OCT 23 1985

MEMORANDUM FOR: Chairman Palladino
Commisisoner Roberts
Commissioner Asselstine
Commissioner Bernthal
Commissioner Zech

FROM: William J. Dircks
Executive Director for Operations, EDO

SUBJECT: BASIS FOR QUANTIFYING OFFSITE PROPERTY LOSSES

On June 27, 1985, the Commission approved the Severe Accident Policy Statement. At that time, the Commission requested a review on the bases for quantifying, in PRA-type cost-benefit analysis, the values and related probabilities of possible offsite property losses.

The attached paper addresses the technical bases and does not include a legal analysis.

(Signed) William J. Dircks

William J. Dircks
Executive Director
for Operations

Enclosure:
Bases for Offsite Property Losses
in Cost-Benefit Analyses

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BASES FOR OFFSITE PROPERTY LOSSES IN COST BENEFIT ANALYSIS

In its deliberations on the "Policy Statement on Severe Accidents Regarding Future Designs and Existing Plants" (50 FR 32138), the Commission elected not to add the word "property" to its traditional statement regarding "public health and safety." This was to avoid creating a potential misunderstanding through an appearance that the Commission might be extending that traditional statement. However, the Commission requested that the staff prepare a paper "on the bases for quantifying, in PRA-type cost-benefit analysis, the values and related probabilities of possible offsite property losses."

1. Nature of Losses

Offsite property losses that may result from nuclear power plant accidents do not reflect direct accident caused physical damage to the property concerned, as might result from fires or explosions. Rather, the losses arise from measures taken to avoid or reduce health-effect risks that might occur if the radioactive material release from the accident were simply ignored, and are similar in many respects to losses from releases of toxic materials. Reactor-accident property losses might include abandonment of contaminated property (land, buildings, productive facilities, personal property), temporary loss of use of property pending decay of radioactivity or its reduction by weathering and decontamination, decontamination costs, evacuation and relocation costs, destruction of foodstuffs, etc. Decontamination may involve occupational exposures.

The importance of the offsite property damage relative to the health effects of accidents is illustrated below by the estimated mean risks of specific plants, namely, Indian Point and Limerick for their respective spectrum of core-melt accidents:

Risk per Reactor Year

	Indian Point Unit 2	Limerick
Early fatalities	0.01	0.005
Cancer fatalities	0.2	0.08
Offsite property damage	$300,000	$50,000

2. Current NRC Staff Practice

Potential offsite property damage from accidents is implicitly part of the considerations in the cost-benefit analyses involved in prioritization and regulatory analysis of generic safety issues and requirements. It is explicitly stated in environmental impact statements. All NRC and NRC-sponsored offsite damage estimates to date have been based on a common calculation method, the CRAC/CRAC2 codes. Current practices are discussed briefly below. Appendices A to D provide further detail.

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2.1 Prioritizations and Regulatory Analyses

The general cost-benefit approach involves two steps. First, the person-rems of risk reduction from a potential change in regulatory requirements is compared with the associated cost impact on the basis of a trade-off coefficient, usually $1,000/person-rem. The $1,000 valuation of a person-rem of public-dose reduction is conventionally assumed to be high enough to include implicit recognition of radioactive release effects other than public health, including offsite property damage.

As shown below, the property damage per unit radiation dose ($/person-rem) is more likely to be significant in less severe (and more probable) accidents (typified by SST 3) than in (the less probable) accidents of high severity (SST 1, SST 2). However, for most cases the risk is associated with the accidents of high severity. The distribution of costs varies with severity. For high severity accidents land and property decontamination and interdiction costs contribute to over 80% of the costs, while evacuation contributes to less than 1%. For low severity accidents land and property decontamination contribute nearly 50% and evacuation contributes about 40%. Property values tend to be co-located with population, so that public dose and property damage from an accident both tend to increase with population density.

Release Category	Person-Rem	Offsite Property Damage, $/Person-Rem Lowest	Highest
SST 1	40,000,000	20	150
SST 2	3,000,000	6	30
SST 3	10,000	50	1,100

The above figures reflect aggregated dose and aggregated damage within 500 miles of the reactor. Though 50-mile-radius figures are not available on a systematic basis, it is believed that the ratio of offsite property damage to person-rem within 50 miles would be typically about twice as high as the 500-mile ratios. (The difference factor would usually be smaller than two for high-population-density sites and larger than two for sites in sparsely populated areas.) This effect results from the fact that dose projections beyond 50 miles would rarely be high enough to lead to property damage.

The second step involves taking into account any special considerations that may be important in connection with the issue but are not adequately reflected, or not reflected at all, in the value-impact formula. This may include special offsite property damage risk aspects. Where significant to the result, which rarely happens, such property damage considerations are addressed explicitly, in as quantitative terms as data permit and the issue requires.

Subject to the exceptions just noted, the current approach relies largely on health-effect aspects as surrogates for the overall impact, including offsite property damage of accidents. This approach is justified by the following considerations:

a. Public health risk is dominated by high severity, low probability accidents and if evaluated at $1000/person-rem, is usually large in comparison with offsite property damage.

b. The imprecision of including offsite property damages in the $1,000/person-rem coefficient is within the wide uncertainties in both health and property risks which are discussed later.

c. Most regulatory actions required on the basis of health-risk considerations and on the basis of property-risk considerations are usually the same: a safely designed, built, and operated plant. (Emergency planning is an exception.)

2.2 Environmental Impact Statements

Analysis of the effect of potential severe (class 9) accidents on offsite and onsite environmental aspects, including property values, is included in environmental impact statements (EISs) related to nuclear power plants, as explained in Appendix B. EISs also include consideration of any special natural or man-made features in the plant's environs.

As an example of an EIS result, the Limerick EIS mean estimate for the actuarial cost of offsite mitigation measures is $50,000 per reactor-year, with the complementary cumulative probability distribution shown below:

Probability of Impact Per Reactor Year	Cost of Offsite Mitigation Measures (1980 dollars) Exceeding the Value
10^{-5}	1,000,000,000
10^{-6}	6,000,000,000
10^{-7}	20,000,000,000
10^{-8}	30,000,000,000

3. Information Base

3.1 Calculation Methods

Offsite property damage estimates were included in the Reactor Safety Study (WASH-1400). Methodological improvements since then (1975), reflected in the subsequent CRAC and then CRAC2 computer codes, have not been of major importance for offsite property damage estimates.

The CRAC and CRAC2 computer codes, used for evaluating person-rem and health effects, also calculate offsite property damage, based on a radiological source term, yearly average meteorology, population distribution, land use, and a variety of other parameters. CRAC or CRAC2 estimates accident property damage for 544 area elements used to map the region around the site out to 500 miles. These area elements are generated by 34 concentric rings and sixteen direction sectors centered at the reactor. The economic data for lost public and private property and interdicted land and farm crop costs for these area elements are generally state averages. County averages have been used within 50 miles when the application required better precision. Other economic effects taken into account include expenses of evacuation and relocation of people and decontamination costs. Table 1, which follows, shows examples of the economic data used in the CRAC and CRAC2 computer codes.

The CRAC results, both person-rem and dollars, are the mean values and associated statistical distribution. However, these statistics consider only the variability in the meterological data. Uncertanities in the other input parameters are not included, but the effect of parameter variations can be determined through sensitivity studies and these are done where warranted.

The bases, capabilities, and limitations of CRAC2 are discussed in Appendix D.

Appendix E presents an overview of recent and current work.

3.2 Uncertainties

The probabilistic estimates of potential offsite property losses are subject to most of the uncertainties involved in estimating the offsite risk in person-rems: the uncertainties in the probabilities of various potential accidents, in source terms, and in the distribution of contamination after release. Changes in total offsite property damage are approximately directly proportional to changes in accident probability or fraction of the core inventory released. While offsite damage could vary widely depending on the particular weather conditions at the time of an accident, the probabilistic estimates are insensitive to site meterology because a yearly average is used.

Additional uncertainties and sensitivities include the following:

1. The effectiveness and cost of various possible decontamination techniques and procedures, for which there is little actual experience. Land and property decontamination are nearly 70% of the total cost of offsite protective measures.

2. Criteria for interdiction (abandonment and resumption of use) of land, property, food, etc. A 25 rem dose to humans has traditionally been assumed in most PRA property damage assessments since WASH-1400. The appropriate reoccupancy criterion may be higher or lower, depending on the values assigned to the classical tradeoff between life values and cost of interdiction, i.e. cost-benefit analyses. For example, a criterion for reoccupancy of 5 rems over 30 years would increase the cost of long-term offsite protective actions by about a factor of four at the Indian Point site.

3. Identification of other factors in offsite property damage. For example, little has been done to date on indirect damage (such as disruption damage in more distant areas not contaminated, and national, socio-economic, and socio-political effects), equity considerations, and any special effects of economic geography.

4. Errors in valuation of land and of damage to various public as well as private goods and resources, including losses due to low-level residual contamination below interdiction and decontamination thresholds; valuation of environmental damage, including damage to natural and man-made features and resources; valuation of water supply interdiction.

Appendices:

A. Treatment of Offsite Property Losses in Prioritization and Regulatory Analysis of Generic Issues
B. Treatment of Offsite Property Losses in EISs
C. Some Highlights from Indian Point
D. Description and Critique of Current Calculation Methods
E. Recent and Current Research

TABLE 1

EXAMPLES OF TYPES OF ECONOMIC DATA USED IN STAFF ANALYSES

A. Site Land Use Data:

	Average Value	
	State of New Jersey	Montgomery County (Pa.) (Limerick)
Seeding Month	May	May
Harvesting Month	September	September
Farmland Fraction	0.218	0.233
Dairy Production Fraction	0.148	0.264
Annual Sale ($/acre)	432	481
Value of Farm ($/acre)	3,915	3,280

B. Evacuation, Interdiction, Decontamination Data:

Unit Cost	Wash-1400 (Nat'l Avg.) 1974 $	Indian Point (Rgn'l Avg.) 1981 $	Limerick (Rgn'l Avg.) 1980 $	Sandia Siting Study (Nat'l Avg.) 1980 $)
Evacuation ($/person)	95	245	225	165
Farm Decontamination ($/acre)	230	584	535	500
Developed Property Decon. ($/person)	1,700	5,135	4,705	4,400
Value of Developed Property ($/person)	17,000	53,870	48,300	32,000
Cost of Relocation Due to Interdiction ($/person)	2,900	5,190	4,620	4,300
Interest & Tax Rate	0.12	0.12	0.12	0.12
Depreciation Rate of Improved Property	0.20	0.20	0.20	0.20

APPENDIX A

TREATMENT OF OFFSITE PROPERTY LOSSES IN PRIORITIZATION AND REGULATORY ANALYSIS OF GENERIC ISSUES

Prioritization and regulatory analyses are based largely on value/impact considerations (Ref. A-1). In quantitative terms, the value and impact are calculated and ratioed to one another, the quotient usually being compared to a standard. The terms "value/impact" and "cost/benefit" are basically equivalent in philosophy, but "value/impact" is the preferred term because it does not imply that only costs are considered.

In prioritizations and regulatory analyses, "value" is usually expressed mathematically in terms of person-rem of public exposure averted by the proposed action times the probability over the lifetime of the plant or plants affected (Ref. A-2, A-3, A-4). This figure is to be understood in an actuarial sense.

The value of a safety measure, stated in person-rem, is compared with the associated cost impact on the basis of a tradeoff coefficient, usually $1,000/person-rem.

The expression of value in terms of total whole-body person-rem is, of course, not a direct measure of all health, safety and economic effects. However, most effects (latent cancers, personal and economic hardship, environmental burden, etc.) are at least roughly proportional to person-rem. And, because of the relatively high degree of uncertainty already associated with accident frequencies, this proportionality can be quite approximate without significantly affecting final results. It should be noted, however, that "value" sometimes must be expressed in something other than person-rem. Issues dealing with emergency evacuation, for example, are not appropriately evaluated in terms of person-rem because evacuations, although they avert prompt fatalities, have little effect on the total radiological exposure of the general population or property damage. In such cases, the surrogate nature of total person-rem is absent.

Usually the value/impact ratio is understood as a simple reciprocal of a cost/benefit ratio: "values" are benefits as expressed in estimated person-rem averted; "impacts" are costs associated with modifying equipment and procedures to reduce the probability of an accident. The numerator has units of person-rem; the denominator is expressed in dollars. Averted offsite financial consequences of an accident, multiplied by their probability, are benefits, but have the units of cost, and may, for analytic convenience, be subtracted from costs. This is, however, ordinarily not done in current staff practice. This is because at the $1,000/person-rem tradeoff coefficient usually used, the benefits are usually dominated by the health effects as represented by the person-rem of population radiation dose, and separate consideration of offsite property losses is seldom warranted.

The current practice of the NRC staff is to calculate an unmodified value/impact ratio, not including any averted offsite property damage credits, etc. Other aspects are then listed, with quantitative estimates if possible, and their potential effect on the value-impact relation is discussed. Offsite property damage is not routinely discussed in this context, but may be included in those unusual circumstances in which it may have a great enough relative significance to affect the outcome. When offsite property damage is to be incorporated, the actuarial cost (probability times dollar consequences) is calculated for all times over the life of the plant. This cost is then discounted (usually at 5% per annum) to the present to get a "present worth" of a future expense. This present worth, which of course is a function of elapsed time, is then integrated over the lifetime of the plant.

In contrast to onsite costs, where capitalization and downtime costs are relatively well documented, offsite costs are more difficult to estimate, and also vary widely from one site to another, making generic assessments difficult.

An example of such calculations (using the CRAC2 computer code) is given in Table A-1, which is based upon Reference A-5. Financial consequences are given in 1980 dollars. The Siting Source Term (SST) release categories are defined as follows:

- SST-1: Severe core damage. Essentially involves loss of all installed safety features. Severe direct breach of containment.
- SST-2: Severe core damage. Containment fails to isolate. Fission product release mitigating systems (e.g., sprays, suppression pool, fan coolers) operate to reduce release.
- SST-3: Severe core damage. Containment fails to isolate by basemat melt through. All other release mitigation systems have functioned as designed.

Table A-1 illustrates a variety of characteristics and limitations of such calculations. Because the consequences of a radioactive release are dependent on weather conditions, these figures are the means of weather-based statistical distributions, not deterministic values. The dollars per person-rem figure varies widely, spanning more than two orders of magnitude. While offsite property damage as well as health effects vary with population density, other factors of demography and economic geography also enter the relation between the two. Thus, offsite property damage does not scale well with person-rem alone. However, it will be noted that for the most severe accidents (SST-1, SST-2) the tabulated estimates of offsite property losses are invariably much lower than the person-rem monetized at $1,000/person-rem. The non-health-related economic consequences become more significant for the less severe accidents, as suggested by the Table A-1 figures for SST-3.

The effect of demography is strong, as can be seen by comparing high and low population density sites. Moreover, land use, demography and even meteorology are not independent, but all tend to be affected by the surrounding terrain. A site on the ocean shore will have population only on one side. The existence of a sea or land breeze at the time of the release can strongly affect the consequences. A site on a major river can be quite different. Population and industrial activity tend to follow the river, and the surrounding land may be very fertile.

The figures in Table A-1 are based on the 1970 census, the best available at the time of development of the data base for the calculations. The general thrust of the implications of the table would not be affected by a population update, since the estimates must in any event be viewed as only roughly approximations.

TABLE A.1

PERSON-REM VS. PROPERTY DAMAGE IN CONSEQUENCES

OF NUCLEAR POWER REACTOR ACCIDENTS

Release Category →	SST 1			SST 2			SST 3		
Plant ↓	Person-Rem, Millions	Property Damage, $, Billions	$ per Person-Rem	Person-Rem, Millions	Property Damage, $, Millions	$ per Person-Rem	Person-Rem, Thousands	Property Damage, $, Millions	$ per Person-Rem
Arkansas 1	13	0.76	58	1.1	16	15	4.4	1.7	390
Braidwood 1	60	3.9	65	4.3	45	10	16	2.2	140
Browns Ferry 3	17	1.1	64	1.2	18	15	4.7	2.7	570
Calvert Cliffs 1	36	1.3	36	1.8	14	7.8	6.0	1.2	200
Dresden 3	43	3.0	70	3.4	29	8.5	12	2.3	190
Indian Point 2	97	9.2	95	8.6	110	13	25	15	600
Limerick 1	78	6.2	79	6.0	99	17	22	14	640
Maine Yankee	11	0.22	20	0.38	2.2	5.8	1.3	0.10	77
San Onofre 2	32	2.7	84	2.8	25	8.9	8.7	2.5	290
Trojan	15	1.5	100	1.3	33	25	4.9	5.3	1,100
Turkey Point 3	5.9	0.77	130	0.91	22	24	4.2	2.2	520
Zion 1	61	4.8	79	5.6	120	21	22	19	860
Average (12 plants)			73			14			460

The person-rem are (in this example) calculated out to essentially an infinite radius (500 miles). Severe economic consequences are likely to be confined to within 50 miles of the plant. In addition, beyond 50 miles the person-rem is due to a very large number of people receiving very low doses. Therefore, the NRC staff normally calculates person-rem only to 50 miles in prioritizations and regulatory analyses, which reduces the person-rem by a factor of about 1.4 to about ten (most for sparsely populated locations; least for high-population-density sites).

The accident consequence calculations, including property damage estimates, were made using the CRAC2 computer code. (For a description of the nature, capabilities, and limitations of CRAC2, see Appendix D.) The results are sensitive to the basic physical modeling of the accident radiological source terms. Adoption of new source terms could result in a reduction of both person-rem and property damage.

Most prioritizations and regulatory analyses are generic. Current staff practice in prioritization is to use one set of calculations of person-rem, based on a uniform population density of 340 persons per square mile (the continental U.S. average projected for the year 2000), a radius of 50 miles and a typical central Midwest plains meteorology. The result is, of course, not indicative of any particular site. The practice is justified on the bases that (a) the emphasis at the prioritization stage is on comparing potential generic issues among each other on a consistent basis, and (b) at the prioritization stage it is usually not known which sites will be affected. Regulatory analyses usually follow the same practice, except in cases where only a few sites are involved, in which case site-specific figures may be used.

In summary, a capability exists to estimate offsite property damage from accidents. The capability is limited in that it suffers from many of the limitations and uncertainties of health effects calculations plus the limitations of the economic models. Current staff practice is to assume that offsite property damage consequences increase with person-rem and that they are usually small in comparison with the person-rem monetized at the $1,000/person-rem tradeoff coefficient usually employed. Thus, the offsite property damage is currently not ordinarily explicitly treated in prioritizations and regulatory analyses, although it may be explicitly addressed in such unusual circumstances as may warrant separate, explicit consideration of offsite property losses.

References

A-1 NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission, January 1983.

A-2 NUREG-0933, "A Prioritization of Generic Safety Issues," December 1983.

A-3 NUREG/CR-2800, Guidelines for Nuclear Power Plant Safety Issue Prioritization,"

A-4 NUREG-1128, "Trial Evaluations in Comparison with the 1983 Safety Goals," June 1985.

A-5 NUREG/CR-2723, "Estimate of Financial Consequences of Nuclear Power Accidents," September 1982.

APPENDIX B

TREATMENT OF OFFSITE PROPERTY LOSSES IN EISs

Pursuant to the Statement of Interim Policy (45 FR 40101-40104, June 13, 1980) environmental impact statements (EISs) published after July 1980 in support of nuclear power plant licensing have included exploration of the economic consequences of severe accidents. The treatment of severe accidents in these EISs consists of detailed probabilistic analyses of the offsite radiological consequences of a number of different postulated accident scenarios.

The analyses of offsite mitigation measures cost (also called property damage cost) for EISs followed the Reactor Safety Study (RSS, WASH-1400) methodology implemented in the CRAC or CRAC2 computer code (see Appendix D). The itemized property damage costs calculated by these computer codes include (a) evacuation cost, (b) costs of interdiction of contaminated crop and milk, (c) cost of decontamination of land and property where practical, (d) cost of interdiction of excessively contaminated land, and (e) cost of relocation of people from the interdicted land.

For the source terms for the EIS analyses, WASH-1400 PWR or BWR release categories (as appropriate) with the WASH-1400 probabilities (after minor corrections) were used for some plants; the WASH-1400 rebaselined (B-1) release categories with rebaselined probabilities were used for the majority of the plants; and plant-specific source terms based on the RSS methodology and assumptions with plant-specific probabilities were used for a few plants. All source terms were adjusted for the plant-specific power levels. In addition to the source terms and their probabilities, the inputs to the computer code included: site-specific meteorology; site-specific projected population distribution for the plant mid-life year; the state-basis average land use data for all states of the entire site region, or for some sites the county-basis average land use data for all counties within approximately the 50 or 60 mile region and the state-basis data for all states outside this inner region (see Appendix D); and the national average or in some cases the regional average economic unit cost data for evacuation, interdiction and decontamination (see Appendix D).

Except for a few recently published EISs, the conditional mean values of consequences (see Appendix D) including the property damage cost, for individual release categories were not separately calculated. For any given kind of consequence, such as offsite mitigation measures cost, the probability weighted conditional mean values of the consequence for all release categories were internally summed by the CRAC code and shown as the risk of the particular kind of consequence. For example, the Limerick EIS (B-2) result for the risk of offsite mitigation measures cost is 50,000 dollars (1980 dollar) per reactor year for which the complementary cumulative distribution function (CCDF) is shown in Figure B-1.

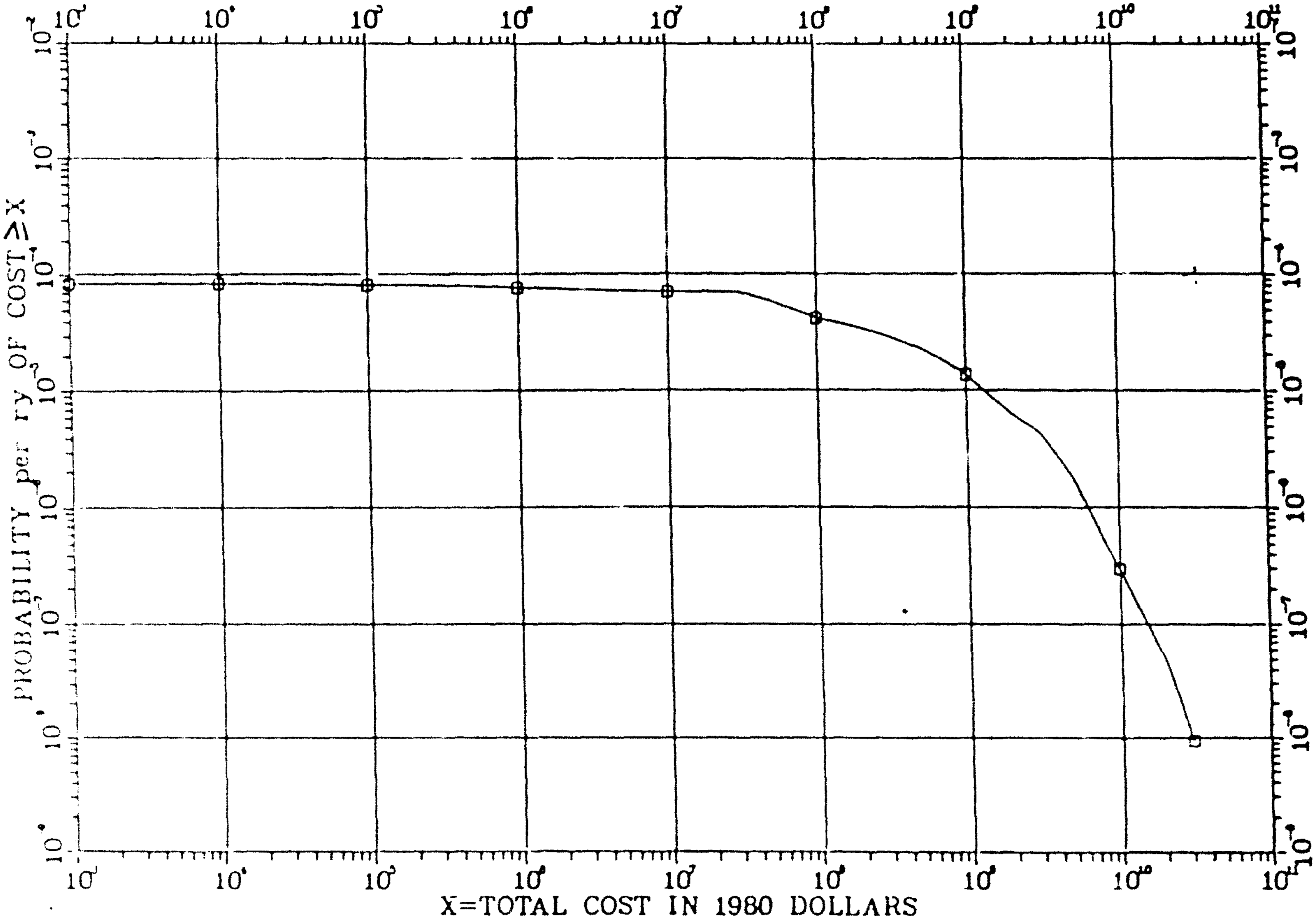


Figure B-1 Probability distribution of cost of mitigation measures

NOTE: There are large uncertainties both in probability and consequence magnitude.

For a few EISs, beginning with Limerick, the secondary cost (see Appendix D) of regional industrial impact in the region outside of the contaminated area within the first year after the accident is also calculated. The estimated risk of this impact for Limerick is 50,000 dollars per reactor year. However, considered on a national scale this estimate may have been an overestimate because the positive and negative economic impacts considered on a wider (national) scale are likely to offset one another so as to result in a smaller risk of secondary cost (see Appendix D). No probability distributions of this secondary impact have been developed.

For reference, the residual person-rem (i.e., the person-rem remaining after the population-exposure reducing effects of mitigation measures were taken into account -- see Appendix D) for the 50-mile region and the entire site region of Limerick are 700 and 1,000, respectively.

There are large uncertainties in the numerical estimates of risks of offsite economic losses for the reactor accidents. The EISs provide a qualitative discussion of uncertainties of reactor accident economic risk estimates due to the assumptions about accident probabilities, source terms, interdiction criteria, property values, decontamination procedures and their effectiveness,etc.

Reference:

B-1. NUREG-0773, "The Development of Severe Reactor Accident Source Terms: 1957-1981," November 1982.

B-2. NUREG-0974, "Final Environmental Statement related to the operation of Limerick Generating Station, Units 1 and 2," April 1984.

APPENDIX C

SOME HIGHLIGHTS FROM INDIAN POINT

Analyses of the offsite mitigation measures cost (also called the property damage cost) for the Indian Point reactors (C-1) (which included estimates of (a) cost of evacuation, (b) costs of interdiction of contaminated crops and milk, (c) cost of decontamination of land and property, where practical, (d) cost of interdiction of excessively contaminated land, and (e) cost of relocation of people from the interdicted land) were made following the Reactor Safety Study (RSS) methodologies implemented in the CRAC computer code which are described in Appendix D of this information paper.

Nine different release categories (source terms) specifically developed for the Indian Point reactors based on the RSS methodology and assumptions, with their probabilities developed from review of an in-depth plant specific PRA, were used. In addition to the source terms and their probabilities, the input to the computer code included: site-specific meteorology; site-specific projected population distribution for the year 1990; county-specific land use data (see Appendix D) for all counties up to 60 miles from the reactors; and state-specific land use data for all states of the site region beyond 60 miles; and regional-basis economic unit cost data (in 1981 dollar) for evacuation, interdiction, and decontamination (see Appendix D).

For each of the nine release categories conditional mean values (conditional upon release, but meteorology and wind direction averaged) of the offsite property damage cost were estimated for each reactor unit. The nine release categories' probability weighted sum of the conditional mean values of property damage cost for each reactor unit, i.e., the risk of offsite property damage cost for each of the Indian Point reactors from all release categories were also estimated. These estimated risks were:

(a) 280,000 dollars per reactor-year for Unit 2, and
(b) 165,000 dollars per reactor-year for Unit 3,
subject to the limitations described in Appendix D.

For reference, the estimated residual person-rem (i.e., the person-rem remaining after the population-exposure reducing effects of mitigation measures were taken into account -- see Appendix D) for the two reactors units were:

Unit 2: (a) 1,800 per reactor-year for the 50-mile region, and
(b) 2,600 per reactor-year for the entire site region

Unit 3: (a) 990 per reactor year for the 50-mile region, and
(b) 1,400 per reactor year for the entire site region

There are large uncertainties in the numerical estimates of risks of offsite economic losses. Qualitative discussion of these uncertainties was provided in the Indian Point hearing testimony by the staff.

Reference

C-1 Section III.C.A Testimony of S. Acharya regarding NRC staff Assessment of Accident Consequences and Risks in Response to Commission Question 1 for the Indian Point hearing.

APPENDIX D

DESCRIPTION AND CRITIQUE OF CURRENT CALCULATION METHODS

The model used by the staff or the staff contractors for calculation of economic costs of mitigating measures to minimize adverse offsite health effects that could result from a major reactor accident accompanied by a large atmospheric release of radionuclides from the containment is the same as developed for the Reactor Safety Study (RSS) (Ref. D-1), which is implemented in the computer codes such as CRAC and CRAC2. The adverse health effects originate from the airborne radioactive material and from the radioactive material that would be deposited in the environment. The principal action that may be taken to minimize the harmful health effects due to airborne material would be to evacuate the people situated in the path of the radioactive cloud. Measures to mitigate the effects of radioactive material deposited on the ground could include impoundment of contaminated crops and milk produced from animals feeding on pasture within the contaminated area, decontamination of land and structures, and interdiction of land (prohibition or restriction of its use) with relocation of people from the interdicted land. These protective actions would result in reductions in health consequences but would also result in economic costs to implement them. These economic costs are collectively known as property damage cost. If the interdiction and decontamination plans were designed on the basis of excessively tolerant radiation standards, then an excessive number of cases and cost of health effects, but lower economic cost of mitigating measures would be incurred. On the other hand, if the standards were stringent, then fewer cases and lower cost of health effects, but excessive cost of mitigating measures would be incurred.

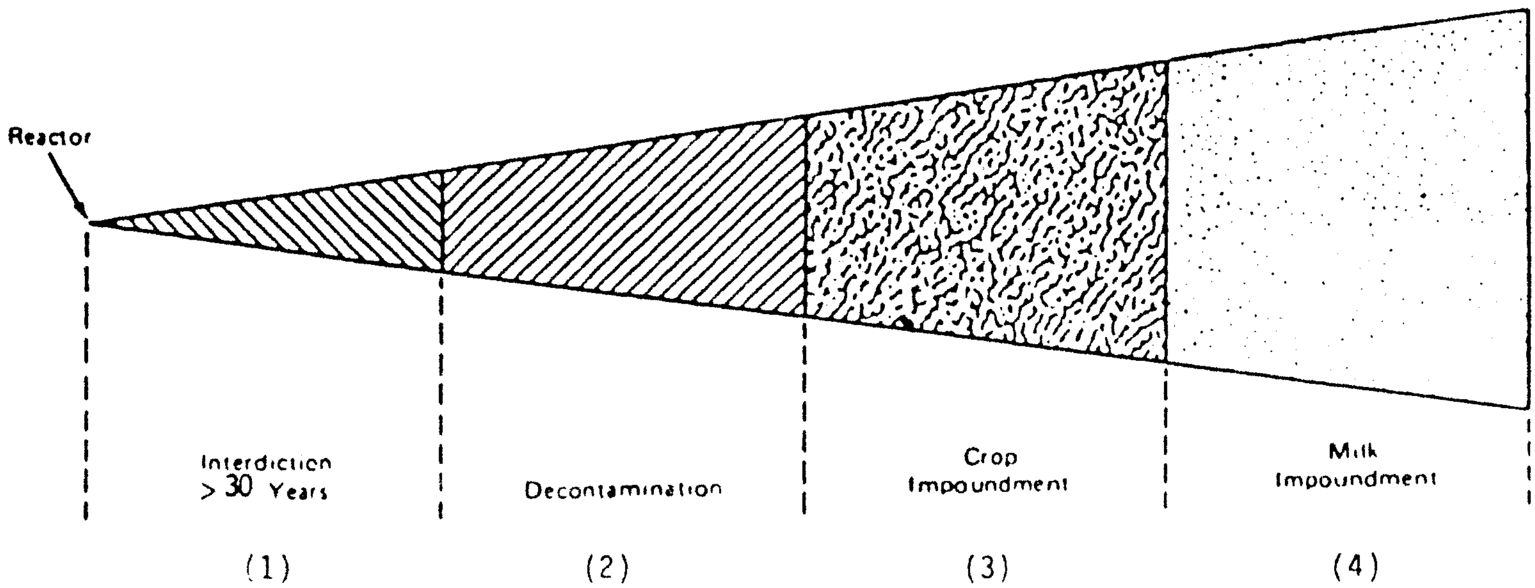
The RSS dose criteria (i.e., the maximum allowable dose levels) for mitigation of effects of radionuclide ground deposition implemented in CRAC and CRAC2 codes are: (a) 25 rem in 30 years to the whole body from long-term groundshine to any person; (b) 3.3 rem to the bone marrow in the first year for strontium (Sr), 3.3 rem to the whole body for cesium (Cs), and 10 rem to the thyroid from milk ingestion pathway to a child; and (c) 2 rem to the bone marrow in the first year for Sr, and 2 rem to the whole body for Cs from the crop (other than milk) ingestion pathway to any person. These criteria were developed for the RSS and were based on the recommendations of the former U.S. Federal Radiation Council and the British Medical Research Council (D-1).

However, it should be noted that the RSS food pathway (milk and crop ingestion) dose criteria are different from similar criteria recently recommended by the Food and Drug Administration (FDA), U.S. Department of Health and Human Services, as a voluntary guidance (not regulations) to the state and local agencies responsible for emergency response planning for radiological incidents for taking protective actions in the event of accidental radiological contamination of human food and animal feeds (D-2). FDA recommended dose criteria for low economic impact situations (less severe accidents) are 0.5 rem to the whole body, bone marrow, or any organ other than the thyroid, and 1.5 rem to the thyroid (termed as preventive protective action guide (PAG)). For high economic impact situations (severe accidents) the FDA criteria (termed as emergency PAG) are 5 rem whole body, bone marrow, or any organ other than thyroid, and 15 rem to the thyroid. (The FDA recommended criteria have received the EPA's commitment for approval (Ref. D-2)).

The staff has not critically evaluated the impact of FDA food pathway dose criteria in economic cost calculations for reactor accident risk assessments. However, the staff experience indicates that the costs of contaminated crop and milk disposal are small (less that 10%) compared to the costs of land and property decontamination, and land interdiction for severe accidents. Therefore, implementation of FDA criteria in the staff's computer codes would not likely have an appreciable impact for severe accidents economic cost assessment.

However, the preceding conclusion may not be applicable for less severe accidents which may require only contaminated crop and milk disposal due to more stringent FDA criteria (FDA has no groundshine criteria), but which may not require any protective action by the RSS criteria. Nevertheless, the total cost of milk and crop disposal would be low due to lower severity of these accidents.

The RSS model of long-term mitigating actions to reduce the effects of ground deposition is schematically shown in Figure D-1. For a ground level and cold release, the degree of ground and vegetation contamination would decrease monotonically with distance from the reactor. The most restrictive contamination criterion would be applied to milk and hence the largest interdicted area would be associated with milk impoundment. This area is the sum of the areas labelled as (1), (2), (3) and (4) in Figure D-1. A less restrictive criterion would be applied to the direct contamination of foliage; therefore, the interdicted crop growing area would be smaller. This area is the sum of the areas labelled as (1), (2) and (3) in Figure D-1. The area identified as (1) in Figure D-1 is marked for interdiction for periods longer than 30 years because of a very high level of contamination which can not be effectively decontaminated. People from this area would be relocated on a long-term basis. The area identified as (2) in Figure D-1 would be interdicted for varying periods of time from 0 to 30 years, and would be returned for occupancy after decontamination at different times. Parts of this area would be decontaminated and allowed for occupancy soon (immediately) after the accident. Occupancy of other parts of this area would be delayed until such different times by which the contamination would fall to lower levels (by radioactive decay and other natural processes) so that these parts of the area can then be effectively decontaminated (on a



Simplified interdiction model.

Figure D-1

staggered basis). People from such areas which would be interdicted would be relocated for varying periods of time until completion of decontamination.

The economic costs identified in the preceding are calculated by the CRAC or CRAC2 code using the supporting economic data supplied as input to these codes. In the computational framework of CRAC or CRAC2 the site region surrounding any specific nuclear power plant and extending out to 500 miles from the plant is spanned by 16 direction sectors of the compass and 34 concentric circular rings centered at the plant. Thus, the site region is divided into 16x34=544 grid area elements. For the purpose of economic costs calculation each area element is tagged (i.e., identified) by the name of the state to which the major part of the area element belongs. Some of the economic data required for these area elements are developed as state-basis average values and are provided as inputs to the computer code. These data elements are: (a) state-average fraction of habitable land used for farming, (b) state-average crop seeding and harvesting months, (c) state-average annual sale of farm products ($/acre), (d) state-average value of farm ($/acre), and (e) state-average dairy production fraction of farm products. For some specific cases of fine-tuned consequence analysis performed by the staff (such as for Indian Point and Limerick) area elements within 50 or 60 miles were identified by county names, and those outside of this inner region were identified by state names. For those elements identified by county, the county-basis average values and data were provided in the input. Generally, References D-3 and D-4 and plant-specific Environmental Reports are the sources for these land-use data.

One of the principal parameters of the consequence model is the population data (actual or projected based on the U.S. Census data) for each of the 544 area elements. For each release analyzed the consequence model calculates the number of affected people and the extent to which they would be affected, for each area element. It is assumed that the contaminated area is large enough for population-average values of some of the economic parameters to be reasonable. Therefore, for these economic parameters the input data are given as per capita costs. The total itemized costs of these categories are calculated as the product of the number of affected people and various per capita costs. These categories of unit costs are: (a) evacuation cost ($/person), (b) value of developed property (residential, business, and public area)($/person), (c) cost of decontamination of developed property (residential, business, and public area)($/person), and (d) cost of relocation of people from interdicted land ($/person). The cost of decontamination of farm land is developed on per acre basis ($/acre). These types of data were initially developed for the RSS based on information provided in the references listed in Chapter 12 of Reference D-1 and have been periodically updated by the staff or its contractors for specific applications following the RSS procedure, and information in additional references (D-5 to D-9).It is assumed that this group of economic data is common to all area elements that would call for them during calculations.

Examples of the types of data discussed in the preceding paragraphs are shown in Table 1 of the main body of this information paper.

In the following paragraphs the procedures for calculation of various itemized elements of economic costs for a given radionuclide release (source term), for a given sequence of weather conditions, and for the wind blowing toward a given direction sector are indicated. The total cost under these conditions is the sum of these itemized costs.

Evacuation Cost is equal to the number of persons evacuated multiplied by the cost of evacuation per person. For a release lasting less than three hours, all persons living within a "key-hole" shaped area (a circle centered at the reactor of 5-mile radius plus a 90° (in RSS 45°) sector centered on the plume direction and extending to 10 miles from the plant) are assumed to be evacuated. For a release lasting longer than three hours, all persons living within a 10-mile radius region are assumed to be evacuated. The cost per evacuee includes costs of transportation, and food and shelter for one week, and the per-evacuee share of cost of evacuator personnel.

Farm Product Disposal Cost:

Milk Disposal: If deposited radioactivity levels are acceptable for immediate inhabitation and crop ingestion, but radiological doses from ingestion of milk are unacceptable then it is assumed that milk would be impounded if the accident occurs during the feed growing season. The cost of milk disposal is the product of the number of acres of farm land affected, milk production per acre per year ($/acre/year), and fraction of the year during which milk doses are unacceptable. The cost of milk disposal is zero if the accident takes place during a non-growing season, because cows are assumed to be fed with stored (uncontaminated) feed.

Crop Disposal: If deposited radioactivity levels are acceptable for immediate inhabitation, but doses from ingestion of the harvested crops contaminated by the accident during the crop growing season are unacceptable, then it is assumed that the annual crop production is impounded. In this case doses from milk are also unacceptable, so that milk is impounded. The cost of disposal of crop is the number of acres of farm land affected times the crop production per acre ($/acre).

Immediate Decontamination and Inhabitation of an area is assumed to occur if the deposited level is initially unacceptable and decontamination can reduce the contamination to an acceptable level immediately. In this case, it is assumed that the annual production of farm products would be impounded if the accident occurred in the growing season. Procedures for costs of farm products (milk and crop) were indicated earlier. The cost of decontamination is the sum of the number of acres of farm land affected times the per acre cost of farm land decontamination and the number of people affected times the per-person cost of residential, business, and public area decontamination.

Land Interdiction Followed by Land and Property Decontamination: Land area interdiction is considered as a likely consequence mitigation measure if the ground contamination at the time of accident is so high that a decontamination effort would not be successful in lowering the levels for immediate occupancy. It is assumed that use of the land would be prohibited at least for some time to allow for radioactive decay and weathering of the deposited radionuclides before decontamination process would be undertaken. The economic loss due to this scenario of land interdiction is the sum of (a) farm product loss if the accident occurred in the growing season, (b) loss of property value during the period of interdiction, (c) cost of relocation of people from interdicted land (based on the number of persons), and (d) cost of decontamination of the interdicted land at some future time before reoccupancy. The economic loss of this scenario is compared with the economic loss in an alternative scenario in which interdiction is continued for a longer period of time until the contamination would fall to allowable levels by natural processes (radioactive decay and weathering) and without ever having to decontaminate. In this latter scenario the economic loss is the sum of (a) the loss of farm product if the accident occurred in the growing season, (b) the loss of property value during the longer period of interdiction, and (c) the cost of relocation of people from interdicted land. If the interdiction period in either of the two scenarios is greater than 30 years the land is assumed to be permanently interdicted. Otherwise, the smaller of the total costs in the two scenarios (decontamination vs. natural processes) is chosen as the economic loss in this category.

Land Interdiction Cost is calculated as the value of the land and improvement just before the accident minus the value of the land and improvement at the end of the interdiction period. The value of the land at the end of the interdiction period is its value before the accident reduced by a cost factor involving interest rate and property tax rate (See Table 1 of the main body of this information paper) to keep the ownership throughout the interdiction period. The value of the improvement at the end of the interdiction period is its value before the accident depreciated (See Table 1 of the main body of this information paper) over the interdiction period (because of obsolescence and lack of maintenance), which is further reduced by the cost factor indicated above.

The probabilistic nature of the economic cost estimate (or estimates of any other types of consequence such as early fatalities, delayed cancer fatalities, person-rem, etc.) by the CRAC or CRAC2 code is inherent in the procedure used in these calculations. Description of the release of radioactive material (source term) for which the consequence estimates are made includes the probability for its occurrence. For a given source term, and conditional upon its occurrence, magnitudes of consequences are estimated for a variety of sequences of meteorological conditions and 16 wind directions. Each sequence of meteorological conditions sampled from the observed site meteorological conditions over a period of one year has an associated probability. So also, the wind blowing toward the 16 direction sectors has separate probabilities. Thus, the results obtained from calculations are probabilistic in nature, reflecting the probabilities associated with the accident occurring, the weather conditions, and the wind direction. The distribution of calculated magnitudes of consequences of any given kind and associated probabilities are usually presented graphically in the form of a complementary cumulative distribution function (CCDF). See Figure B-1 of Appendix B for an example of a CCDF plot. The sum of the probability weighted magnitudes of consequences of a given kind is the expectation value (or mean), or risk, of the particular type of consequence, and is approximately equal to the area under the CCDF for that consequence. If the probability of occurrence of the accident is not included (or is set equal to 1.0) in the mean value estimate of a consequence, then the mean value is only a meteorology and wind direction weighted mean value of the consequence known as the conditional mean value (conditional upon occurrence of the accident). The risk of a given kind of consequence is equal to the product of the conditional mean value of the consequence and the probability of the accident to which the consequence is due.

In the spectrum of elements of the economic cost that would likely be incurred to mitigate the consequences of a large atmospheric release of radionuclides from a severe reactor accident, the elements that were not estimated in the RSS and are not modeled in the CRAC and CRAC2 codes are:

- Cost of temporary relocation from hot spots outside the 10 mile emergency planning zone
- Cost of temporary relocation during immediate decontamination
- Cost of adverse health effects
- Secondary economic costs
- Liquid pathway contamination costs

Each of these cost elements is briefly discussed in the following paragraphs.

Cost would be incurred for immediate, but temporary, relocation of people from radioactive hot spots (highly contaminated areas) outside the 10 mile plume exposure pathway emergency planning zone. The hot spots are expected to be identified by field measurement of levels of ground radioactive contamination immediately after plume passage. People from these areas would likely be advised to relocate temporarily until completion of any further evaluation. The number of people to be relocated from hot spots outside the 10-mile zone is expected to be highly dependent on the radionuclide release magnitudes, energy associated with release (cold vs. hot), population distribution, weather conditions, and wind direction. On the high side, the cost of this temporary relocation would be about the same order of magnitude as that estimated for evacuation. The cost of evacuation is generally less than 10% of the total property damage estimated by the staff. Therefore, the omission hitherto of this cost element in CRAC or CRAC2 has only a small impact in the staff's property damage estimate. The new consequence code now being developed for the staff at Sandia as part of the MELCOR program will include this cost element (Ref. D-10).

The land area identified as (2) in Figure D-1 would be marked for decontamination and subsequent reoccupancy. As discussed earlier, part of this area can be immediately decontaminated and allowed for occupancy. However, the land that can be decontaminated immediately would in a real situation be decontaminated only over a time interval during which the decontamination processes would be carried out. (Decontamination of developed property would involve firehosing or replacing the roofings and pavings, firehosing the outside walls, and replacing the lawns. Decontamination of farmland would involve deep ploughing for tilled land and grazing land, and scraping the surface soil for orchards. These procedures would require procuring the necessary material and equipment, and personnel to do the work. Appropriate disposal of the replaced material would also be necessary.) During this period of decontamination action, people from the affected land undergoing decontamination would be temporarily relocated until the decontamination process is complete. The cost of this temporary relocation is not estimated in CRAC or CRAC2 but will be estimated in the new consequence code mentioned earlier. Preliminary findings at Sandia indicate that its inclusion would not have substantial impact on the property damage estimates.

The cost of health effects includes (a) the direct cost of medical treatment of illness due to radiation exposure of people, including diagnosis, treatment, and care, and (b) the indirect cost due to loss of productivity because of illness or premature death from the health effects. These costs are not estimated in CRAC or CRAC2. A model developed by the Pacific Northwest Laboratories for health effect cost estimates is being integrated by Sandia into the new consequence code mentioned earlier. Preliminary estimates by Sandia (Ref. D-10, D-11), indicate that inclusion of health effect costs would increase the currently estimated economic cost by 20 to 30 percent.

Secondary economic costs would likely arise from temporary or permanent closure of business in the areas which are outside the areas directly impacted by land interdiction, decontamination, or crop and milk interdictions. These closures would have additional economic effects beyond the contaminated areas through the disruption of regional markets and sources of supplies. These secondary costs are not estimated by CRAC or CRAC2. Application of a model developed by the Bureau of Economic Analysis, U.S. Department of Commerce to the Limerick site indicated that, without inclusion of compensating beneficial effects, such as use of the unused capacity in the physically unaffected area to offset the initial lost production in the physically affected area, the secondary cost within the first year after the accidents could be comparable to the economic cost calculated in CRAC or CRAC2. The RSS (Ref. D-1) noted that distinction should be made between the regional cost and the national cost of mitigating measures. The regional cost is necessarily larger than the national aggregate or resource cost because it includes only losses and is not offset by any of the gains that may result. While the nation as a whole would be assumed to obtain no economic gains from mitigating measures, certain corporate businesses or individuals might do so. In general, it is likely that flexibility in national and regional economies which is observed after most disasters would result in lessening of the secondary impacts from mitigative measures. Therefore, it can be concluded that the complete accounting of the secondary economic cost would not appreciably impact the estimates normally made by CRAC or CRAC2, although in some specific instances it may be important.

Economic costs of liquid pathway contamination following severe reactor accidents are generally not evaluated by the staff although in several Environmental Statements and for a few environmental hearings the staff has provided estimates of person-rems that may result from use of the contaminated liquid pathways. Economic cost could be incurred in several ways as discussed below:

a) Interdiction of the source of the contaminated ground water where the radionuclides from base-mat melt-through would contaminate an underlying aquifer. Arrangement must be made to provide replacement drinking water to the region if the normal drinking water supply would be affected by this interdiction.

b) Interdiction of surface water contaminated by atmospheric fallout of radionuclides on open water bodies and radionuclide run-off from land into open water bodies. Alternate drinking water supply must be provided during the period of interdiction, if the affected water bodies were normal sources of drinking water.

c) Interdiction of aquatic foods grown in the contaminated water for several years after contamination.

d) Denial of recreational uses of the waters and shorelines of the affected water bodies.

The new consequence code at Sandia will have capability to provide the estimate of cost of liquid pathway contamination.

As a matter of convenience, or as a recommended procedure, the staff normally does not use the sum of the itemized cost elements estimated by CRAC or CRAC2 in the cost-benefit analysis. Instead, the staff uses $1,000 times the residual person-rem (i.e., the person-rem remaining after the population-exposure reducing effects of mitigation measures were taken into account (see next paragraph)) estimated by CRAC or CRAC2 for the 50-mile site region as a surrogate measure of economic cost which in many instances happens to bound the sum of all itemized cost elements calculated by CRAC or CRAC2. Examples of the observed bounding nature of $1,000 times the residual person-rem for the entire site region (as distinct from the 50-mile region) with respect to the property damage cost are shown in Table D.1. Although the residual person-rem for the 50-mile region varies from 10% to 70% of the residual person-rem for the entire site region, (depending primarily on the population distribution of the site), it too bounds the CRAC or CRAC2 estimated property damage cost for most accident sequences and for most sites. (For additional pertient examples, see Appendix A.)

The adjective "residual" used to qualify the person-rem in the preceding paragraph is to distinguish it from the full potential person-rem (i.e., un-mitigated or un-reduced value of person-rem) as explained below. The CRAC or CRAC2 output of person-rem (which is not a physical effect per se) is only a byproduct of the CRAC or CRAC2 runs primarily made for realistic estimates of health effects and property damage accounting for the credits for dose reducing actions of the mitigating measures such as evacuation, interdiction and decontamination. This byproduct person-rem is only what is left of the full potential person-rem after a part of the full potential person-rem is eliminated by the dose reducing actions of the mitigation measures; therefore, it is indeed the residual person-rem.

As a result of the dose reducing actions of interdiction and decontamination (which are currently triggered by the CRAC and CRAC2 codes internally on the basis of the RSS criteria discussed earlier), the full potential person-rems of source terms of different magnitudes larger than necessary to trigger interdiction and decontamination are reduced by different amounts. On the other hand, the full potential person-rem from source terms which are low enough to contaminate the environment only lightly, and not exceed the interdiction and decontamination dose criteria, will not be reduced at all; in this case, the CRAC or CRAC2 person-rem outputs are not residual but are full potential values, because the interdiction and decontamination processes were not turned on by the codes. Because of these underlying phenomena taking place during the computational processes of CRAC or CRAC2 codes, the residual person-rems are highly nonlinear functions of the source term magnitudes, and lead to apparent anomalies. For example, for two source terms of magnitudes differing from each other by a constant factor, the residual person-rems may not be related by the same factor, or even in some cases the residual person-rem estimates for these two source terms may turn out to be approximately equal; on the other hand, the full potential person-rems would approximately be related by the same factor as the source term magnitudes. The anomaly is only apparent because its underlying cause is well understood.

TABLE D.1

Examples of Residual Person-rem x $1,000 Versus Offsite Property Damage Cost Estimate

A. Sandia Siting Study with SST1* Source Term (Annual Probability 1(-5)**) for a 3412 Mwt PWR

	Mean Consequence Conditional on Release			Probability Times Conditional Mean Consequence (Risk)		
Site Name	Property Damage Cost ($)	Residual Person-rem	Residual Person-rem x $1,000 ($)	Property Damage Cost ($/RY)	Residual Person-rem (Per RY)	Residual Person-rem x $1,000 ($/RY)
Indian Point	1.2(10)	1.3(8)	1.3(11)	1.2(5)	1.3(3)	1.3(6)
Catawba	2.0(9)	2.5(7)	2.5(10)	2.0(4)	2.5(2)	2.5(5)
Limerick	6.6(9)	8.2(7)	8.2(10)	6.6(4)	8.2(2)	8.2(5)
Nine Mile Point	1.3(9)	2.4(7)	2.4(10)	1.3(4)	2.4(2)	2.4(5)
Point Beach	1.8(9)	2.7(7)	2.7(10)	1.8(4)	2.7(2)	2.7(5)
B. Staff's Indian Point Unit 2 Analysis with RC-B*** Source Term (Annual Probability 4.3(-7)), 2758 Mwt PWR						
Indian Point 2	5.8(9)	5.4(7)	5.4(10)	2.5(3)	2.5(1)	2.3(4)
C. Staff's Limerick Analysis with IV-T/DW**** Source Term (Annual Probability 2(-7)), 3458 Mwt BWR						
Limerick	5.0(9)	8.0(7)	8.0(10)	1.0(3)	1.6(1)	1.6(4)

* A generic source term involving severe core damage, loss of all ESFs, and direct breach of containment.
** $1(-5) = 1 \times 10^{-5}$
*** Interfacing Systems LOCA.
****ATWS with containment failure via overpressurization; failure location in dry well.

References:

D-1 WASH-1400 (NUREG-75/014), "Reactor safety Study, An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," October 1975; Appendix VI.

D-2 FR Vol. 47, No. 205, 47073-47083, "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies," Food and Drug Administration, Department of Health and Human Services, October 22, 1982.

D-3 U.S. Department of Commerce, "Statistical Abstract of the United States," (published annually).

D-4 U.S. Department of Commerce, "County and City Data Book," (published annually).

D-5 U.S. Department of Commerce, "Taxable Property Values and Assessment/Sales Price Ratios," Census of Governments, 1977, Vol. 2.

D-6 U.S. Department of Commerce, "Census of Mineral Industries," 1977.

D-7 U.S. Department of Commerce, "Census of Local Governments."

D-8 U.S. Department of Commerce, " Local Area Personal Income: 1975-80."

D-9 U.S. Department of Commerce, "Census of Agriculture," 1978.

D-10 NUREG/CR-3673, "Economic Risks of Nuclear Power Reactor Accidents," R. P. Burke, D. Aldrich, and N. Rasmussen, April 1984.

D-11 NUREG/CR-2723, "Estimated Financial Consequences of Nuclear Reactor Accidents," D. R. Strip, September 1982.

APPENDIX E

RECENT AND CURRENT RESEARCH

Introduction

Several organizations are working on economic consequence models, under NRC sponsorship and also under the sponsorship of other agencies. This work includes the application of existing models and computer codes to specific tasks, the study of the characteristics and limitations of existing models, and the development of new, more detailed, and more specialized models and codes.

Sandia National Laboratory

Sandia has been the site of an ongoing NRC-sponsored research program investigating the consequences of reactor accidents, including economic consequences. Two recent reports include estimates of offsite property damage based on the CRAC2 computer code:

> NUREG/CR 2723 (E-1) includes estimates of offsite property damage as well as onsite costs of replacement power and cleanup. Calculation results are presented on 156 reactor-site combinations. (The offsite damage costs do not include indirect costs, socio-economic costs, and health care costs.) Some highlights are presented in Appendix A.
>
> NUREG/CR-2899 (E-2) includes an analysis of the relationship between offsite property damage and public radiation dose based on the 156 reactor-site combinations of NUREG/CR-2723.

The characteristics of the CRAC2 computer model are still under active study (E-3), but the CRAC2 code is the usual choice in regulatory investigations, e.g. references E-4 and E-5. In addition, new models have been developed for estimating the costs of offsite protective actions (and radiation-induced health effects) after severe LWR accidents (E-6). The models will be incorporated into the consequence model in the MELCOR series of risk assessment codes to estimate the offsite economic impacts of accidents. The cost of population evacuation, temporary relocation, agricultural product disposal, land and property decontamination, land interdiction, permanent population relocation, and health impacts which may be incurred after an accident are included in the models. The major differences between the new model and the CRAC2 model are:

1. The new model accounts for short-term emergency phase and intermediate phase population movement costs not included in the CRAC2 model.

The modeling of staged protective measure implementation is used to provide realistic estimates of the costs of post-accident population protective measures. The projection of doses over multiple time periods accounts for the duration of protective measures which may be necessary for short and long-lived radionuclide releases. The staged implementation of offsite protective measures after severe LWR accidents is considered to be realistic because perfect information would not be immediately available in post-accident situations, and dose rates may change rapidly with time.

2. The model accounts for population relocation which may be necessary during the decontamination and cleanup process.

   It may be necessary to relocate individuals away from areas in which radionuclides have deposited after a severe LWR accident. These individuals may have been evacuated before the release of material, in which case it is only necessary to extend their stay out of the area, or movement of additional individuals from contaminated areas might be required. As improved information is gathered concerning the dose rates from deposited radioactive material, individuals may be permitted to reenter those areas in which projected doses do not exceed acceptable levels.

3. The model allows user definition of all protective action criteria to be applied in post-accident situations.

   The new economic consequence model allows specification of the time period for integration of emergency phase groundshine doses, the criterion to which projected individual doses are compared, and the time period for temporary population relocation in areas where the specified criterion is exceeded. The protective action criterion for the "emergency phase" period is defined based on projections of individual doses for surface-deposited materials.

4. Most economic parameters can be specified on a spatial interval basis for site-specific calculations.

   This makes the model more "portable" from one site to another, and also allows the parameters to be updated more readily.

5. All cost values have been updated and expressed in 1982 dollars.

6. Additional attributes of the decontamination program are estimated in the new economic model. Dose to decontamination workers is estimated and included in the health effect calculations.

7. Dose calculations correspond closely to the protective actions which are implemented in each area. This provides the ability to estimate both costs and benefits of various protective actions.

8. Health effect costs and onsite cost components can be included in the estimation of total accident costs.

Reference E-6 provides a comparison of the mean offsite cost components for the particular case of an SST-1 release at the Surry site, as calculated by the CRAC2 code and the new economic model. The results of both models (see Table E-1) indicate that the cost of property decontamination is the most important contributor to total offsite property damage for an SST-1 release at the Surry plant. The cost of property interdiction in areas where decontamination cannot reduce dose rates to acceptable levels is the second most important contributor to offsite property damage for this large release of radioactive material. The emergency phase relocation, intermediate phase relocation, and decontamination period relocation costs are relatively small for this accident release category. However, these costs dominate the initial evacuation costs, which are the only population relocation costs included in the CRAC2 models. Updated costs of decontamination, interdiction, and relocation in the new economic model result in total cost estimates less than a factor of 2 higher than those from the CRAC2 model.

Reference E-6 also states that calculations performed for various other U.S. LWR sites and release categories have resulted in offsite cost predictions as much as factors of 2 to 4 higher than those predicted by the CRAC2 code.

Uncertainties in the health and economic consequences of potential reactor accidents are also currently being investigated. Systematic and rigorous techniques for studying uncertainty in the output of CRAC2 (and for estimating the relative contributions of model assumptions to that uncertainty) have been implemented (References E-7, E-8). In particular, statistical approaches to conducting uncertainty and sensitivity analyses of models and data pertinent to estimating offsite radioactivity and property damage have been evaluated. Important variables identified by this process include: source term, the cross-wind dispersion parameters of the plume atmospheric transport, property value, and decontamination cost.

Pacific Northwest Laboratory

Work continuing at PNL includes study of the methods, effectiveness, and costs of decontamination of property and the economic effects of property interdiction. The work includes assembly of a reference data base and development of a computer program, called DECON. A related PNL study is to improve a computer code, HECOM, which calculates the economic costs of radiation induced health effects.

Table E-1 - Comparison of offsite cost estimates from CRAC2 and new models, conditional on SST1 accident release, Surry #2 plant.

Cost Component	CRAC2 Mean Costs	New Model Mean Costs
Evacuation	$\$3.0\times10^6$	$\$4.5\times10^6$
Emergency Phase Relocation	-	$\$2.3\times10^7$
Intermediate Phase Relocation	-	$\$8.6\times10^7$
Agricultural Product Disposal	$\$8.0\times10^7$	$\$9.1\times10^7$
Population Relocation During Decontamination	-	$\$9.3\times10^7$
Land and Property Decontamination	$\$4.2\times10^8$	$\$6.6\times10^8$
Land and Property Interdiction	$\$1.9\times10^8$	$\$1.6\times10^8$
Interdicted Population Relocation	$\$4.9\times10^7$	$\$2.6\times10^7$
Total Offsite Costs	$\$7.4\times10^8$	$\$1.1\times10^9$

A recently issued PNL report, NUREG/CR-3566 (E-9) is a broad background exploration, largely qualitative, of the various types of possible economic consequences of the most severe and unlikely accidents (SST-1). An associated report from PNL, with a quantitative emphasis, "Offsite Consequences of Radiological Accidents: Methods, Costs and Schedules for Decontamination," J. Tawil et al., was in the publication process at the time of this writing.

The programs at PNL were originated to assist the NRC in the preparation of Environmental Impact Statements (EIS). The NRC has included accident scenarios in EISs since 1971. However, the accident at Three Mile Island suggested a need for changes in NRC policies relating to the potential impacts of serious accidents. Previous policy was therefore revised to require an analysis of health and safety risks associated with public exposure to radiological releases; these analyses were to reflect the current state of knowledge regarding such risks. In addition, consideration was required of potential socioeconomic impacts associated with emergency measures during and following an accident.

The model most commonly used by the NRC to estimate offsite accident consequences is the CRAC2 code. Because CRAC2 is relatively crude in the way it estimates off-site accident consequences -- except those relating to the health effects -- other models available to the NRC or currently under development serve to complement the information provided by the CRAC2 code (E-6). The MASTER model developed at Pacific Northwest Laboratories was designed to forecast regional economic action and assess the regional economic impacts caused by regional economic changes (E-9). It also can be used to provide estimates of direct and indirect regional impacts. HECOM is a health effects cost model that takes CRAC2's estimates of the health effects of an accident and uses these to provide estimates of the direct cost of health care and the societal losses due to impaired productivity and premature death caused by the accident (E-9, E-10).

DECON is a computer model currently under development that takes the CRAC2-produced ground concentrations of contaminations and identifies cost-effective decontamination procedures (E-9). Given a user-supplied radiation standard, DECON identifies the least costly decontamination method that will at least meet the standard. DECON contains the decay and weatherization models from CRAC2, which reduce the exposure levels over time. This means that, by waiting, one may be able to use decontamination methods that are effective but less costly. On the other hand, deferral means foregoing the use of potentially valuable property. DECON incorporates these concepts to determine the optimal time to decontaminate each property unit. Since the various input requirements are known, DECON can also provide an estimate of the manpower and equipment needed to carry out the decontamination schedule.

Finally, a model is being developed for FEMA (E-9). Named the Economic Recovery Dynamics Model (ERDM), it has the potential to investigate the consequences from various policy decisions that might be made following a severe reactor accident. (The primary purpose of the model is defense related.)

Bureau of Economic Analysis

Under contract with NRC the Bureau of Economic Analysis (BEA), US Department of Commerce has adapted one of its modeling systems (Regional Input-Output Modeling System) (RIMS II) to estimate regional industry-specific output (in dollars) and employment losses as a consequence of hypothetical reactor accidents. The BEA economic model incorporates site specific data, taken from CRAC2, on areal contamination and assumptions about the length of time of industrial and agricultural disruption. Also, the model uses county level data for 496 industrial sectors and state specific input-output multiplier coefficients from RIMS II. Estimates of losses are made for both the physically affected (contaminated) areas and the total economic study area, which consists of the physically affected area and other counties that have close economic linkages with the physically affected area (E-11 and E-12).

Use of the model on 14 plants to date indicates that the estimate of output losses is heavily dependent on the economic characteristics of the region within which a plant is located. On an expected value basis (probabilistic) estimates of first-year-after-accident output losses per reactor-year, in 1980 dollars, have varied from less than $5,000 (Vogtle, low surrounding population density) to $50,000 (Limerick, high population density). On a deterministic basis (one release category and dispersion of radionuclides in one compass direction) estimates of output losses range over many orders of magnitude, even for a single plant. Maximum loss estimates for Vogtle and Limerick differed by a factor of 26. Minimum (least severe release category and compass direction) output loss estimates for Vogtle and Limerick were $0.

Environmental Protection Agency

The EPA is developing implementation guidance for Protective Action Guides (PAGs) for relocation (E-13). The guidance will be intended for use by state and local officials for protecting the public from exposure to radiation from surface contamination and from inhalation of resuspended radioactive materials. It is not expected that this EPA guidance will include criteria for re-entering interdicted areas after relocation, since there would be time to develop such criteria after an accident, should one occur.

Should the EPA in fact establish specific relocation guidance as a result of its current work and should that guidance differ from currently used relocation criteria assumptions, estimates of property damage due to interdiction and decontamination could be correspondingly affected.

Defense Nuclear Agency

The Defense Nuclear Agency (DNA) has conducted a series of three nuclear weapon accident exercises. The latest (NUWAX-83), conducted in 1983, involved simulation of a helicopter crash leading to dispersion of nuclear weapon material by high-explosive explosion and fire. The exercise focused on developing working relationships and cleanup approaches. It included about 600 player participants from DOD, DOE, FEMA, other Federal agencies (but not NRC), and the Commonwealth of Virginia. A Joint Task Group of approximately 300 persons furnished exercise control, evaluation, and support. Though the NRC did not participate in the exercise, the NRC staff has been following the work. The DNA's After Action Report (E-14), providing a detailed analysis, included identification and discussion (but no resolution) of a number of "lessons-learned" questions bearing on property damage, which may have reactor accident counterparts (though for the DNA the key contaminant was plutonium rather than fission products, which are likely to dominate reactor accident consequences). Examples include: (a) Do you leach contamination into the soil? (b) When and how should a fixative be applied? What kind? (c) Should people be allowed to occupy an area that will subsequently be decontaminated? (d) Should re-entry be allowed at different contamination levels at different sites (e.g., roads, work places, residences)?

In the study of decontamination and other factors important to the monetary valuation of property losses, the DNA has engaged the Pacific Northwest Laboratories to extend the NRC-sponsored DECON program to weapons applications (E-15).

R&D Associates

NRC has sponsored work with R&D Associates to develop methods for assessing cost effectiveness of alternative accident-consequence mitigation approaches, to aid in NRC decision-making. This effort has produced a scoping study (E-16) which evaluated alternative mitigation systems for reactor accidents, evaluating them in terms of costs.

One of the more interesting results of this work was the calculation of the relationship of the cost of land interdiction to the interdiction dose criterion, for the particular case of a severe accident (SST 1) at Indian Point 2. If the 30-year projected dose limit considered acceptable for individuals to return to an interdicted area were liberalized to 50 rem, from the 25 rem usually assumed, the interdiction cost estimate dropped by a factor in excess of 2, while tightening it to 5 rem increased the cost about sevenfold.

Efforts Abroad

Much of the current research efforts abroad, by member countries of the Organization for Economic Cooperation and Development (OECD), Nuclear Energy Agency (NEA), Committee on the Safety of Nuclear Installations

(CSNI) for better assessment of reactor accident consequences is aimed toward refinement of methods for estimating environmental contamination by atmospheric transport, dry deposition, deposition by rain and snow, deposition and runoff in urban areas, migration of radionuclides in soil, and long-term environmental pathways (including food chain pathway) of radiological exposure of the public. Substantial effort is devoted to theoretical and experimental modeling of shielding protection provided by houses and structures, filtering effect of houses and deposition indoors, decontamination procedures, and their effectiveness in winter conditions (ice, snow) (E-17).

Research efforts abroad for assessment of property damage is relatively less compared with efforts toward modeling of accident consequence mitigating measures and their effectiveness. However, some of the foreign computer codes, such as the British computer code MARC, can estimate property damage costs. The MARC economic model (also called the ECONO-MARC model) is quite different from the U.S. model in CRAC or CRAC2. The basic assumption underlying the ECONO-MARC model is that the cost of mitigating measures, such as land area interdiction, will be a function of the area's contribution to the gross domestic product (GDP) prior to the accident. GDP is a measure of economic output which is used in national income and product accounts. The ECONO-MARC model assesses the impact of the mitigating measures (evacuation, agricultural product bans, permanent population relocation) on regional contribution to GDP. The ECONO-MARC model provides a broad macroeconomic measure of the offsite impacts of reactor accident mitigating measures (does not include decontamination) for Britain, which are not directly comparable to CRAC and CRAC2 economic impact estimates that are based on microeconomic models and assumptions which may be specific to the U.S. (See Ref. E-6).

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E-17 Enclosure to Circular Letter to Committee of Experts on Accident Consequence (GRECA), SEN/SIN (85), 16 Draft, May 2, 1985.