 CHRONC input parameters, their ranges, units and Entergy values are provided in Table 14. The results of the ISR sensitivity analysis on all of the quantitative parameters are provided in Table 15.

The OECR calculated in Table 15 is obtained by adding the total offsite economic cost for each of the eight release categories[16] after weighting them by their respective frequencies:

$$OECR_{total} = \sum_{i=1}^{8} f_i C_i$$

where f_i is the frequency (i.e. probability) of release category i and
C_i is the total economic cost of release category i.

[16] The eight release categories are pre-defined releases of radionuclides which vary by several parameters such as release delay, duration and heat. The probability of each release category is calculated using probabilistic safety analyses, which considers the possible failures of structures, systems and components of the nuclear power plant.

Table 14: Entergy's CHRONC input parameters (all input cost values are in 2005 USD)

Field	Description	MACCS2 Range min	MACCS2 Range max	Units	Entergy Input value 1	Entergy Input value 2	Entergy Input value 3
CDFRM	Farmland Decontamination Cost	1	1.00E+05	dollars/hectare	972	2160	
CDNFRM	Nonfarm Decontamination Cost	1	1.00E+05	dollars/person	5184	13824	
DLBCST	Decontamination Worker Labor Cost	1	1.00E+06	dollars/man-year	60480		
DOSELONG	COMIDA2 Model Long-Term Dose Limit	0	1.00E+10	Sv	0.005	0.015	
DOSEMILK	COMIDA2 Model First-Year Milk Dose Limit	0	1.00E+10	Sv	0.025	0.075	
DOSEOTHR	COMIDA2 Model First-Year Nonmilk Dose Limit	0	1.00E+10	Sv	0.025	0.075	
DPFRCT	Farm Production Dairy Fraction	0	1	unitless	0.198		
DPRATE	Property Depreciation Rate	0	1	per year	0.2		
DSCRLT	Long-Term Phase Dose Criterion	1.00E-20	1.00E+05	Sv	0.04		
DSCRTI	Intermediate-Phase Dose Criterion	0	1.00E+05	Sv	1.00E+05		
DSRATE	Societal Discount Rate for Property	0	1	per year	0.12		
DSRFCT	Decontamination Factors	1.01	100	unitless	3	15	
DUR_INTPHAS	Duration of Intermediate-Phase Period	0	3.15E+07	seconds	0		
EVACST	Emergency-Phase Cost of Evacuation/Relocation	0	1000	dollars/person-day	46.7		
EXPTIM	Maximum Exposure Time for CHRONC Calculations	0	1.00E+10	seconds	9.45E+08		
FRACLD	Fraction of Site Area that is Land	1.00E-06	1	unitless	0.95		
FRCFRM	Fraction of Site Land Used for Farming	1.00E-06	1	unitless	0.382		
FRFDL	Farm Labor Cost Fraction	0	1	unitless	0.3	0.35	
FRFIM	Farm Wealth Improvements Fraction	0	1	unitless	0.25		
FRMPRD	Average Annual Farm Production Value	0	1.00E+05	dollars/hectare	371		
FRNFDL	Nonfarm Labor Cost Fraction	0	1	unitless	0.7	0.5	
FRNFIM	Nonfarm Wealth Improvements Fraction	0	1	unitless	0.8		

Field	Description	MACCS2 Range min	MACCS2 Range max	Units	Entergy Input value 1	Entergy Input value 2	Entergy Input value 3
GWCOEF	Long-Term Groundshine Coefficients	1.00E-20	1	unitless	0.5	0.5	
KSWTCH	Diagnostic Output Option Switch	0	1	integer	0		
LVLDEC	Number of Decontamination Strategies	1	3	integer	2		
NGWTRM	Number of Terms in Groundshine Weathering Equation	1	2	integer	2		
NRWTRM	Number of Terms in Resuspension Weathering Equation	1	3	integer	3		
NUMWPI	Number of Radionuclides for Water Ingestion	1	10	integer	4		
POPCST	Per Capita Cost of Long-Term Relocation	1.00E-06	1.00E+06	dollars/person	8640		
RELCST	Relocation Cost per Person-Day	0	1000	dollars/person-day	46.7		
RWCOEF	Long-Term Resuspension Factor Coefficients	1.00E-20	1	per meter	1.00E-05	1.00E-07	1.00E-09
TFWKF	Farm Worker's Work Fraction	0	1	unitless	0.1	0.33	
TFWKNF	Nonfarm Worker’s Work Fraction	0	1	unitless	0.33	0.33	
TGWHLF	Groundshine Weathering Half-Lives	1.00E-06	1.00E+12	seconds	1.60E+07	2.80E+09	
TIMDEC	Decontamination Times	1.00E-06	3.15E+07	seconds	5.18E+06	1.04E+07	
TMPACT	Time Action Period Ends	TMIPND	1.00E+10	seconds	1.58E+08		
TRWHLF	Resuspension Weathering Half-Lives	1.00E-06	1.00E+12	seconds	1.60E+07	1.60E+08	1.60E+09
VALWF	Value of Farm Wealth (per Hectare)	1.00E-06	1.00E+06	dollars/hectare	50071 (2004 USD)		
VALWNF	Value of Nonfarm Wealth (per Capita)	1.00E-06	1.00E+06	dollars/person	208838 (2004 USD)		
WINGF	Water Transfer Fraction to Humans	0	1	unitless	5.00E-06		
WSHFRI	Initial Water Washoff Fraction	0	1	unitless	0.01	0.005	
WSHRTA	Annual Water Washoff Fraction	0	1	/year	0.004	0.001	

Table 15: Input sensitivity results

Input parameter changed	Entergy's Value	New Value (Entergy plus 10%)	Total OECR ($/yr)	Sensitivity
-	-	-	2.12E+05	-
EVACST	46.7	51.4	2.12E+05	0%
RELCST	46.7	51.4	2.12E+05	0%
TIMDEC (DF1)	5.18E+06	5.70E+06	2.15E+05	1%
TIMDEC (DF2)	1.0368E+07	1.14E+07	2.15E+05	1%
VALWF	50071	5.51E+04	2.12E+05	0%
VALWNF	208838	2.30E+05	2.23E+05	5%
EXPTIM	9.45E+08	1.04E+09	2.12E+05	0%
CDFRM (DF1)	972	1069.2	2.12E+05	0%
CDFRM (DF2)	2160	2376	2.12E+05	0%
CDNFRM (DF1)	5184	5702.4	2.14E+05	1%
CDNFRM (DF2)	13824	15206.4	2.15E+05	2%
CDNFRM (DF1 AND DF2)	5184, 13824	5702.4, 15206.4	2.17E+05	2%
FRFDL (DF1)	0.3	0.33	2.12E+05	0%
FRNFDL (DF1)	0.7	0.77	2.12E+05	0%
TFWKF (DF1)	0.1	0.11	2.12E+05	0%
TFWKNF (DF1 and DF2)	0.33	0.36	2.12E+05	0%
DLBCST	60480	66500	2.12E+05	0%
DPRATE	0.2	0.22	2.17E+05	2%
DSRATE	0.12	0.14	2.19E+05	3%
POPCST	8640	9500	2.17E+05	2%
VALWF	50071	55000	2.12E+05	0%
FRFIM	0.25	0.28	2.12E+05	0%
FRNFIM	0.8	0.88	2.18E+05	3%
DSCRLT	0.04	0.044	2.00E+05	-6%
DOSELONG	0.005	0.0055	2.12E+05	0%
DOSEMILK	0.025	0.028	2.12E+05	0%
DOSEOTHR	0.025	0.028	2.12E+05	0%
TMPACT	1.58E+08	1.74E+08	2.20E+05	4%
GWHLF (all groundshine terms)	0.5	0.55	2.29E+05	8%
TGWHLF (all groundshine terms)	1.60E+07	1.76E+07	2.18E+05	3%

Input parameter changed	Entergy's Value	New Value (Entergy plus 10%)	Total OECR ($/yr)	Sensitivity
RWCOEF (all resuspension terms)	1.00E-07	1.10E-05	2.13E+05	0%
TRWHLF (all resuspension terms)	1.60E+08	1.76E+07	2.13E+05	0%
WSHFRI (all waterborne radionuclides)	0.01	0.011	2.12E+05	0%
WSHTRA (all waterborne radionuclides)	0.004	0.0044	2.12E+05	0%
WINGF (all waterborne radionuclides)	5.00E-06	5.50E-06	2.12E+05	0%

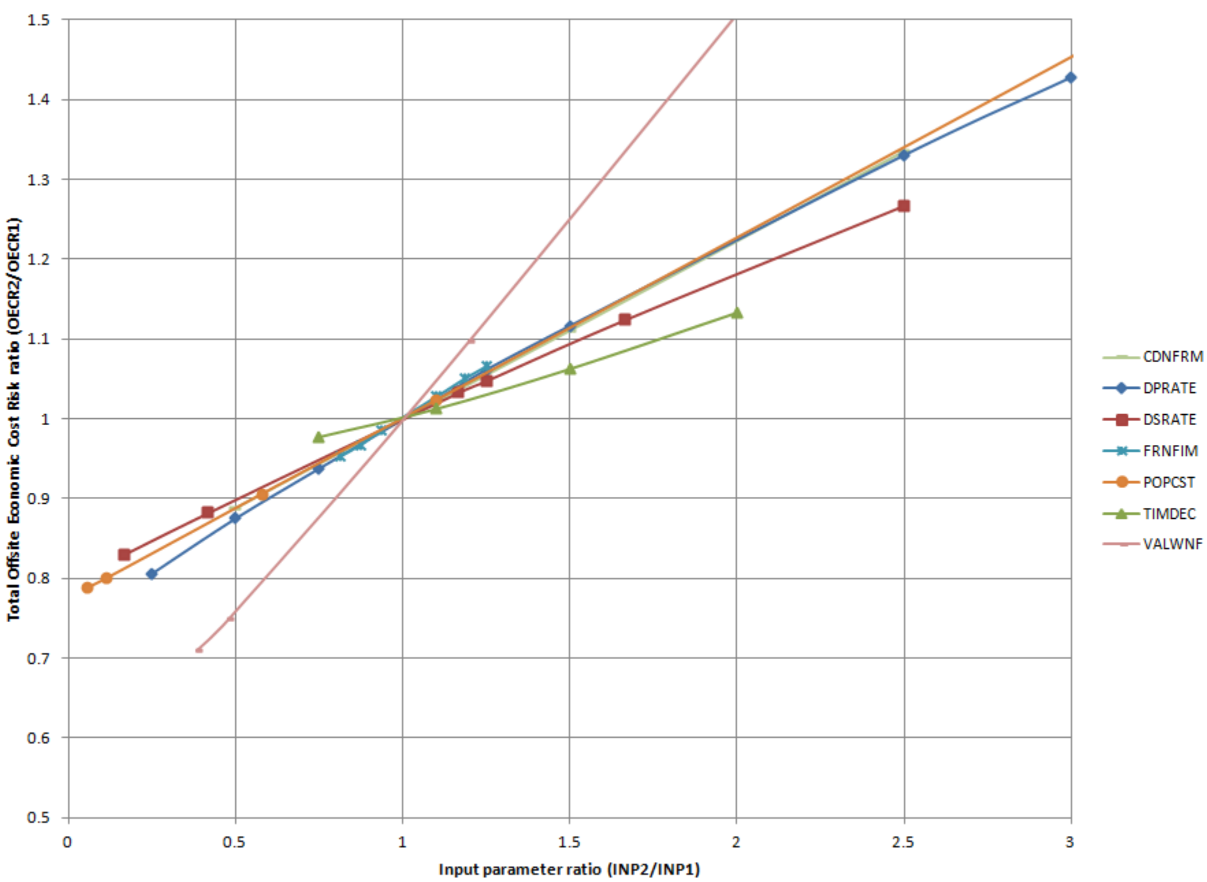

Figure 8: Sensitivity plot

ANNEX C CDNFRM Calculation

This annex includes ISR's calculation of CDNRFM using CONDO and RISO values, in tabular form. ISR took all values from CONDO [8] or RISO [9].

Costs in CONDO were quoted in 1996 pounds (GBP); ISR assumed a currency exchange rate of 1.6 USD per GBP. Costs reported by RISO were quoted in 1995 Euros or ECUs, which at the time was approximately equivalent to USDs, and then CPI-adjusted to 2011 costs. Finally, all costs were CPI-adjusted to 2005 costs for comparison to Entergy's decontamination costs. CPI adjustments were based on the CPI values given in the table below.

For soil/grass areas, ISR assumed that plants and shrubs occupied 30% of the area, trees occupied 20% of the area and soil and grass occupied 50% of the area. This assumption was made for all population densities (i.e. semi-urban, urban and hyper-urban). Since the decontamination of soil/grass areas is less cost and labour intensive than that of buildings and paved areas, the effect of any errors in these assumptions is not significant.

Table 16: Annual average CPI values

Year	Average CPI		Year	Average CPI
1986	109.6		2001	177.1
1987	113.6		2002	179.9
1988	118.3		2003	184.0
1989	124.0		2004	188.9
1990	130.7		2005	195.3
1991	136.2		2006	201.6
1992	140.3		2007	207.342
1993	144.5		2008	215.303
1994	148.2		2009	214.537
1995	152.4		2010	218.056
1996	156.9		2011	224.550
1997	160.5			
1998	163.0			
1999	166.6			
2000	172.2			
Source: US Department of Labor, Bureau of Labor Statistics, Consumer Price Index – All Urban Consumers (CPI-U), US City Average. Extracted from ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt on November 10, 2011.				

Table 17: Decontamination in semi-urban areas - building fractions

Surface	Low shielded building fraction of land area	Low proportion	Weighted value	Medium shielded building fraction of land area	Med proportion	Weighted value	High shielded building fraction of land area	High proportion	Weighted value	Total weighted area
External walls	1.7	0.05	0.085	1.6	0.8	1.28	5.5	0.15	0.825	2.19
Roofs	1	0.05	0.05	1	0.8	0.8	1	0.15	0.15	1
Internal walls	8.86	0.05	0.443	8.71	0.8	6.968	27.6	0.15	4.14	11.551

Table 18: Decontamination in urban areas - building fractions

External walls	1.7	0.05	0.085	1.6	0.6	0.96	5.5	0.35	1.925	2.97
Roofs	1	0.05	0.05	1	0.6	0.6	1	0.35	0.35	1
Internal walls	8.86	0.05	0.443	8.71	0.6	5.226	27.6	0.35	9.66	15.329

Table 19: Decontamination in hyper-urban areas - building fractions[17]

External walls	1.7	0.05	0.085	1.6	0.15	0.24	5.5	0.8	4.4	4.725
Roofs	1	0.05	0.05	1	0.15	0.15	1	0.8	0.8	1
Internal walls	8.86	0.05	0.443	8.71	0.15	1.3065	27.6	0.8	22.08	23.8295

[17] The proportion fractions (low, medium and high) shown here for hyper-urban areas were derived by ISR using extrapolation from urban values

Table 20: Light decontamination in semi-urban areas (CONDO)

Area	Process	DF	Fragmented Cost ($/km^2)	Continuous Cost ($/km^2)	Surface fraction (Semi-Urban)	Additional fraction to separate surface fraction	Fragmented fraction	Final Fragmented Cost ($/km2)	Final Continuous Cost ($/km2)
Roads - paved areas	Fire hosing or high pressure hosing	3 to 5	7.68E+04	1.39E+05	0.40	1.00	0.5	1.54E+04	2.78E+04
Building - roofs	Peelable coatings	5	9.12E+06	4.16E+06	0.40	1.00	0.75	2.74E+06	4.16E+05
Building - walls	Peelable coatings	5	4.32E+06	4.16E+06	0.40	2.19	0.75	2.84E+06	9.11E+05
Building - interiors	Vacuuming, cleaning and washing	5	1.60E+06	1.60E+06	0.40	11.55	0.75	5.54E+06	1.85E+06
Plants and shrubs	Removal	1.4	6.88E+05	9.28E+04	0.20	0.30	0.75	3.10E+04	1.39E+03
Trees	Felling and removal	10	4.16E+06	4.16E+06	0.20	0.20	0.75	1.25E+05	4.16E+04
Soil and grass	Cutting and collection	3	1.92E+05	1.41E+04	0.20	0.50	0.75	1.44E+04	3.52E+02
							Total (1996 USD)	**1.13E+07**	**3.25E+06**
								1.46E+07	
							Total (2005 USD)	**1.82E+07**	

Table 21: Heavy decontamination in semi-urban areas (CONDO)

Area	Process	DF	Fragmented Cost ($/km2)	Continuous Cost ($/km2)	Surface fraction (Semi-Urban)	Additional fraction to separate surface fraction	Fragmented fraction	Final Fragmented Cost ($/km2)	Final Continuous Cost ($/km2)
Roads - paved areas	Removal and replacement	50	3.84E+07	1.34E+07	0.40	1.00	0.5	7.68E+06	2.69E+06
Building - roofs	Sandblasting	10	3.20E+06	4.32E+06	0.40	1.00	0.75	9.60E+05	4.32E+05
Building - walls	Sandblasting	10	3.20E+06	4.32E+06	0.40	2.19	0.75	2.10E+06	9.46E+05
Building - interiors	Vacuuming, cleaning and washing	5	1.14E+07	1.14E+07	0.40	11.55	0.75	3.94E+07	1.31E+07
Plants and shrubs	Removal	1.4	6.88E+05	9.28E+04	0.20	0.30	0.75	8.64E+04	2.88E+04
Trees	Felling and removal	10	4.16E+06	4.16E+06	0.20	0.20	0.75	1.25E+05	4.16E+04
Soil and grass	Turf removal	10	8.80E+04	8.96E+04	0.20	0.50	0.75	6.60E+03	2.24E+03
							Total (1996 USD)	**5.03E+07**	**1.72E+07**
								6.75E+07	
							Total (2005 USD)	**8.40E+07**	

Table 22: Light decontamination in urban areas (CONDO)

Area	Process	DF	Fragmented Cost ($/km2)	Continuous Cost ($/km2)	Surface fraction (Urban)	Additional fraction to separate surface fraction	Fragmented fraction	Final Fragmented Cost ($/km2)	Final Continuous Cost ($/km2)
Roads - paved areas	Fire hosing or high pressure hosing	3 to 5	7.68E+04	1.39E+05	0.40	1.00	0.5	1.54E+04	2.78E+04
Building - roofs	Peelable coatings	5	9.12E+06	4.16E+06	0.50	1.00	0.6	2.74E+06	8.32E+05
Building - walls	Peelable coatings	5	4.32E+06	4.16E+06	0.50	2.97	0.6	3.85E+06	2.47E+06
Building - interiors	Vacuuming, cleaning and washing	5	1.60E+06	1.60E+06	0.50	15.33	0.6	7.36E+06	4.91E+06
Plants and shrubs	Removal	1.4	6.88E+05	9.28E+04	0.10	0.30	0.5	1.03E+04	1.39E+03
Trees	Felling and removal	10	4.16E+06	4.16E+06	0.10	0.20	0.5	4.16E+04	4.16E+04
Soil and grass	Cutting and collection	3	1.92E+05	1.41E+04	0.10	0.50	0.5	4.80E+03	3.52E+02
							Total (1996 USD)	**1.40E+07**	**8.28E+06**
								2.23E+07	
							Total (2005 USD)	**2.78E+07**	

Table 23: Heavy decontamination in urban areas (CONDO)

Area	Process	DF	Fragmented Cost ($/km2)	Continuous Cost ($/km2)	Surface fraction (Urban)	Additional fraction to separate surface fraction	Fragmented fraction	Final Fragmented Cost ($/km2)	Final Continuous Cost ($/km2)
Roads - paved areas	Removal and replacement	50	3.84E+07	1.34E+07	0.40	1.00	0.5	7.68E+06	2.69E+06
Building - roofs	Sandblasting	10	3.20E+06	4.32E+06	0.50	1.00	0.6	9.60E+05	8.64E+05
Building - walls	Sandblasting	10	3.20E+06	4.32E+06	0.50	2.97	0.6	2.85E+06	2.57E+06
Building - interiors	Vacuuming, cleaning and washing	5	1.14E+07	1.14E+07	0.50	15.33	0.6	5.22E+07	3.48E+07
Plants and shrubs	Removal	1.4	6.88E+05	9.28E+04	0.10	0.30	0.5	2.88E+04	2.88E+04
Trees	Felling and removal	10	4.16E+06	4.16E+06	0.10	0.20	0.5	4.16E+04	4.16E+04
Soil and grass	Turf removal	10	8.80E+04	8.96E+04	0.10	0.50	0.5	2.20E+03	2.24E+03
							Total (1996 USD)	**6.38E+07**	**4.10E+07**
								1.05E+08	
							Total (2005 USD)	**1.31E+08**	

Table 24: Light decontamination in hyper-urban areas (CONDO)

Area	Process	DF	Fragmented Cost ($/km2)	Continuous Cost ($/km2)	Surface fraction (Hyper-Urban)[18]	Additional fraction to separate surface fraction	Fragmented fraction[18]	Final Fragmented Cost ($/km2)	Final Continuous Cost ($/km2)
Roads - paved areas	Fire hosing or high pressure hosing	3 to 5	7.68E+04	1.39E+05	0.25	1.00	0.5	9.60E+03	1.74E+04
Building - roofs	Peelable coatings	5	9.12E+06	4.16E+06	0.70	1.00	0.4	2.55E+06	1.75E+06
Building - walls	Peelable coatings	5	4.32E+06	4.16E+06	0.70	4.73	0.4	5.72E+06	8.26E+06
Building - interiors	Vacuuming, cleaning and washing	5	1.60E+06	1.60E+06	0.70	23.83	0.4	1.07E+07	1.60E+07
Plants and shrubs	Removal	1.4	6.88E+05	9.28E+04	0.05	0.30	0.5	5.16E+03	6.96E+02
Trees	Felling and removal	10	4.16E+06	4.16E+06	0.05	0.20	0.5	2.08E+04	2.08E+04
Soil and grass	Cutting and collection	3	1.92E+05	1.41E+04	0.05	0.50	0.5	2.40E+03	1.76E+02
							Total (1996 USD)	**1.90E+07**	**2.61E+07**
								4.51E+07	
							Total (2005 USD)	**5.61E+07**	

[18] The surface and fragmented fractions shown here for hyper-urban areas were derived by ISR using extrapolation from urban values

Table 25: Heavy decontamination in hyper-urban areas (CONDO)

Area	Process	DF	Fragmented Cost ($/km2)	Continuous Cost ($/km2)	Surface fraction (Hyper-Urban)[19]	Additional fraction to separate surface fraction	Fragmented fraction[19]	Final Fragmented Cost ($/km2)	Final Continuous Cost ($/km2)
Roads - paved areas	Removal and replacement	50	3.84E+07	1.34E+07	0.25	1.00	0.5	4.80E+06	1.68E+06
Building - roofs	Sandblasting	10	3.20E+06	4.32E+06	0.70	1.00	0.4	8.96E+05	1.81E+06
Building - walls	Sandblasting	10	3.20E+06	4.32E+06	0.70	4.73	0.4	4.24E+06	8.58E+06
Building - interiors	Vacuuming, cleaning and washing	5	1.14E+07	1.14E+07	0.70	23.83	0.4	7.58E+07	1.14E+08
Plants and shrubs	Removal	1.4	6.88E+05	9.28E+04	0.05	0.30	0.5	1.44E+04	1.44E+04
Trees	Felling and removal	10	4.16E+06	4.16E+06	0.05	0.20	0.5	2.08E+04	2.08E+04
Soil and grass	Turf removal	10	8.80E+04	8.96E+04	0.05	0.50	0.5	1.10E+03	1.12E+03
							Total (1996 USD)	**8.58E+07**	**1.26E+08**
								2.12E+08	
							Total (2005 USD)	**2.64E+08**	

[19] The surface and fragmented fractions shown here for hyper-urban areas were derived by ISR using extrapolation from urban values

Table 26: Decontamination in semi-urban areas (RISO)

Area	Process	Cost ($/km2), 2011	Surface fraction (Semi-Urban)	Additional fraction to separate surface fraction	Final Cost ($/km2)
Roads - paved areas	High pressure hosing	1.22E+06	0.40	1.00	4.88E+05
Building - roofs	Rotating brush	3.86E+06	0.40	1.00	1.55E+06
Building - walls	High pressure hosing	1.22E+06	0.40	2.19	1.07E+06
Building - interiors	Vacuuming, cleaning and washing	7.64E+06	0.40	11.55	3.53E+07
Soil and grass	Cutting and collection	4.18E+04	0.20	1.00	8.36E+03
				Total (2011 USD)	**3.84E+07**
				Total (2005 USD)	**3.34E+07**

Table 27: Decontamination costs for urban areas (RISO)

Area	Process	Cost ($/km2)	Surface fraction (Urban)	Additional fraction to separate surface fraction	Final Cost ($/km2)
Roads - paved areas	High pressure hosing	1.22E+06	0.40	1.00	4.88E+05
Building - roofs	Rotating brush	3.86E+06	0.50	1.00	1.93E+06
Building - walls	High pressure hosing	1.22E+06	0.50	2.97	1.81E+05
Building - interiors	Vacuuming, cleaning and washing	7.64E+06	0.50	15.33	5.85E+07
Soil and grass	Cutting and collection	4.18E+04	0.10	1.00	4.18E+03
				Total (2011 USD)	**6.28E+07**
				Total (2005 USD)	**5.46E+07**

Table 28: Decontamination costs for hyper-urban areas (RISO)

Area	Process	Cost ($/km2)	Surface fraction (Hyper-Urban)[20]	Additional fraction to separate surface fraction	Final Cost ($/km2)
Roads - paved areas	High pressure hosing	1.22E+06	0.25	1.00	3.05E+05
Building - roofs	Rotating brush	3.86E+06	0.70	1.00	2.71E+06
Building - walls	High pressure hosing	1.22E+06	0.70	4.73	4.04E+06
Building - interiors	Vacuuming, cleaning and washing	7.64E+06	0.70	23.83	1.27E+08
Soil and grass	Cutting and collection	4.18E+04	0.05	1.00	2.09E+03
				Total (2011 USD)	**1.34E+08**
				Total (2005 USD)	**1.17E+08**

[20] The surface fractions shown here for hyper-urban areas were derived by ISR using extrapolation from urban values

ANNEX D VALWNF Calculation

The description, justification and discussion regarding the VALWNF are found in Section 4.3. This annex includes the tabulated values for the re-calculation of VALWNF.

All though portions of them lie within the 50-mile radius zone, Entergy did not include the following counties in the determination of VALWNF: Pike, PA, Hunterdon, NJ, Middlesex, NJ, Monmouth, NJ, Ocean, NJ, Somerset, NJ, and Richmond, NY. Entergy excluded these counties because they comprise less than 50% of any spatial element in the 50-mile radius zone [30].

Table 29: VALWNF values and calculation

State	County	2004 GCP (Billions USD)	2004 pop. (Million)	2004 GCP ($/person)	Original (1997) VNFRM from SECPOP ($/person)	US GDP Increase factor from 1997 to 2004	Entergy Final (2004) VNFRM ($/person)	ISR Final (2004) VNFRM ($/person)	Pop. weighting factor	ISR Weighted (2004) VNFRM over entire data set ($/person)
NY	Kings	47.4	2.5	18,960	104,714	1.42	123,701	167,921	0.13	21,830
NY	Queens	334.6	5.81	57,590	169,126	1.42	226,728	298,181	0.31	92,436
CT	Fairfield	49.8	0.9	55,333	232,659	1.42	287,881	386,304	0.05	19,315
CT	Litchfield	7.1	0.19	37,368	148,522	1.42	186,016	248,649	0.01	2,486
CT	New Haven	40.8	0.84	48,571	144,105	1.42	192,427	253,569	0.05	12,678
NJ	Bergen	50.8	0.9	56,444	205,863	1.42	262,186	349,296	0.05	17,465
NJ	Essex	39.8	0.8	49,750	147,351	1.42	197,400	259,365	0.04	10,375
NY	Sullivan	2.6	0.08	32,500	104,859	1.42	139,374	181,668	0.004	727
NJ	Morris	31.3	0.49	63,878	213,389	1.42	277,661	367,435	0.03	11,023
NJ	Passaic	19.9	0.5	39,800	121,880	1.42	161,864	213,181	0.03	6,395
NJ	Sussex	4.5	0.15	30,000	136,197	1.42	165,741	223,748	0.01	2,237
NJ	Union	25.9	0.53	48,868	160,860	1.42	209,708	277,700	0.03	8,331
NY	Dutchess	11.9	0.29	41,034	129,000	1.42	169,417	224,544	0.02	4,491
NY	Nassau	63.1	1.34	47,090	192,755	1.42	239,932	321,294	0.07	22,491
NY	Orange	12.9	0.37	34,865	113,976	1.42	148,873	197,002	0.02	3,940
NY	Putnam	2.5	0.1	25,000	154,926	1.42	180,274	245,391	0.01	2,454
NY	Rockland	11.8	0.29	40,690	163,105	1.42	203,359	272,716	0.02	5,454
NY	Suffolk	63.2	1.47	42,993	149,615	1.42	192,471	255,829	0.08	20,466
NY	Ulster	6.3	0.18	35,000	104,090	1.42	138,739	183,074	0.01	1,831
NY	Westchester	43.4	0.94	46,170	217,278	1.42	263,389	355,260	0.05	17,763
Total	All counties within the 50-mi radius zone								**VALWNF**	**284,189**

ANNEX E MACCS2 economic cost flowcharts

This annex includes visual representations (flowcharts) of the MACCS2 code, related to how it interprets and calculates total costs. The fields indentified in red are user-defined inputs, while normal borders are calculated values.

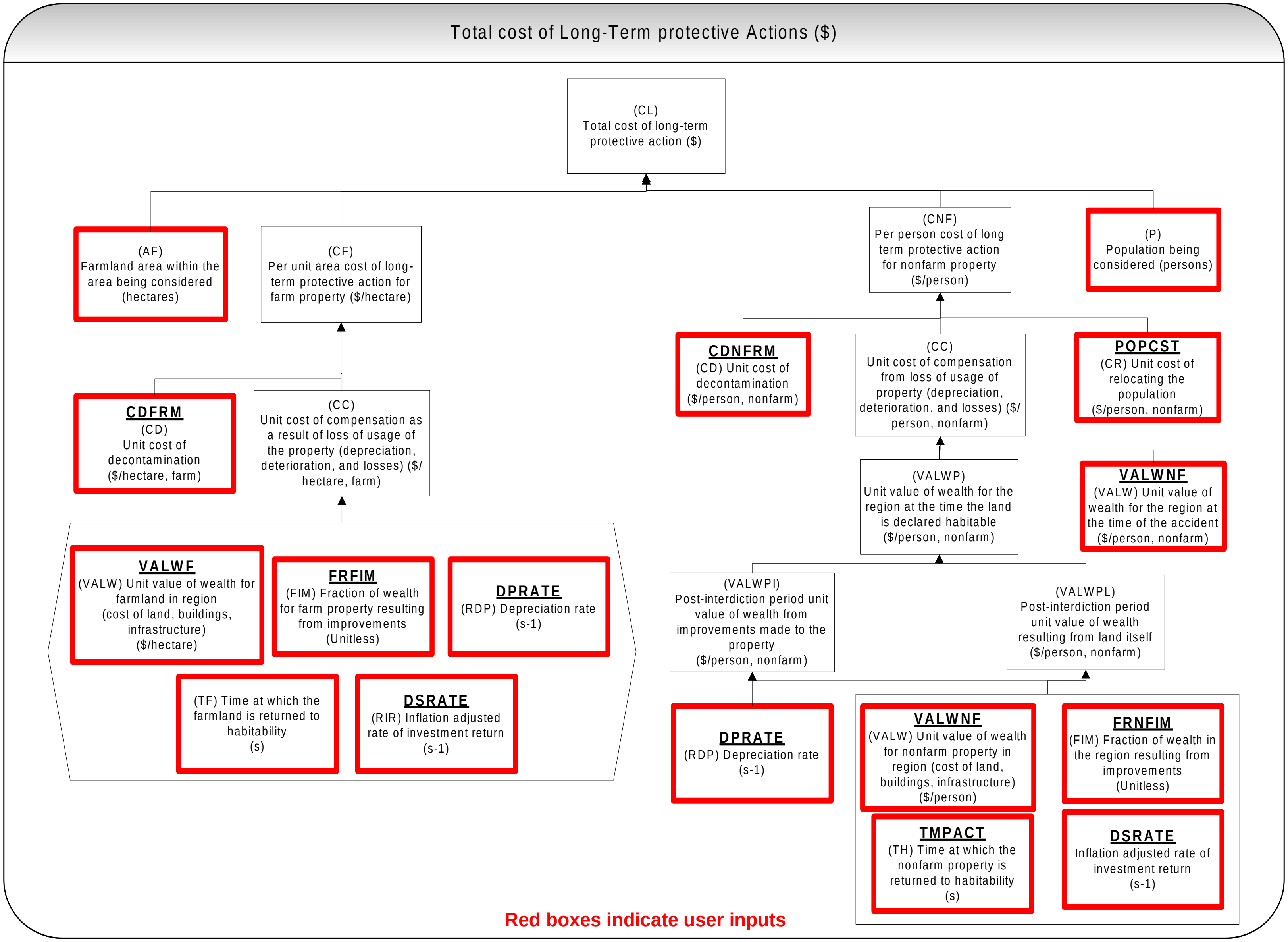

Figure 9: Total cost of long-term protective actions

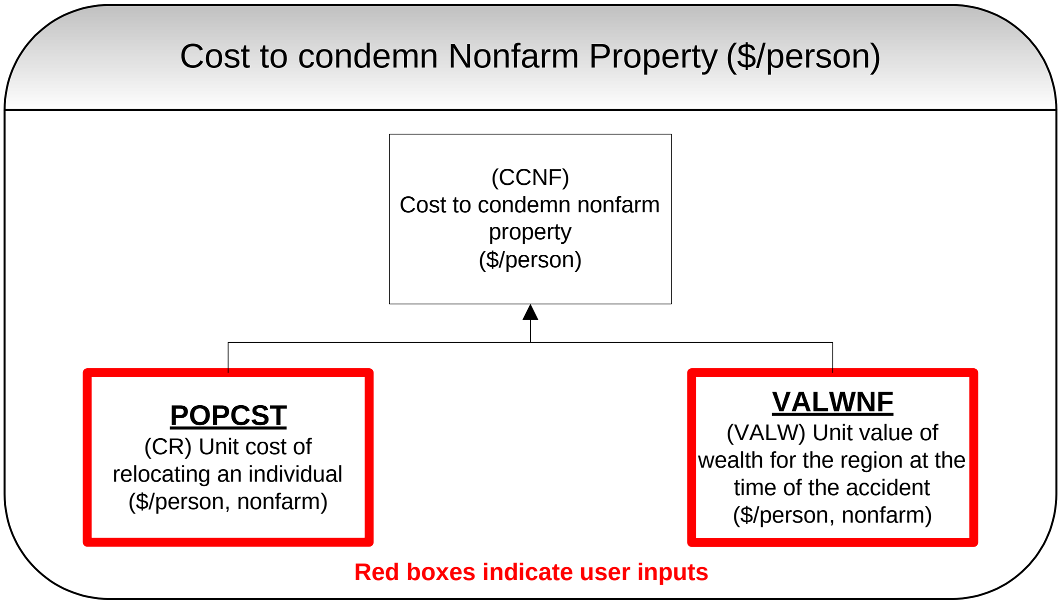

Figure 10: Cost to condemn nonfarm property

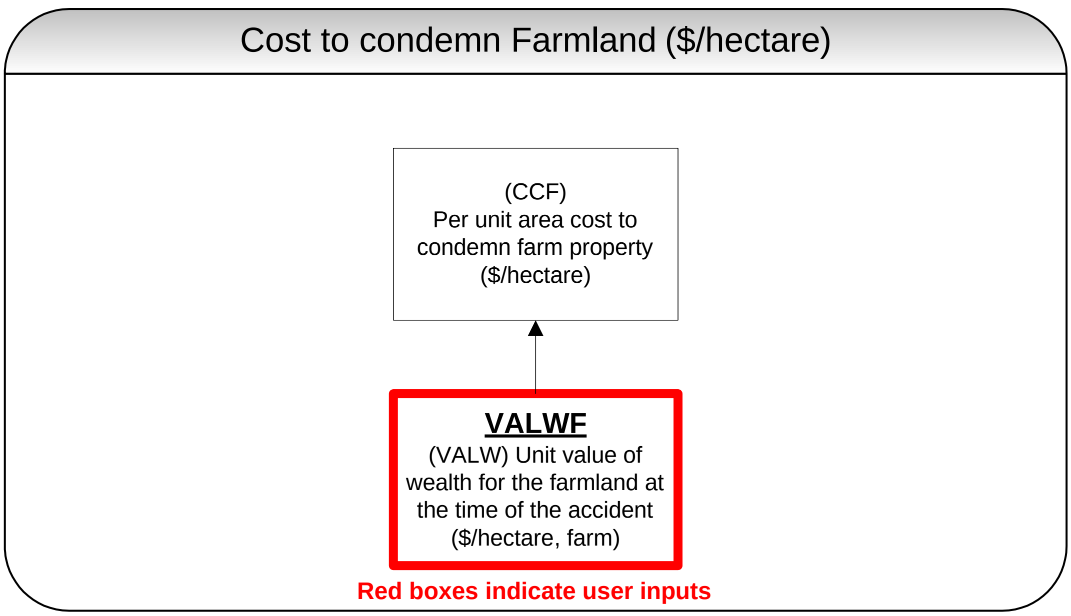

Figure 11: Cost to condemn farmland

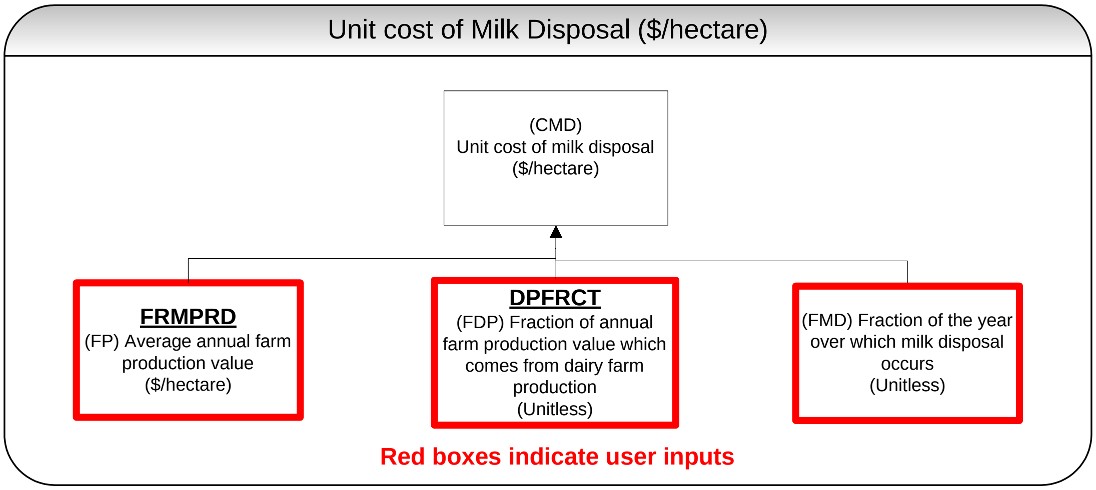

Figure 12: Cost of milk disposal

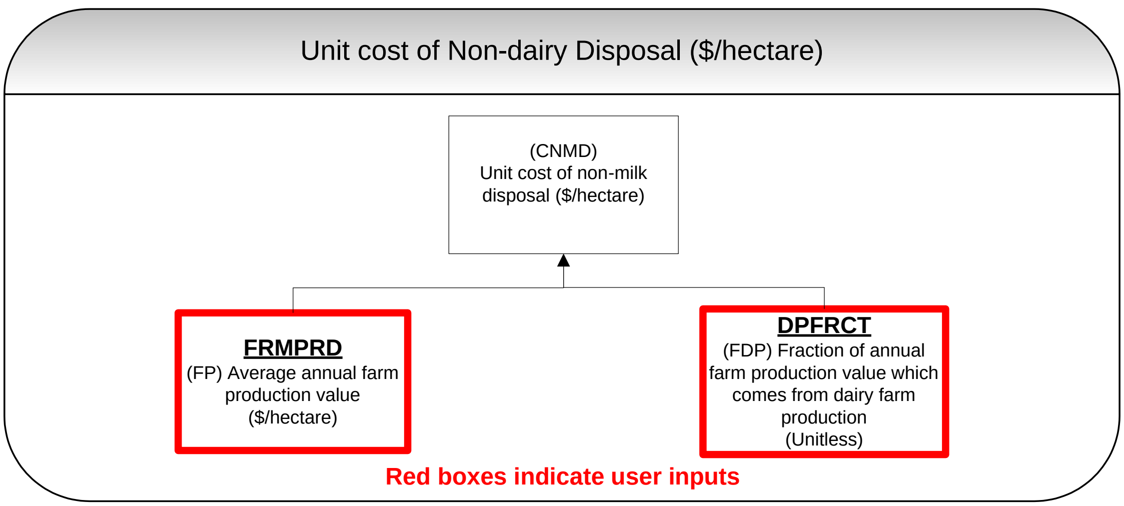

Figure 13: Cost of non-dairy disposal

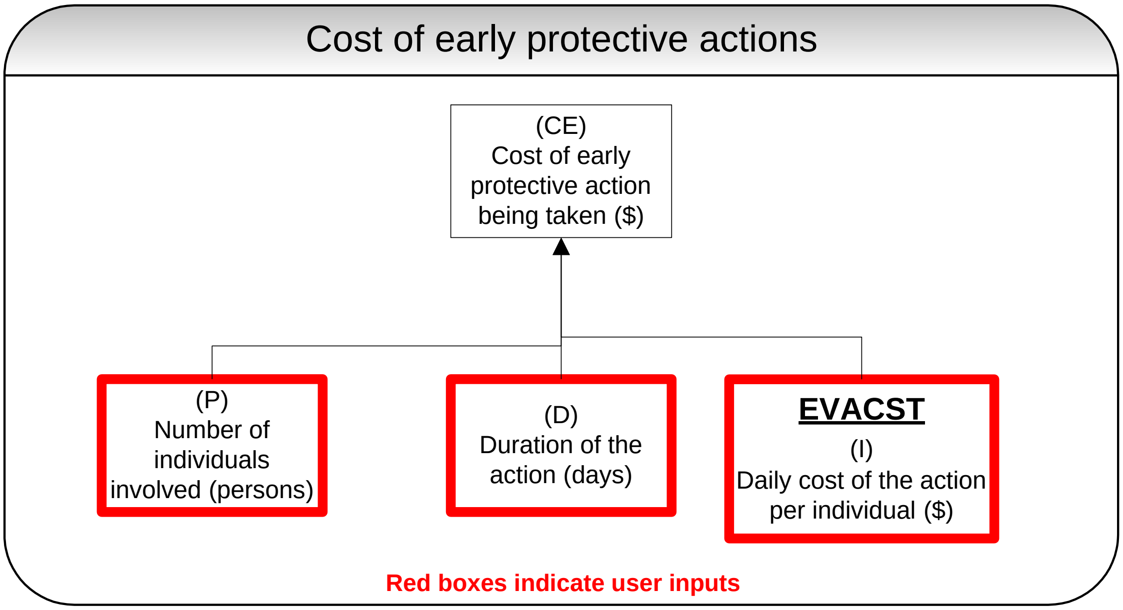

Figure 14: Cost of early protective actions

ANNEX F Timeline of certain references

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