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<u>PWA- Dr. Lyman, MAAP Code-Lessons Learned</u>

A CRITIQUE OF THE RADIOLOGICAL CONSEQUENCE ASSESSMENT CONDUCTED IN SUPPORT OF THE INDIAN POINT SEVERE ACCIDENT MITIGATION ALTERNATIVES ANALYSIS

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In Memoriam: John Gofman

Introduction

In order to conduct the Severe Accident Mitigation Alternatives (SAMA) analysis for the Environmental Report submitted as part of its application for renewal of the licenses for the Indian Point 2 and 3 reactors, Entergy Nuclear was required to conduct a quantitative assessment of the radiological consequences of severe accidents at the Indian Point nuclear plant. This analysis is needed to calculate the value of the radiological consequences that would be averted if the SAMAs considered by Entergy were implemented. When combined with calculated core damage frequencies from the Indian Point Probabilistic Risk Assessment (PRA), the annual radiological risk to the public from severe accidents can be computed, and the value of the averted risk associated with each SAMA can be compared to the SAMA's cost to evaluate which options, if any, are cost-beneficial.

The calculation of radiological risk to the public is a highly uncertain exercise. The uncertainties are associated both with the values of the severe accident frequencies and the quantitative results of consequence calculations. This report will focus on the consequence assessment.

We find that in three significant respects, Entergy's consequence calculations are seriously flawed and do not lead to an assessment of risk to the public that is sufficiently conservative to serve as a reasonable basis for its SAMA analysis:

First, the source term used by Entergy to estimate the **consequences of the most severe accidents with early containment failure is based on radionuclide release fractions generated by the MAAP code** (a proprietary industry code that has not been validated by NRC), which are smaller for key radionuclides than the release fractions specified in

NRC guidance such as NUREG-1465 and its recent reevaluation for high-burnup fuel.[1] The source term used by Entergy results in lower consequences than would be obtained from NUREG-1465 release fractions and release durations.

Second, Entergy **fails to consider the uncertainties in its consequence calculation resulting from meteorological variations by using only mean values for population dose and offsite economic cost estimates.**

Third, **the population dose conversion factor of** $2000/person-rem used by Entergy to estimate the cost of the health effects generated by radiation exposure underestimates the cost of the health consequences of severe accidents by failing to address the value of lives lost as a result of acute radiation syndrome, in addition to cancer.

As a result of these deficiencies in Entergy's analysis, Entergy rejected most SAMAs on the basis that they were not cost-beneficial. In contrast, an analysis based on the more severe consequences that we have calculated would likely conclude that many of these SAMAs in fact would be cost-effective.

We have used the MACCS2 code to conduct an independent evaluation of severe accident consequences for Indian Point Unit 2 for the highest-impact severe accident scenario. Our results indicate that Entergy's baseline consequence analysis significantly underestimates (by more than a factor of three) mean population doses and other off-site costs resulting from such an accident. This is partly due to the particular source term used by Entergy, which was derived from calculations using the industry-developed MAAP code, as opposed to our study, which used a source term derived from NRC studies and regulatory guidance. In addition, we find that taking into account reasonable uncertainties associated with meteorological variations (in particular, by considering the 95th percentile consequences over the course of a year rather than the mean consequences) can increase the consequences by at least another factor of three relative to the mean consequences.

In summary, we calculate for the highest-impact severe accident scenario that the 95th percentile equivalent cost of off-site health impacts is more than ten times greater than Entergy's estimate of the equivalent cost of off-site health impacts. We also find that the 95th percentile off-site economic impacts for this scenario is over 70 times greater than Entergy's estimate of off-site economic impacts for the same scenario, and is over 12 times greater than Entergy's estimate of the <u>total</u> cost (off- and on-site) for <u>all</u> severe accident scenarios, the value it used to determine the cost-effectiveness of candidate SAMAs.

We have not carried out a similar analysis of Entergy's consequence assessment for IP3, but we would expect to find similar results in that case as well.

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[1] L. Soffer, et al. U.S. Nuclear Regulatory Commission, "Accident Source Terms for Light-Water Nuclear Power Plants: Final Report," NUREG-1465, February 1995; Energy Research, Inc., "Accident Source Terms for Light-Water Nuclear Power Plants: High-Burnup and MOX Fuels: Final Report," ERI/NRC 02-202, November 2002.

Major Flaws in the Entergy SAMA Analysis

1. The source terms used by Entergy to estimate the consequences of severe accidents Radionuclide release fractions generated by the MAAP code, which has not been validated by NRC, are consistently smaller for key radionuclides than the release fractions specified in NUREG-1465 and its recent revision for high-burnup fuel. The source term used by Entergy results in lower consequences than would be obtained from NUREG-1465 release fractions and release durations.

For example, the IP2 cesium release fraction for the early containment failure, high release ("early high") category used by Entergy is 0.229, compared to a total of 0.75 for NUREG-1465. It has been previously observed that MAAP generates lower release fractions than those derived and used by NRC in studies such as NUREG-1150. A Brookhaven National Laboratory study that independently analyzed the costs and benefits of one SAMA in the license renewal application for the Catawba and McGuire plants noted that the collective dose results reported by the applicant for early failures

> "…seemed less by a factor between 3 and 4 than those found for NUREG-1150 early failures for comparable scenarios. The difference in health risk was then traced to differences between [the applicant's definitions of the early failure release classes] and the release classes from NUREG-1150 for comparable scenarios … the NUREG-1150 release fractions for the important radionuclides are about a factor of 4 higher than the ones used in the Duke PRA. The Duke results were obtained using the Modular Accident Analysis Package (MAAP) code, while the NUREG-1150 results were obtained with the Source Term Code Package [NRC's state-of-the-art methodology for source term analysis at the time of NUREG-1150] and MELCOR. Apparently the differences in the release fractions … are primarily attributable to the use of the different codes in the two analyses."[2]

Thus the use of source terms generated by MAAP, a proprietary industry code that has not been independently validated by NRC, appears to lead to anomalously low consequences when compared to source terms generated by NRC staff. In fact, NRC has been aware of this discrepancy for at least two decades. In the draft "Reactor Risk Reference Document" (NUREG-1150, Vol. 1), NRC noted that for the Zion plant (a four-loop PWR quite similar to the Indian Point reactors), that "comparisons made between the Source Term Code Package results and MAAP results indicated that the MAAP estimates for environmental release fractions were significantly smaller. It is very difficult to determine the precise source of the differences observed, however, without

[2] J. Lehner et al., "Benefit Cost Analysis of Enhancing Combustible Gas Control Availability at Ice Condenser and Mark III Containment Plants," Final Letter Report, Brookhaven National Laboratory, Upton, NY, December 23, 2002, p. 17. ADAMS Accession Number ML031700011.

performing controlled comparisons for identical boundary conditions and input data."[3] We are unaware of NRC having performed such comparisons.

In light of this, it is clear that Entergy should not rely on MAAP-generated source terms in its SAMA analysis unless it can provide a technically credible justification for the differences between them and those developed by NRC.

In contrast, we have based our analysis on the more conservative NUREG-1465 source term, which has undergone extensive review by the public, and which is being voluntarily implemented by licensees in other regulatory applications.[4] The NUREG-1465 source term was also reviewed by an expert panel in 2002, which concluded that it was "generally applicable for high-burnup fuel."[5] This and other insights by the panel on the NUREG-1465 source term are being used by the NRC in "radiological consequence assessments for the ongoing analysis of nuclear power plant vulnerabilities."[6]

2. Entergy fails to consider the uncertainties in its consequence calculation resulting from meteorological variations by only using mean values for population dose and offsite economic cost estimates.

Entergy applies an inconsistent approach to its consideration of the uncertainties in its risk calculations. Entergy conducted an uncertainty analysis for its estimate of the internal events core damage frequency (CDF). As a measure of the uncertainty inherent in the internal events CDF as determined by the PRA, Entergy provides the ratio of the CDF at the 95th percentile confidence level to the mean CDF, which it calculates to be 2.1 for IP2 and 1.4 for IP3 (ER at 4-51). It then bases its SAMA cost-benefit evaluation on the 95th percentile CDF (ER at E.1-31), rather than the mean CDF. However, Entergy omits consideration of the uncertainties associated with other aspects of its risk calculation. In particular, it does not consider the impact of the uncertainties associated with meteorological variations, which we find to be even greater than the CDF uncertainties reported by Entergy.

The consequence calculation, as carried out by the MACCS2 code, generates a series of results based on random sampling of a year's worth of weather data. The code provides a statistical distribution of the results. We find, based on our own MACCS2 calculations, that the ratio of the 95th percentile to the mean of this distribution is typically a factor of 3 to 4 for outcomes such as early fatalities, latent cancer fatalities and off-site economic consequences. Because these ratios are greater than the ones considered in Entergy's CDF uncertainty analysis, it is illogical to ignore these uncertainties, as Entergy has done. For consistency, the "baseline benefit with uncertainty" that Entergy uses in the SAMA

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[3] U.S. NRC, "Reactor Risk Reference Document: Main Report, Draft for Comment," NUREG-1150, Volume 1, February 1987, p. 5-14.
[4] In adapting NUREG-1465 for this purpose, we have assumed that all radionuclides released to containment are released to the environment in early containment failure scenarios, as explained in this author's attached report, "Chernobyl-on-the-Hudson?"
[5] J. Schaperow, U.S. NRC, memorandum to F. Eltawila, "Radiological Source Terms for High-Burnup and MOX Fuels," December 13, 2002.
[6] J. Schaperow (2002), op cit.

cost-benefit evaluation should be based on the 95th percentile of the meteorological distribution in addition to the 95th percentile of the CDF distribution. This would also be consistent with the approach taken in the License Renewal GEIS, which refers repeatedly to the 95th percentile of the risk uncertainty distribution as an appropriate "upper confidence bound" in order not to "underestimate potential future environmental impacts."[7]

3. The population dose conversion factor of $2000/person-rem used by Entergy to estimate the cost of the health effects generated by radiation exposure is based on a deeply flawed analysis and seriously underestimates the cost of the health consequences of severe accidents.

Entergy underestimates the population-dose related costs of a severe accident by relying inappropriately on a $2000/person-rem conversion factor. Entergy's use of the conversion factor is inappropriate because it (a) does not take into account the significant loss of life associated with early fatalities from acute radiation exposure that could result from some of the severe accident scenarios included in Entergy's risk analysis; and (b) underestimates the generation of stochastic health effects by failing to take into account the fact that some members of the public exposed to radiation after a severe accident will receive doses above the threshold level for application of a dose- and dose-rate reduction effectiveness factor (DDREF).

The $2000/person-rem conversion factor is intended to represent the cost associated with the harm caused by radiation exposure with respect to the causation of "stochastic health effects," that is, fatal cancers, nonfatal cancers, and hereditary effects.[8] The value was derived by NRC staff by dividing the Staff's estimate for the value of a statistical life, $3 million (presumably in 1995 dollars, the year the analysis was published) by a risk coefficient for stochastic health effects from low-level radiation of $7x10^{-4}$/person-rem, as recommended in Publication No. 60 of the International Commission on Radiological Protection (ICRP). (This risk coefficient includes nonfatal stochastic health effects in addition to fatal cancers.) But the use of this conversion factor in Entergy's SAMA analysis is inappropriate in two key respects. As a result Entergy underestimates the health-related costs associated with severe accidents.

First, the $2000/person-rem conversion factor is specifically intended to represent only stochastic health effects (e.g. cancer), and not deterministic health effects "including early fatalities which could result from very high doses to particular individuals."[9] However, for some of the severe accident scenarios evaluated by Entergy at IP, we find that large numbers of early fatalities (hundreds to thousands) could occur, representing a significant fraction of the total number of projected fatalities, both early and latent. This

[7] U.S. NRC, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," NUREG-1437, Vol. 1, May 1996, Section 5.3.3.2.1.
[8] U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy," NUREG-1530, 1995, p. 12.
[9] U.S. NRC (1995), op cit., p. 1.

is consistent with the findings of the Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437).[10] Therefore, it is inappropriate to use a conversion factor that does not include deterministic effects. According to NRC's guidance, "the NRC believes that regulatory issues involving deterministic effects and/or early fatalities would be very rare, and can be addressed on a case-specific basis, as the need arises."[11] Based on our estimate of the potential number of early fatalities resulting from a severe accident at Indian Point, this is certainly a case where this need exists. Second, the $2000/person-rem factor, as derived by NRC, also underestimates the total cost of the latent cancer fatalities that would result from a given population dose because it assumes that all exposed persons receive dose commitments below the threshold at which the dose and dose-rate reduction factor (DDREF) (typically a factor of 2) should be applied. However, for certain severe accident scenarios at IP evaluated by Entergy, we calculate that considerable numbers of people would receive doses high enough so that the DDREF should not be applied.[12] This means, essentially, that for those individuals, a one-rem dose would be worth "more" because it would be more effective at cancer induction than for individuals receiving doses below the threshold. To illustrate, if a group of 1000 people receive doses of 30 rem each over a short period of time (population dose 30,000 person-rem), 30 latent cancer fatalities would be expected, associated with a cost of $90 million, using NRC's estimate of $3 million per statistical life and a cancer risk coefficient of 1×10^{-3}/person-rem. If a group of 100,000 people received doses of 0.3 rem each (also a population dose of 30,000 person-rem), a DDREF of 2 would be applied, and only 15 latent cancer fatalities would be expected, at a cost of $45 million. Thus a single cost conversion factor, based on a DDREF of 2, is not appropriate when some members of an exposed population receive doses for which a DDREF would not be applied.

A better way to evaluate the cost equivalent of the health consequences resulting from a severe accident is simply to sum the total number of early fatalities and latent cancer fatalities, as computed by the MACCS2 code, and multiply by the $3 million figure. Again, we do not believe it is reasonable to distinguish between the loss of a "statistical" life and the loss of a "deterministic" life when calculating the cost of health effects.

Results of IP2 Consequence Assessment

We have performed our own calculation of the consequences of a severe accident at IP2, using the MACCS2 code. The model is largely based on the one used in this author's 2004 study "Chernobyl-on-the-Hudson? (copy attached)," to which the reader is referred for all details. The model was revised, based on Entergy's ER, to incorporate (1) the core inventory specified in Table E.1-13, and (2) the expected population in 2034. To calculate the latter, we scaled the output of the SECPOP2000 code by a factor of 1.145.

[10] U.S. NRC, Generic Environmental Impact Statement for License Renewal of Nuclear Plants, NUREG-1437, Vol. 1, May 1996, Table 5.5.
[11] U.S. NRC, "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy (1995), op cit., p. 13.
[12] The default value of the DDREF threshold is 20 rem in the MACCS2 code input.

This normalized the total population within 50 miles to 19.2 million, to correspond to Entergy's projection of the total population within 50 miles of the IP site in 2034.[13] We use a finer site data input grid than Entergy does, with 21 intervals between 0 and 50 miles, compared to the five intervals used by Entergy. This allows for more accurate modeling of the dose and economic consequences.

The model we use is different compared to the one used by Entergy in a number of notable respects. First, we use a source term derived from NUREG-1465, as discussed previously, with regard to both the magnitude and timing of radionuclide releases. We use a two-plume model based on the approach of NUREG/CR-6295[14] that more realistically models the releases that would occur in an early containment failure scenario.[15] We also assume that the entire population of the 10-mile EPZ evacuates as determined by the evacuation time estimates provided by KLD Associates in 2004 (ER reference E.1-21), whereas Entergy assumes no evacuation at all. (It is not clear whether Entergy assumes sheltering or normal activity for the inhabitants of the EPZ.) We use the evacuation scenario because we have found that for the source term that we utilize, the all-sheltering scenario actually results in a smaller number of latent cancer fatalities than in an evacuation scenario, in part because more individuals succumb to acute radiation syndrome in the former scenario (and thus do not get cancer).[16]

In our model, we utilize the option in MACCS2 to calculate consequences for an entire year's worth of weather conditions, starting on each hour of the year. Each of these 8760 results is a weighted sum of results evaluated for each of the 16 compass directions, with the weighting determined by the Indian Point site wind rose. The accident is assumed to occur randomly at any time during the year. (Entergy does not make clear in the ER whether it calculated as large a number of outcomes or used the random sampling function of MACCS2, which selects only a few hundred hours during the year for evaluation.) We use the meteorological data file originally compiled for the Indian Point site for the CRAC2 study, which is publicly available.

Our results for off-site health consequences within a 50-mile radius of IP for the "early high" release category with full evacuation, compared to Entergy's, are presented in

[13] We have adjusted the SECPOP2000 input and output files to correct the errors disclosed in the August 2007 memo to SECPOP2000 users from Sandia National Laboratories and verified that the county data file is being read correctly. However, according to a personal communication from Nathan Bixler of Sandia National Laboratories, there is another potential problem with SECPOP2000 that was not mentioned in the August 2007 memo. When this problem is rectified, we will amend our calculations accordingly.

[14] R. Davis, A. Hanson, V. Mubayi and H. Nourbakhsh, *Reassessment of Selected Factors Affecting Siting of Nuclear Power Plants*, NUREG/CR-6295, US Nuclear Regulatory Commission, 1997, p. 3-30.

[15] Entergy's model assumes a single plume with a duration of over 22 hours, which is longer than for any other early containment failure source term we have encountered. We note that when we ran the MACCS2 code using Entergy's source term for the "early, high" scenario, the MACCS2 output file contained the following warning: "The total release duration exceeds 20 hours. This may cause erroneous results to be produced." Thus it is unclear to us that Entergy's results for this case are even valid.

[16] We find for our source term that the evacuation scenario actually results in a slightly greater number of combined early and latent fatalities. This appears to be an artifact of the particular population data file used rather than a reflection of a general principle.

Table I. The values for latent cancer fatalities as a result of "early" exposures (e.g. during the 1-week emergency phase) are reported separately from those resulting from "chronic" exposures (those resulting from the intermediate and long-term phases, as defined by MACCS2). The results for "chronic" exposures depend in on the parameters for long-term protective actions and have greater uncertainties than the results for "early exposures. We assume, for purposes of comparison, that Entergy's result for total population dose is the sum of both early and chronic exposures.

TABLE I
Health Impacts of "Early, High" Release

	This study	Environmental Report (Table E.1-14)
Mean early fatalities	860	Not reported
Mean latent cancer fatalities from early exposure	37,600	Not reported
Mean latent cancer fatalities from chronic exposure	950	Not reported
Mean latent cancer fatalities (total)	38,500	Not reported
Mean population dose (person-Sv)	4.97×10^5	1.58×10^5
95th percentile early fatalities	4,440	Not reported
95th percentile latent cancer fatalities from early exposure	129,000	Not reported
95th percentile latent cancer fatalities from chronic exposure	3,450	Not reported
95th percentile latent cancer fatalities (total)	130,000	Not reported
95th percentile population dose from early and chronic exposures (person-Sv)	1.64×10^6	Not reported

Our mean population dose result is over three times greater than that calculated by Entergy. To try to understand the reason for this difference, we reran the calculation with Entergy's MAAP-derived source term. For the no-evacuation (all-sheltering) scenario, we found a 45% reduction in population dose to 276,000 person-rem, which is still nearly twice Entergy's result of 158,000 person-rem. Without access to all the MACCS2 input files used by Entergy in its calculation, we cannot identify the other factors that may account for the remainder of the difference. But it is clear that the choice of source terms alone can have a significant (at least two-fold) impact on the population dose results.

We can also see from Table I that the 95th percentile population dose is over three times the mean population dose, and the 95th percentile number of early fatalities is over five times the mean value. This demonstrates that Entergy's focus on the mean consequences significantly underestimates the potential consequences of accidents occurring during less frequent but not uncommon meteorological conditions.
As discussed above, we maintain that the mean population dose is not an accurate representation of the total cost detriment associated with lives lost, because it does not include the costs of early fatalities, which as one can see from Table I, are substantial. In addition, as shown above, use of population dose as a surrogate for latent cancer fatalities is not appropriate because the total population dose does not account for the non-linear relationship between population dose and total number of latent cancer fatalities when the range of individual doses include both doses above and below the DDREF threshold. To remedy these problems, the total number of early fatalities and latent fatalities should be summed and the total multiplied by the monetary equivalent of lives lost, which is $3 million in NRC guidance.

From this data, we obtain an equivalent cost, at $3 million per life lost, of $118 billion for the mean case. For the 95th percentile case, the equivalent cost of the latent cancer fatalities alone would be $390 billion.[17] This should be compared to the result if only the equivalent cost of the population dose, using the $2000/person-rem conversion factor, were considered: $99.8 billion and $328 billion for the mean and 95th percentile, respectively.

However, in either case these results are far greater than Entergy's calculated equivalent cost of $31.6 billion. From the results presented in Table II, we see that our result for the cost detriment associated with loss of life from the "early, high" release is approximately 3.7 times greater than Entergy's result for the mean case, and over 12 times greater for the 95th percentile case. According to Entergy's calculations, this scenario is the largest single contributor (47%) to the overall population dose risk.

TABLE II
Equivalent Cost of Off-Site Health Impacts of "Early, High" Release

	This study	Environmental Report
Mean off-site health impacts equivalent cost (early and latent cancer fatalities)	$118 billion	$31.6 billion
95th percentile health impacts equivalent cost	$390 billion	Not reported

[17] The MACCS2 code does not have an option for calculating the sum of early and latent cancer fatalities, and therefore does not report the 95th percentile value of this sum.

(latent fatalities only)		

We have also obtained results for the off-site economic costs from the "early, high" release. We generally follow the methodology of Beyea, Lyman and von Hippel for our calculation of economic impacts.[18] The model utilizes the results of a 1996 Sandia National Laboratories report that estimates radiological decontamination costs for mixed-use urban areas.[19] We refer interested readers to these two references for information on the limitations and assumptions of the model.

Our results, as calculated by SECPOP2000 and the MACCS2 code, are also considerably higher than Entergy's results. In Table II, the MACCS2 results, which were obtained from 1996 and 1997 data, were converted to 2005 dollars by multiplying by an inflation factor of 1.2.

TABLE III
Off-Site Economic Impacts of "Early, High" Release

	This study	Environmental Report
Mean off-site economic impacts	\$816 billion	\$34.2 billion
95^{th} percentile off-site economic impacts	\$2.48 trillion	Not reported

By using the standard discount factor applied by Entergy (e.g. see page 4-53 of the ER), Entergy's frequency result, and neglecting the risk contributions of all other scenarios, we find a mean monetary equivalent present dollar value for the "early, high" release of \$825,514, and a 95^{th} percentile present dollar value (for latent cancers alone) of \$2.73 million.

Again using the same discount factor, we find a mean present dollar value of the off-site economic consequences of the "early, high" release of \$5.71 million, and a 95^{th} percentile present dollar value of \$17.3 million.

Adding the equivalent cost of off-site health impacts to the off-site economic cost, we find for the "early, high" release alone the mean total cost equivalent present dollar value is \$6.54 million. (We have not made our own estimates of on-site dose and on-site economic costs.) This is nearly seven times greater than Entergy's estimate of the sum of these two costs for all release categories.

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[18] J. Beyea, E. Lyman and F. von Hippel, "Damages from a Major Release of 137Cs into the Atmosphere of he United States," *Science and Global Security* 12 (2004) 1-12.

[19] D. Chanin and W. Murfin, *Site Restoration: Estimates of Attributable Costs From Plutonium Dispersal Accidents*, SND96-0057, Sandia National Laboratories, 1996.

For the 95th percentile, the present dollar value off-site economic cost for the "early, high" release alone is over 72 times Entergy's mean estimate for the same release and over 12 times Entergy's mean estimate for all costs (off- and on-site) and all release categories of $1.34 million.

These results are summarized in Table IV.

TABLE IV
Present Dollar Value Equivalent of "Early, High" Release Consequences

	This study	Environmental Report
Mean present dollar value of total off-site costs	$6.54 million	$460,334
95th percentile present dollar value equivalent of off-site fatalities (latent cancers only)	$2.73 million	Not reported
95th percentile present dollar value of off-site economic impacts	$17.3 million	Not reported

We have not carried out a review of Entergy's calculations for the other release categories that contribute to the Indian Point 2 severe accident risk. However, we would expect similar findings to those we have obtained in our review of the "early, high" release. In our judgment, many SAMA candidates would become cost-effective based on the difference in mean consequences alone, and many more rejected SAMA candidates would become cost-effective when the 95th percentile case is considered. If we were to extrapolate our result for the 95th percentile off-site costs of the "early,high" release to all release categories, leading to a nearly twenty-fold increase in total economic cost compared to Entergy's estimate, even the most costly SAMAs, such as the Phase II SAMA #015, "Strengthen Containment," could well become cost-effective.

We note that this conclusion would be further strengthened if we incorporated the increased frequency of the "early, high" release category estimated by Dr. Gordon Thompson in his November 2007 report *Risk-Related Impacts from Continued Operation of the Indian Point Nuclear Power Plant.*

Based on these findings, we believe that Entergy has grossly underestimated the off-site costs of severe accidents at Indian Point, and should revise its estimates using more credible and conservative source terms. It should also consider the 95th percentile consequence values of the distribution with respect to weather variations and use these values as the upper confidence bound in carrying out the SAMA cost-benefit evaluation for Indian Point. Entergy should use a methodology for calculating the cost equivalent of off-site health impacts that properly accounts for individuals who receive acute radiation doses above the threshold for early fatalities, and for those who receive chronic doses above the threshold for application of a DDREF.

Analysis

Our estimate of the mean off-site economic consequences of the "early, high" release is approximately 20 times Entergy's estimate. We have identified some of the reasons for the difference, but not all of them. The difference in source terms does not appear to be as great a factor as for the calculation of health impacts. The differences in the choices of economic and other parameters between Entergy's model and ours also plays a role. For instance, we use decontamination cost estimates obtained from a 1996 Sandia study that are significantly higher than those used by Entergy, which uses values based on the default parameters in the MACCS2 code. However, even after running the code with Entergy's source term and economic parameters, we still find economic consequences at least an order of magnitude greater than Entergy's. The results are also dependent on factors such as the dose criteria for triggering interdiction and condemnation actions. We use a more restrictive model than the default MACCS2 model in order to more closely approximate the EPA Protective Action Guides.[20] In any event, it is clear that reasonable differences in parameter choices can lead to order-of-magnitude differences in consequences in the MACCS2 long-term economic consequences model, and that Entergy has not done due diligence in exploring the sensitivity of their results to parameter variations.

[20] U.S. Environmental Protection Agency, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," Washington, DC, 1991.