# Generalized Dose Assessment Methodology for Informing Emergency Planning Zone Size Determinations

Task 1.1-1.3 Report for User Need NSIR-2017-002


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# 1 Introduction

In Task 1 of User Need NSIR-2017-002 dated 25 July 2017, the Office of Nuclear Security and Incident Response (NSIR) requested that the Office of Nuclear Regulatory Research (RES) undertake research to review the dose assessment methodologies that informed the plume exposure pathway and ingestion exposure pathway emergency planning zone size determinations in NUREG-0396, “Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants” ( Nuclear Regulatory Commission 1978). Specifically, the review should determine if the probabilistic dose versus distance methodologies can be generalized to inform planning zones of various sizes. The first three subtasks of Task 1 were as follows:

- Subtask 1.1 Describe a generalized dose assessment methodology based on NUREG-0396.
- Subtask 1.2 Describe the assumptions and bases for assumptions needed for a generalized dose assessment methodology.
- Subtask 1.3 Provide flow charts depicting a general dose assessment methodology and evaluation process for supporting planning zones of various sizes.

This report addresses these subtasks.

# 2 Methodology

RES staff reviewed the discussions in NUREG-0396 to ascertain how dose assessments were carried out and used to inform the recommendation of an approximately ten mile plume exposure emergency planning zone and the approximately fifty mile ingestion pathway emergency planning zone for the contemporary fleet of large light water reactors. The rationale for the quantitative analyses supporting the recommended planning bases is largely documented in Appendix I of NUREG-0396.

RES staff focused its review on the discussions in Appendix I and its supporting references. RES staff performed limited quantitative analyses to confirm that the interpretations of the analyses based on review of Appendix I of NUREG-0396 were consistent with the quantitative results provided therein. In addition, staff reviewed historical literature to determine how the different quantitative analyses documented in Appendix I may have informed the recommendation of a ten mile plume exposure planning zone and a 50 mile ingestion pathway planning zone. This historical literature included information such as a transcript of a meeting of the Commission at which the technical bases for NUREG-0396 were discussed, as well as information from the 1980’s related to a request from Seabrook to reduce the size of the planning zone based on probabilistic risk assessment (PRA) information. This information was reviewed for initial familiarization purposes only, so no further work has been done to ascertain whether there may be additional technical information in the historical record.

NUREG-0396 recommended considering information related to a spectrum of accidents, including both design basis accidents (DBA) and a range of beyond design basis (also referred to as “Class 9”) accidents that included both less severe “melt-through” type releases that did not result in large atmospheric releases, and more severe “atmospheric” releases. Based on the review of historical literature, it appears that information from both scaling and reanalysis of DBA analysis data and information derived from PRA information on BDBA likelihood and consequences were considered. The selection of the current planning zone sizes appears to have been based on professional judgment considering a variety of lines of evidence, rather than being based on a specific prescriptive dose assessment methodology. The dose assessment methodologies described in this report are therefore also intended to inform the selection of planning zone sizes, but are not intended as prescriptive guidance to analytically derive the geographic area over which emergency planning would be required.

## 2.1 Dosimetric Criteria

For DBAs and for less severe Class 9 accidents (BDBAs) that did not involve containment failure and release to the atmosphere, the report focused on the likely range to which EPA and FDA protective action guides (PAGs) could be exceeded for both the plume exposure and ingestion pathways. For these scenarios, the plume exposure PAGs used in the analysis comprised levels of 1-5 rem to the whole body and 5-25 rem to the thyroid. Whether these were acute doses or committed effective doses was not specified. The ingestion exposure PAGs used in NUREG-0396 were based on exposure to the thyroid from ingestion of milk, and included values of “*30 rem thyroid to an individual and 10 rem thyroid to a suitable sample of the population (usually calculated on the basis of an infant's thyroid)*” (p. I-41). The analysis also considered a potential revision to the milk ingestion PAGs which would suggest that “*measures such as placing dairy cows on stored feed will be recommended for projected exposure levels as low as about 1.5 rem to the infant thyroid*” (p. I-43).

For the more severe Class 9 accidents (BDBAs) that involved large releases to the atmosphere associated with severe core damage coupled with containment failure, consideration was given primarily to the prevention of early health effects via the plume exposure pathway. The dose levels used appear to be 50 and 200 rem to the whole body. Whether these were acute doses or a committed effective dose was not specified, but based on their use in evaluating the potential for early health effects, it seems reasonable to interpret these as acute doses. There were no identified dosimetric criteria for ingestion exposures associated with more severe Class 9 accidents (BDBAs).

It should be noted that the specification of a dose is incomplete unless it also includes information such as the precise dosimetric quantity or the exposure assumptions (e.g., the exposure pathways, exposure durations, or shielding assumptions used etc.) used to quantify the dose. The complete details for estimating doses for comparison to the levels discussed above were not consistently provided in the report, and it appears that somewhat different exposure assumptions (such as exposure pathways and exposure durations) may have been used for quantitative analyses based on DBA conditions and those based on BDBA (i.e., PRA-based) analyses.

## 2.2 Considerations Derived from Review of DBA analyses

To evaluate the range to which PAG levels might be exceeded for DBAs, the report considered information from general meteorological considerations, 10 CFR 100 siting analyses, and documented Safety Analysis Report (SAR) Chapter 2 accident analyses.

### 2.2.1 Plume Exposure Pathway

For the analyses that relied upon DBA calculations for siting analyses, it appears that the exposure pathways included only exposure to airborne material (inhalation and cloudshine), and that ground deposition and depletion of the plume by wet or dry deposition was not considered. For these analyses, it appears that the exposure period was limited to two hours based on the likelihood of a wind shift associated with stable, low wind speed conditions. This is consistent with the statement on p. I-16 that "*Table I-2 presents projected upper bound (no wind shift) values of 2 hour whole body and thyroid doses at various distances given a 25 rem and 300 rem dose level at an exclusion radius (r )*", the statement on p. I-28 that *"… for purposes of these calculations it was assumed that the dose of any individual would be limited to that of the first two hours after the accident*", and the text in the figures of I-6 through I-9.

The meteorological considerations discussed in the report included the effect of wind speed on both dispersion as well as on plume arrival time (which would provide more time for an individual to evacuate out of the path of the plume) and the likelihood of wind shifts (which would limit the exposure period of individuals in any given downwind direction). The report noted that the relatively conservative meteorology typically assumed in DBA analyses corresponded to moderately stable (Pasquill-Gifford

Class F), low wind speed (<1 m/s) conditions. The report noted that although such conditions would give rise to less dispersion, they would also result in relatively long travel times and a higher likelihood of plume meander or wind shifts.

DBA considerations from 10 CFR 100 siting analyses included an estimate of the distance to which the 1-5 rem whole body PAGs might be exceeded, given that releases from a facility could give rise to doses of up to 25 rem to the whole body and 300 rem to the thyroid at the exclusion area boundary (EAB) (assuming a two hour exposure) or at the edge of the low population zone (LPZ) (assuming a 30 day exposure). The authors of NUREG-0396 noted that centerline concentrations (and therefore doses) should drop by a factor approximately proportional to $(r/r_0)^{-a}$ where the value of the constant "a" could range from 1-2, with a value of approximately 1.5 for most meteorological conditions. Therefore, a centerline dose of 25 rem whole body or 300 rem thyroid at an assumed one mile EAB would drop to below 1-5 rem at a distance of 10 miles.

In addition to the extrapolating EAB and LPZ dose results from siting analyses, the doses from DBAs were also inferred from a review of DBA-Loss of Coolant Accident (LOCA) analyses from seventy existing safety analyses. The report examined the drop in dose from a two hour exposure under conservative DBA-LOCA conditions. Curves showing the results from analyses of centerline dose versus distance for a DBA-LOCA at two hours, assuming 5$^{th}$ percentile meteorology and a straight line plume trajectory, were provided in Figures I-6 and I-8. The report suggests that the 5$^{th}$ percentile meteorology "*can nominally be characterized by class F stability and very low wind speeds (e.g., 2 miles/hour or less)*" (p. I-27). However, it is unclear exactly how the dose assessment was carried out to generate these curves. The curves in Figures I-6 and I-8 appear to be reasonably consistent with the dispersion of a non-depositing plume traveling downwind at low wind speeds.

Based upon the lines of evidence based on review of DBA analyses, the report therefore concluded that doses above plume exposure PAG levels of 1-5 rem to the whole body were unlikely beyond ten miles given a DBA.

### 2.2.2 Ingestion Exposure Pathway

There is very little documentation of the quantitative analyses based on DBA analyses used to inform the size of the ingestion pathway EPZ. Noting that the "*The ratio of thyroid dose commitment factor (related to air concentration) for the milk pathway to the inhalation (plume exposure) pathway is of the order of 300 for I-131*", the considerations for ingestion pathway planning zone from siting calculations suggested that "*potential dose commitments via the milk pathway could exceed the ingestion PAG for tens of miles from the reactor site*". No specific distance related to the ingestion pathway was provided related to review of 10 CFR 100 siting analyses.

In relation to the review of documented Safety Analysis Report (SAR) Chapter 2 accident analyses, it appears that original analyses were developed

> "…showing a distance relationship of potential dose to an infant's thyroid from milk consumption. As was done for the plume exposure, conservative calculational techniques were used to attempt to bound the results of the ingestion exposure. For example, the straight line trajectory was used with no credit taken for wind shifts. All of the assumptions of the Reactor Safety Study for the calculation of thyroid dose from milk ingestion were used for this analysis. The results of figure 1-10 show that for the DBA-LOCA, ingestion doses above PAG's are unlikely to occur beyond about 50 miles from power plants." (p. I-34).

The methodology appears to be based on estimating a critical deposition level for I-131 corresponding to a specified ingestion dose (using the deposition to dose methodology from U.S. Nuclear Regulatory Commission 1975), then estimating the maximum range at which that critical deposition level could occur. The exposure assumptions (e.g., consumption rates, biokinetic assumptions, etc) that would be needed to translate a ground deposition level to the ingestion dose used for comparison to the ingestion PAGs were not explicitly provided in the report, although it appears that the WASH-1400 ingestion model (which is documented in some detail) was used.

The key assumptions from WASH-1400 appear to include (at a minimum) the deposition velocity used to estimate dry deposition to ground, and the methodology to estimate doses from a given ground deposition level. It is unclear if wet deposition processes were included in the generation of this curve. The deposition velocity used in U.S. Nuclear Regulatory Commission 1975 is described in Appendix VI, p. 6-2): "*The consequence model uses a deposition velocity of $10^{-2}$ m/sec, with a possible range of $10^{-3}$ to $10^{-1}$ m/sec, for both particles and gases (except the noble gases, for which $v_d$ = 0).*" The assumptions of the Reactor Safety Study (RSS) for the calculation of thyroid dose from milk ingestion are documented in Appendix E.3 of Appendix VI. For example, the concentration factors (total intake by a critical individual as a result of direct deposition, Ci per Ci/$m^2$, denoted CF) are provided in Table VI-E-5, and Appendix E.3 clarifies that "*The CF factors in the list above are derived for the respective critical segment of the general population, for example, iodine ingestion via milk is based on data for a young child.*" The dose conversion factors for ingestion of radionuclides (rem per curie ingested) are provided in Table VI-8-4. However, the ingestion correction factor for age, although discussed in Appendix D6.2 and D6.3, is unclear, stating "*Correction ratios $D_{CH}/D_{AD}$ computed in this way are listed* *in Table VI D-6 for iodine-131, cesium-137, strontium-89, and strontium-90 for ages 1, 5, and 10 years. … If they are used to calculate doses from exposure via ingestion, they need to be multiplied by the ratio of activities of these radionuclides in the total diet of the child and the adult.*" (p. D-18)

It should be noted that the assumptions used to bound the maximum range of ingestion exposure above PAG levels (which require the inclusion of deposition to ground and therefore plume depletion) may be different from the assumptions needed to bound the results of a dose assessment that does include deposition to ground. For example, stable low wind speed conditions generally give rise to the highest atmospheric concentrations at a given distance when plume depletion is not considered. However, use of a very high deposition velocity coupled with very low wind speed could result in significant depletion of airborne material within a relatively short distance of the reactor, thereby reducing the maximum range at which a given ground deposition could occur. In such cases, higher wind speeds may actually be more conservative than lower wind speeds. This may explain why the inferred wind speed from Figure I-10 (5 hour arrival time to 50 miles, or 10 mph) is much faster than the inferred wind speed from Figures I-6 and I-8 (20 hours arrival time to 40 miles, or 2 mph). In such cases, the selection of conservative meteorological conditions may not be straightforward. In addition, precipitation can effectively remove airborne radioactivity by wet deposition, which can lead to "hotspot" areas of elevated deposition at longer ranges than could occur by dry deposition alone. However, there is no indication as to whether wet deposition was considered in the development of Figure I-10. On the other hand, ingestion exposures would generally be a longer term problem, and there will generally be longer times available to identify and interdict contaminated food and water relative to plume exposure. These considerations may be important in dose assessments supporting the identification of an ingestion planning zone but would be challenging to capture quantitatively.

## 2.3 Considerations Derived from Review of PRA-based Severe Accident Analyses.

Severe accident analyses considered in NUREG-0396 included information from WASH-1400 (U.S. Nuclear Regulatory Commission 1975) as well as information from a study of offsite radiological emergency protective measures for core melt accidents (D. C. Aldrich 1978; Aldrich, McGrath and Rasmussen 1979). These analyses considered both the frequency and consequences from a range of beyond design basis accidents.

For the plume exposure considerations derived from WASH-1400, a variety of dose levels were evaluated. As stated on p. I-37 of NUREG-0396, "*Doses are given for the critical values for which* *emergency planners should be concerned. One and five rem whole body doses correspond to the lower range of the PAGs; 50 rem whole body corresponds to the dosage at which early illnesses start to occur; and 200 rem whole body is the dose at which significant early injuries start to occur*." For severe BDBAs, consideration appears to be given primarily to the prevention of early health effects. The dose levels used appear to be 50 and 200 rem whole body. For ingestion pathway considerations derived from severe accident analyses, only PAG levels were evaluated (i.e., there was no counterpart to the larger doses associated with early health effects considered for the plume exposure pathway), and RES staff assumes that the modeling assumptions of WASH-1400 were used to model ingestion doses.

### 2.3.1 Plume Exposure Pathway

For the plume exposure pathway considerations derived from WASH-1400, it appears that original analyses were carried out based on information from WASH-1400. It is stated that

> "A set of such curves has been prepared for all of the RSS accident release categories (figure I-11). These curves include both Pressurized and Boiling Water Reactor (PWR & BWR) accidents. Doses are given for the critical values for which emergency planners should be concerned. One and five rem whole body doses correspond to the lower range of the PAGs; 50 rem whole body corresponds to the dosage at which early illnesses start to occur; and 200 rem whole body is the dose at which significant early injuries start to occur. As can be seen from figure I-11, core melt accidents can be severe, but the probability of large doses drops off substantially at about 10 miles from the reactor." (p. I-37)

Although the computational approach to the generation of these curves is not provided, RES staff assumed that the analyses were similar to those from D. C. Aldrich 1978, for which more methodological information was provided. As stated on p. I-45,

> "Figures I-15 and I-16 give the additional perspective of the study on the probabilities and needs for emergency planning in terms of the core "melt-through" and "atmospheric" categories and a range of expected emergency actions. Figure I–15 shows the probabilities of exceeding thyroid and whole body PAGs versus distance from the reactor, conditional on the occurrence of a "melt-through" release. The probabilities are calculated for an individual located outdoors, and are presented for both lower and upper PAG levels for each organ. A similar curve is shown in figure I-16 for the "atmospheric" releases."

There is considerably more discussion of the calculational approaches and assumptions provided in D. C. Aldrich 1978. It appears reasonable to assume that the computation of doses for all three sets of curves were consistent with the calculations of the RSS, and therefore included exposure to both airborne material (inhalation and cloudshine) and deposited material (groundshine). The exposure period appears to be 24 hours for groundshine[1], and a dose commitment of 1 year for inhaled material. This is consistent with the captions to Figure I-11 ("*Whole body dose calculated includes: external dose to the whole body due to the passing cloud, exposure to radionuclides on ground, and the dose to the whole body from inhaled radionuclides*", as well as the caption to Figures I-15 and I-16 ("*Whole body (thyroid) dose calculated includes: external dose to the whole body (thyroid) due to the passing cloud and 1-day exposure to radionuclides on ground, and the dose to the whole body (thyroid) from inhaled radionuclides within 1 year*"). The shielding factors appear to be consistent with an individual located outdoors with no shielding apart from natural ground roughness, based on footnote a of Figures I-15 and I-16 ("*Shielding factor for airborne radionuclides = 1.0. Shielding factor for radionuclides deposited on ground = 0.7. 1 day exposure to radionuclides on ground"*). Inhalation rates were not provided, but presumably are consistent with those used for WASH-1400.

RES staff performed limited analyses using the MACCS code and assumptions drawn from WASH-1400 to understand the methodological aspects of producing curves such as those provided in NUREG-0396 Figures I-11, I-15, and I-16. Staff concluded that reproduction of these curves was feasible, although details such as the selection and weighting of source terms and the selection of meteorological data remain subject to uncertainty. Staff also identified other documented analyses that attempted to emulate NUREG-0396 Figure I-11. These include Brookhaven National Laboratory 1986 and Leaver and Metcalf 1999. Based on review of these documents, coupled with staff preliminary analyses, it appears that the development of curves such as those shown in Figures I-11, I-15, and I-16 is feasible provided that sufficient information from a PRA on source terms and relative frequencies is available. An important aspect of developing such curves is the appropriate selection and combination of results from individual source terms. It appears that a set of dose-exceedance curves was generated for each source term, frequency-weighted (either with absolute frequencies or relative frequencies), and then summed to yield the resulting curve.

### 2.3.2 Ingestion Exposure Pathway

Information on the likelihood of the distance to which particular ingestion doses could be exceeded given a range of beyond design basis accidents was provided in Figure I-14. There is no obvious

[1] It may be relevant to note that a period of 24 hours for assessing exposure to groundshine may have been a common assumption for the time needed for expeditious relocation from high dose areas in the early phase of an accident. As stated on p. 9-3 of App VI of WASH-1400, "Beyond a distance of 25 miles from the reactor, the ground dose is truncated at 7 days if the people are relocated and at 24 hours if people are immediately relocated from small areas due to locally high dose rates." A similar assumption was used in a roughly contemporary analysis of fatality risks from severe reactor accidents from Paddleford 1974.

"knee" in this curve analogous to the dropoff in doses above 200 rem to the whole body in Figure I-11 (considering all source terms) or the dropoff in doses exceeding PAG levels in Figure I-15 (considering only "melt-through" releases, i.e., no large release to the atmosphere). As stated on p. I-41, "*The distance for which emergency planning is needed is not easily determined from the information given in the figure. It is evident that doses can potentially be quite high out to considerable distances*". For ingestion pathway considerations based on severe accident analyses, the analysis therefore equated the likelihood of exceeding ingestion pathway PAGs beyond the ingestion pathway planning zone should be comparable to the likelihood of exceeding plume exposure PAGs beyond the plume exposure planning zone, and on that basis, concluded that an ingestion planning zone on the order of 50 miles would correspond to a plume exposure planning zone of ten miles.

# 3 Identification of a Generalized Methodology based on NUREG-0396

The following generalized methodology has been developed to be consistent with the approaches used in the NUREG-0396 quantitative analyses, to the extent that the details of those analyses can be discerned. Additional discussion on aspects of the methodology specific to the plume and ingestion pathways are in sections 3.1 and 3.2. The generalized methodology roughly follows the technical elements described in the ASME/ANS standard for radiological accident offsite consequence analysis ( American Society of Mechanical Engineers / American Nuclear Society 2017). Key assumptions of the generalized methodology include the following:

- Adequate information from a PRA on radiological source terms, and either their absolute or relative frequencies.
- The atmospheric release pathway is the risk-dominant contributor to offsite doses (i.e., no consideration of direct exposures or releases to liquid pathways).
- The atmospheric release consists of neutral density non-reactive aerosols or gases (with radioactive decay and in-growth corrections as appropriate).
- Use of a straight-line Gaussian plume segment-type atmospheric dispersion model (with modifications as needed to account for near-field dispersion phenomena) to estimate atmospheric concentrations.
- A specified exposure duration.
- No credit for protective actions during the specified exposure period.

There are two general approaches to the development of an EPZ methodology in NUREG-0396 as follows:

1) An approach based on evaluating the results of DBA source terms to estimate the range at which plume exposure and ingestion PAGs may be exceeded (which may be termed the "DBA-based approach", and
2) An approach based on the use of PRA information to estimate the range at which plume exposure and ingestion PAGs could be exceeded for less severe BDBAs (those not involving containment failure and release to the atmosphere), coupled with an estimate of the range at which early health effects could be expected in the event of more severe accidents (those involving core damage coupled with containment failure or bypass).

If sufficient information is available from a PRA that is judged to be of acceptable scope, level of detail, and degree of realism for its intended purpose or application, the second approach is considered more comprehensive; however, in keeping with the approach of multiple lines of evidence used in NUREG-0396, corroboration of a PRA based approach with information derived from a DBA-based analysis may be beneficial.

Figure 1: Generalized Dose Assessment Methodology based on NUREG-0396

**1. PROBLEM FORMULATION**

- Identify exposure pathways of interest for EPZ dose calculations.
- Identify dosimetric criteria and their associated dosimetric measures to be used to inform EPZ size determination. For example, these may include acute organ doses (for evaluation of early health effects) or committed effective doses (for evaluation against PAG levels).

**2. SOURCE TERM**

- Identify release scenarios, considering a range of accident conditions from DBA to beyond DBA. For BDBA scenarios, evaluate their associated frequencies.
- For each release scenario, develop a quantitative radiological source term by specifying release characteristics (time dependent release rates, release duration, release locations, physical/chemical form, plume buoyancy, etc.).

**3. METEOROLOGICAL DATA DEVELOPMENT**

- Evaluate sources of meteorological data (wind speed, atmospheric stability, precipitation, etc) for temporal and geographical representativeness and select a source of meteorological data.
- Develop meteorological data to evaluate a range of meteorological conditions; alternately, select conservative transport and dispersion conditions.

**4. ATMOSPHERIC TRANSPORT MODEL**

- Select appropriate dispersion parameterizations for vertical and crosswind diffusion coefficients.
- Select conceptual approaches for treatment of near-field effects such as elevated releases, building wake effects, plume meander, buoyant plume rise, etc.
- Select conceptual approach for treatment of wet and dry deposition.

**5. EXPOSURE MODEL**

- No credit for pre-planned protective actions such as evacuation or sheltering.
- Specify exposure parameters (e.g., shielding factors, breathing rates, exposure durations, etc). For ingestion pathways, specify food chain parameters and food/water ingestion rates.
- Select a source of recognized pathway dose conversion factors for the dose assessment.

**6. DOSE ESTIMATION**

- Estimate pathway-specific doses for dosimetric measures identified in Step 1 and the release scenario specific source terms specified in Step 2 at a range of distances using:
  - atmospheric and ground deposition concentrations from the atmospheric transport model developed in Steps 3 and 4 and
  - exposure assumptions and dose conversion factors from step 5.

**7. PROBABALISTIC DOSE AGGREGATION**

- For severe accidents (BDBA), aggregate dose results using frequency information developed in step 1.
- Identify dosimetric criteria related to each release scenario. For DBA and less severe BDBA scenarios that do not involve containment failure to atmosphere, evaluate against recommended PAGs. For more severe BDBA scenarios, evaluate against dosimetric criteria related to prevention of early health effects.

## 3.1Generalized Methodology for Plume Exposure Pathway

The following generalized methodology for the plume exposure pathway has been developed to be consistent with the approaches used in the NUREG-0396 and should include:

- Evaluation against plume exposure PAG levels for DBA or more likely BDBA source terms, or against the potential for severe early health effects for unlikely BDBA source terms giving rise to large atmospheric releases.
- Selection of a conservative DBA source term without consideration of frequency, or selection of a range of BDBA source terms with consideration of their relative frequencies.
- Selection of either conservative meteorological conditions (for DBA source terms) or selection of a range of meteorological conditions (for BDBA source terms).
- Selection of an atmospheric dispersion model that is appropriate to the range of distances being examined. Credit for enhanced dispersion due to processes such as plume meander or building wake effects, or the potential for buoyant plume rise resulting in elevated releases, may be considered with justification.
- For DBA source terms, exposure pathways include exposure to passing cloud (inhalation and cloudshine). For BDBA source terms, exposure pathways also include consideration of deposition to ground and resulting groundshine doses.
- No credit for protective actions or dose reduction from structures is assumed, although reduction of groundshine doses from ground roughness is included.
- Exposure periods for exposure to airborne materials (inhalation and cloudshine) include the time of cloud passage. If groundshine doses are included (e.g., when considering BDBA source terms), an exposure duration of at least 24 hours (or up to 4 days if the PAG dose methodology is used) is assumed. However, realistic consideration of the likelihood of wind shifts, which would (at any given downwind location) limit exposure to airborne materials and limit the period of deposition to ground, may be reasonable.

## 3.2 Generalized Methodology for Ingestion Pathway

The development of a generalized methodology for the ingestion pathway planning zone may be challenging. In general, the ground deposition at which agricultural PAGs could be exceeded could occur at longer ranges than those at which PAGs based on plume exposure (i.e., the EPA early phase PAG levels) could be exceeded. For example, wet deposition during plume travel could result in localized areas exceeding agricultural PAGs without exceeding PAGs based on the direct exposure pathways of inhalation, cloudshine, and groundshine. However, the timing of protective actions needed to limit doses from food and water ingestion would be on a longer time scale than those needed to protect against direct exposure to a passing plume. As noted in NUREG-0396, "*The ingestion pathway exposures in general would represent a longer term problem, although some early protective actions to minimize subsequent contamination of milk or other supplies should be initiated (e.g., put cows on stored feed)*. (NUREG-0396 pp 13-14)". Ingestion doses could be limited at any distance provided that mechanisms for the timely identification of contaminated food and water are in place.

To the extent that an ingestion pathway planning zone based on a NUREG-0396 dose-based methodology is needed, the following assumptions would be consistent with the analyses in NUREG-0396:

- Evaluation against ingestion PAGs for a limiting population, such as doses to infants from I-131 in milk from cattle grazing on open pastures.
- Selection of a conservative (i.e., large) DBA source term without consideration of frequency, or selection of BDBA source terms with consideration of their relative frequencies.
- Selection of either conservative meteorological conditions (for DBA source terms) or selection of a range of meteorological conditions (for BDBA source terms). The selection of conservative meteorological conditions may differ from the conservative meteorological conditions selected for the plume exposure planning zone.
- Selection of an atmospheric dispersion model that is appropriate to the range of distances being examined. Credit for enhanced dispersion due to processes such as plume meander or building wake effects, or the potential for buoyant plume rise resulting in elevated releases, may be considered with justification.
- Exposure and dose assessment based on the characteristics of a limiting population, such as ingestion of milk by infants.
- No credit for protective actions or dose reduction from agricultural interdiction is assumed.
- For BDBA source terms, the size of the ingestion pathway planning zone should be such that the likelihood of exceeding ingestion pathway PAGs beyond the ingestion pathway planning zone should be comparable to the likelihood of exceeding early phase PAGs beyond the plume exposure planning zone, given that consistent modeling approaches (scenario selection and weighting, source term development, atmospheric transport, dispersion, and deposition, etc) were used for the respective pathways.

# 4 Conclusion

Based on a review of NUREG-0396 and related documents, it appears that the broad outlines and major assumptions of a dose assessment methodology to inform the extent of an emergency planning zone can be developed. However, detailed information on specific assumptions used to quantitatively develop dose information was not always clear from this review.

There are two elements of a potential generalized methodology that were not assessed as part of this review because they do not appear to have been explicitly addressed in NUREG-0396. The first is that a quantitative approach for the treatment of epistemic (including model and parameter) uncertainty was not clearly identified in the review of the dose assessments in NUREG-0396. Therefore, no recommendations are provided for the treatment of epistemic uncertainty in this document. The second is that considerations for evaluating the quality of the source term and frequency information are not addressed in this document. NUREG-0396 used the best information available at the time, which consisted of information from existing documents such as licensee safety analysis reports and from WASH-1400. The quality of any quantitative dose assessment will depend upon the quality of the source term information used to estimate the doses. This would be true both for DBA dose calculations as well as for BDBA dose calculations. For BDBA dose calculations requiring consideration of multiple source terms, the quality of the relative or absolute frequency estimates would be an additional factor. We recommend that additional work be conducted to provide additional details on the treatment of epistemic uncertainty and the development of information on source term and their frequencies.

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