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Framework and Plan for Assessment of Offsite Protective Action Strategies for Radiological Emergencies

Introduction and Background

This document describes a process by which the effectiveness of offsite protective action strategies for radiological emergencies at commercial nuclear power plants can be assessed. Industry has developed this process in anticipation of a possible collaborative effort with NRC or at least an effort in which NRC and industry exchange information as the work unfolds. NRC is currently charged with considering the relative effectiveness of sheltering vs. evacuation (October, 2003 Staff Requirements Memorandum), and the industry believes such an assessment requires a thorough, technically sound, and internally consistent framework. The creation of such a framework is a logical first step in the assessment process.

The framework needs to include:

- A means to identify an appropriate range of activity release scenarios (combinations of release magnitude and timing, notification times, information known about the plant condition at the time of notification, and weather) to consider in the assessment,

- An approach to characterize, quantify, and validate a range of plausible offsite emergency response scenarios for each release scenario including warning time, evacuation time estimates (ETEs), and degrees of response among various groups of individuals (or "cohorts") living within or transiting the plume-exposure EPZ at the time of the release,

- A methodology for determining radiation exposure to the cohorts as a function of their post-accident movement and/or sheltering (which may or may not conform to the pre-planned post-accident movement and/or sheltering),

- A means of confirming that a particular strategy is practical and can be implemented by offsite agencies, and a metric for quantifying the success of a particular strategy and ranking the strategies, and

- A plan for NRC and licensee interaction to implement lessons learned from the assessment upon its completion.

The first three of these elements are simply technical, the fourth has both technical and policy attributes, and the fifth is strictly a matter of policy.

The four technical elements amount to a reevaluation of the technical basis for offsite emergency planning (EP). It would be logical to build into the framework a means of making this reevaluation risk-informed; but in any case, the objective would be to create a more sound and technically up-to-date basis for EP (the current basis is based on technology that is 30 years old). This basis would encompass activity release scenarios arising from internal events, external events, and terrorist events.

There are a several reasons for the industry undertaking this effort at this time, perhaps the most significant of which is the fact that the licensees are significant stakeholders in the effectiveness of offsite emergency response and the associated the protective action process. Additional points that support such an effort at this time include:

- It is time to update the existing planning basis (primarily embodied in NUREG-0396 and NUREG-0654) which was developed before and immediately after the TMI-2 accident based on accident descriptions from a 1975 study (WASH-1400). In the three decades since that time, the U.S. commercial nuclear power industry has acquired a greatly expanded operational experience base as well as significant knowledge on severe accident prevention and mitigation which has evolved since the TMI-2 accident.

- In the post-September 11, 2001 environment, there is renewed interest in nuclear power plant emergency response and the basis for EP requirements.

- Such an effort is a logical extension of an effort already underway to look at a related issue (fast breaker), and industry has performed its own fast breaker study and submitted it to FEMA and NRC.

- NRC is initiating its own undertaking to reevaluate the EP basis (see October, 2003 Staff Requirements Memorandum) including:
    - Update of protective action recommendation (PAR) guidance
    - Improvement of EP guidance
    - Review and update of approaches to ETEs
    - Improvement of how EP programs are communicated
    - Reviewing the adequacy of existing EP basis to contend with terrorist-initiated events
    - Top to bottom review of regulation and guidance relating to EP.

- Risk-informed approaches are being encouraged.

The industry effort to reevaluate the EP technical basis is intended to be a generic assessment. This assessment will be performed with updated information on severe accidents and improved accident consequence and protective action models. It is intended to use simplified methods in this generic assessment in order to hold down costs and expedite the schedule. A key output from the generic assessment will be a demonstration of the potential impact of smart protective actions strategies on public consequences (e.g., protective action strategies that are effective in reducing

consequences for more severe accidents and/or weather conditions at high population density sites). Such strategies might include evacuation in a direction away from the plume, evacuation by walking from near-site areas (e.g., one or two miles), staged evacuation, more specific guidance on sheltering vs. evacuation, making roads one-way in near-site areas, and use of historical weather data (e.g., wind direction, wind direction duration, rain vs. no rain, etc. as a function of the season and day vs. night) to provide insights on pre-planned protective action strategies in a probabilistic way.

This information on the protective action strategies can then be provided to interested licensees and state and local agencies to be used as a starting point for updating and improving guidance on protective action recommendations and decisions for specific plants and sites.

Work Breakdown Structure

I. Develop Risk-Informed (R-I) Basis for EP Reevaluation Industry and NRC are now encouraging a R-I approach to regulation. The basis for such an approach is embodied in regulatory guidance and a substantive database of risk information developed over the last 15 to 20 years including:

- The Commission's Safety Goal Policy issued in the 1980s which provides guidelines on probabilities for large releases.
- Two decades of research and improved understanding of prevention and mitigation of severe accidents in risk context.
- A generation of probabilistic risk assessments (PRAs) performed on the operating plants which provide a substantial base of risk information.
- NRC guidance which was issued on use of risk-informed applications in license amendments.
- Successful implementation of a R-I approach in the Reactor Oversight Process

Accordingly, the reevaluation of the technical basis for EP will utilize a R-I approach. To develop this R-I approach, the following will be done:

1. Define a risk metric which measures the effectiveness of offsite emergency response. This risk metric will be similar in concept to the core damage frequency (CDF) and large early release frequency (LERF) metrics in R.G. 1.174 (i.e., an x vs. y plot where the baseline risk metric is along the x-axis, and the change in that metric is along the y-axis). The offsite emergency response risk metric will, however, go beyond the CDF and LERF metrics since we are addressing EP which is by definition defense-in-depth for core damage prevention and mitigation and since some of the changes we will be assessing (e.g., sheltering vs. evacuation, evacuation distance) only impact offsite consequences.

2. Relate the offsite emergency response risk metric to the safety goal to define an acceptable level of defense-in-depth from emergency response. This will determine a R-I level of emergency response.

   As part of the process of defining an acceptable level of defense-in-depth from emergency response, the uncertainty in the risk metric should be addressed and allowance made for this uncertainty.

3. Develop a methodology for evaluating the margin in the 10 mile EPZ which exists given updated release frequencies and source terms. This methodology will be similar to that used in NUREG-0396 with a R-I approach applied to consideration of release frequencies.

It is recognized that this R-I component of the reevaluation framework is an input to determining the scope and level of detail of the other parts of the EP technical basis. It is also recognized that there are certain aspects of the EP technical basis for which enough is known to begin work immediately. Thus, it is intended that the development of an R-I basis for this work will be completed in parallel with the start of other EP reevaluation tasks, and that, once completed, results from the R-I basis development would be utilized to refine these tasks as they proceed.

II. Establish Updated Activity Release Categories As explained in the introduction, the activity release scenarios are combinations of activity release categories (release magnitude and timing and notification times), information known about the plant condition at the time of the notification (and therefore, contained in the notification), and the weather. The release categories may or may not be associated uniquely with accident sequences or accident sequence types. There is an advantage in transparency if such uniqueness can be established and supported, but uncertainty considerations with respect to containment performance and/or source term variability sometimes calls for the mapping of a given accident sequence into a number of different release categories. It is also true, however, that a large fraction of potential release categories would be either too small or too delayed to challenge the protective action strategies and associated emergency response scenarios being considered. Such release categories would not be included in this work. So the objective of the framework in this area would be (1) to include enough releases categories to adequately test protective action strategies but (2) to minimize the number of release categories and to uniquely associate them with specific accident sequences or accident sequence types wherever possible.

Terrorist-initiated accident sequences would be included in the updated set of release categories to be used for EP reevaluation. It is not expected that new release categories would be needed to address terrorist-initiated sequences, but the possibility needs to be considered. Use will be made of industry PRA work and other studies on various threats, as well as anticipated EPRI work on the nuclear power sector for Guidance on Risk Analysis and Management for Critical Asset Pretection (RAMCAP) which is under development by the ASME Homeland Security Institute LLC for the U.S. Department of Homeland Security (DHS).

It is anticipated that the work to establish updated activity release categories will be

performed on two plant types: a PWR, large dry containment, and a BWR Mark I. Using these two plant types should be representative of most U.S. plants. Additional plant types can be considered at a later time if necessary. The framework for definition of updated release categories will consist of the following:

1. A description of each accident sequence type including initiating event, major system failures, and containment response. The accident sequence types can then be combined with applicable containment failure modes and grouped into release categories which are the basis for activity release magnitude and timing. For example, the PWR accident sequence types (by initiating event) could include fast station blackout (SBO), slow SBO, LOCA, transients, SGTR, and interfacing LOCA (V sequence). The PWR containment failure modes could include bypass (SGTR and V sequence), early failure, and late failure. The BWR accident sequence types (by initiating event) could include fast station blackout (SBO), slow SBO, LOCA, transients, and ATWS. The BWR containment failure modes could include drywell shell meltthrough, wetwell vent, and drywell rupture.
2. The frequency of each release category
3. The release parameters for each release category
4. The terrorist-initiated accident sequences to be considered
5. Appropriate information for external events, low power/shutdown, and spent fuel pool accidents
6. Re-examination of the release magnitude, timing, and other release parameters for release categories where there may be excess conservatism (e.g., in an IPE or other source of information). Calculations may be necessary to reduce this conservatism.

The sources of information to be considered for defining updated release categories include

- NUREG-1150 plant information,
- Updated Individual Plant Examination (IPE) study information (updated for license renewal),
- Recent industry and NRC research studies to refine probabilities associated with accident sequences and containment failure mode combinations (sometimes referred to as accident progression bins or APBs) and to make more realistic assessments of the frequency of occurrence of and releases from APBs of interest,
- MAAP 4 calculations where necessary to define details of release
- The recently completed industry study on fast-breaking sequences

III. Identify Representative Weather Sequences The other part of the activity release scenario is the weather. The wind speed, wind direction, atmospheric stability, and precipitation (if any) determine the rate of spread of the released activity and its ground

deposition. It also bears on the characterization of the emergency response (e.g., road conditions).

MACCS2 is the accepted U.S. software for evaluating offsite consequences and protective action effects. Many parts of MACCS2 are up-to-date and adequate (e.g., weather sequence binning process, dose conversion factors, health effects data); and therefore, the generic weather sequence data will be developed in a manner consistent with the MACCS2 structure. Site-to-site variability will be characterized by changing the conditional probability of the different weather bins and their representative weather sequences.

IV. Develop Improved Consequence Models This task is to develop models that support evaluation of the effect on offsite consequences of realistic protective action strategies.

There are three areas where significant limitations exist in MACCS2, namely, the plume dispersion model, the protective action model, and modeling of uncertainties.
The proposed technical approach is not to develop a revised version of MACCS2 but rather to develop updated and improved models to address limitations in MACCS2. This update will consist of a stand-alone dose rate map model in which MACCS2-generated dose rates for the relevant pathways (immersion, inhalation, and exposure to ground contamination) would be calculated as functions of time, location within the EPZ, and activity release scenario. MAACS2 modifications, if any, will be undertaken only to facilitate the preparation of dose rate arrays (as functions of time and location) to complete the dose rate map for each activity release scenario considered.

The intent is that these be simple models that allow the impact of a given protective action strategy to be estimated without utilizing an excessively fine grid structure or addressing all of the details of a given site (e.g., specific road networks or other detailed site features). However, sufficient detail will need to be included (both in terms of grid structure and site characteristics) to permit representative and meaningful evaluation of the various protective action strategies put forward for consideration.

The notification time for the general emergency (and the information contained in the notification, part of the activity release scenario) plus any delay in the ordering of protective actions on the part of the offsite authorities will be used as the starting point for the ETE. In the NUREG-1150 XSOR source term codes, the “warning time” was generally assigned to the time of core uncovery or core collapse, and the difference between this time and start of release (“warning interval”) was used in binning the source terms for consequence analysis. Given the importance of timing (i.e., the start of the emergency response relative to the start of release), the framework should provide for clarification of the time that the notification is given to offsite authorities (“notification time”) and the time the warning is given to the population and the offsite agencies implementing the emergency response (“warning time”). All other delays are then included in the ETE.

Additional effort may also be needed in calculating the effectiveness of sheltering. The framework should provide for a review of sheltering models and improvements, if necessary. For example, high wind speeds tend to increase dispersion which is generally beneficial, but high wind speeds may also reduce sheltering effectiveness.

Finally, the framework should provide for consideration of how weather at the time of notification can affect the selection of a protective action strategy; not only from what is being observed at the time of the notification, but also possibly by what will *probably* occur in the near term during implementation of the strategy based on the season of the year and the time of day (i.e., known weather patterns).

Given the above, the following steps are envisioned for the consequence analysis, and the framework should provide for their implementation:

1. Select site characteristics. An emphasis in this work should be to develop protective action strategies that are effective for high population density sites. Low population density sites can also be addressed if resources are available. Site parameters will include population density, approximate road networks, housing types, and other site characteristics that may facilitate or inhibit emergency response (rivers, streams, etc.).
2. Define representative weather sequences for different weather types. MACCS2, for example, groups weather sequences into 32 bins. A group of weather sequences will have common parameters such as atmospheric stability, wind speed, wind direction, and rain or no rain. Persistence of wind direction for a given starting wind direction may also be important. A probability will be associated with each weather group for use in quantifying the relative likelihood of each associated release scenario. Each group will then be represented by one or more weather sequences that can then be the basis for determining the protective action parameters for that group where the protective action strategy and evacuation parameters (e.g., evacuation speed, evacuation direction) depend on the weather.
3. Configure MACCS2 to provide dose results for single weather sequences so that the dependency of protective action parameters on weather, time of day, wind direction, etc. can be addressed. The dose results will be in the form of dose rate maps, i.e., dose rate vs. location in the EPZ, time after accident initiation, and pathway.
4. Develop an improved sheltering and evacuation model. The sheltering and evacuation model would address the following:
    a. Consideration of potential time difference between declaration of general emergency (GE) and beginning of release, mobilization time and evacuation speed as a function of time after declaration of GE, the location from which the evacuee originates his/her trip (distance away from site), the season, the weather conditions, the time of day, the day of the week, the population increment, and the radiological conditions.
    b. Incorporation of features that allow consideration of a protective action strategy in which it is assumed that the public can be informed of expected

plume movement and responds accordingly (e.g., a portion of the informed public moves away from the plume trajectory).

c. More explicit consideration of evacuation direction (i.e., approximate route of evacuation based on the specified road network).
d. Consideration of more realistic sheltering models.
e. Consideration of multiple evacuation and sheltering phases for a single protective action scenario. For example, people should be allowed to take shelter, evacuate, and take shelter again (MACCS2 presently only allows users to specify one phase of sheltering and then one phase of evacuation in series).

5. An ETE model will be applied to determine the evacuation parameters as a function of time for a given site (e.g., mobilization time, evacuation speed, evacuation direction) for various initial conditions (weather, time of day, day of week, season, population increment or "cohort", location from which cohorts initiates their evacuation or undertake sheltering).
6. It is expected that the activity release categories will already contain an uncertainty treatment in the assigning of frequencies. Similarly, weather types can be assigned different frequencies to account for site-to-site variability or even uncertainty for a given site. The combinations of activity release and weather, therefore, would already reflect uncertainties. For the consequence analysis, the framework would have to provide for additional uncertainties, particularly with respect to release/notification/warning times and the ETEs. Definition of cohorts would also be uncertain. Monte Carlo analysis may be necessary to define the specific sets of values to be used in the consequence analysis with respect to these protective action parameters, and the framework should consider that possible need.
7. The above approach in steps 1 through 6 assumes that the existing MACCS2 plume model will be used (treating weather conditions as uniform over the entire region of interest in which a given Gaussian plume always moves in one fixed direction, that direction being the wind direction during that hour of the weather sequence in which the source term release begins, although though multiple plumes can be considered). This is being done because it simplifies the work and it is judged that protective action strategies, which mainly impact people near the site, can be developed and assessed reasonably well using such an approach. Although not on the critical path of 1 to 6 above, it would be useful to have an improved plume model to address the effects on plume dispersion of changing wind direction and speed, atmospheric stability, terrain, and river channeling. Such a model could then be used to confirm that accident consequences, including the protective actions, are not significantly altered when analyzed using a more sophisticated treatment of the plume. It could also be used in future work if a revised version of MACCS were to be developed.

V. Assess Protective Action Strategies The framework must provide for the assessment of protective action strategies using the activity release scenarios defined in II and III and the consequence model of IV. The steps in the assessment are envisioned as follows:

1. Develop descriptions of protective actions (i.e., mobilization times, evacuation directions, evacuation speeds, sheltering vs. evacuation) for the site model under consideration. There will be a series of protective actions which depend upon the weather type and specific wind speed and direction, information contained in the plant notification, time of day, etc. A given protective action should be defined to reduce early health effects and to reduce overall dose, and yet be simple enough to be evaluated efficiently by the models described above and to be clearly communicated to and understood by the offsite agencies implementing the action. In developing the descriptions of these protective actions, consideration should be given to improvements in information technology that may now facilitate transmission of real time information to large numbers of people in an emergency. It is, therefore, appropriate to consider smarter protective strategies which take advantage of this information technology. Examples of the types of smarter protective action strategies and related information to be considered include:

   - Evacuation in direction away from plume
   - Evacuation from near site areas (e.g., 1 or 2 miles) by walking
   - Staged evacuation
   - More specific guidance on sheltering vs. evacuation
   - Making roads one-way in near site areas
   - Use of historical weather data (e.g., wind direction, wind direction persistence, wind speed, rain vs. no rain, etc. as a function of the season and day vs. night) to provide insights on pre-planned protective action strategies
   - Capability and role of real time plume monitoring
   - Use of plume marking (e.g., dye injection)
   - Real time optimization of protective actions

   Also as part of developing the descriptions, discussions should be held with nuclear plant emergency response personnel responsible for making protective action recommendations (PARs), and with county and state officials responsible for making protective action decisions (PADs) (see 3. below). It seems advantageous to involve state and county EP representatives early in this effort.

2. Assess the effect of the protective actions against the risk metric from I. Adjust the protective actions as necessary to satisfy the risk metric.

3. Review the protective actions with nuclear plant emergency response personnel responsible for making PARs and with county and state officials responsible for making PADs. The purpose of these reviews is to confirm that the protective actions are practical and able to be implemented by the plant and offsite agencies. Make adjustments as necessary.

4. Characterize the protective actions as a set of strategies that can be the basis for determining protective actions for real sites.

VI. Evaluate NUREG-0396 EPZ Margin This task is to perform a NUREG-0396, Figure I-11 type evaluation using the updated activity release scenarios to confirm that margin exists in the 10 mile EPZ.

Deliverables and Schedule

The main deliverable from this effort will be a final report documenting the reassessment of protective action strategies and establishing a revised technical basis for emergency planning. This final report, or related intermediate white papers, will include the following:

- A R-I approach to defining what is an acceptable level of defense-in-depth for emergency response.
- An updated set of activity release categories, which includes consideration of terrorist-initiated accidents, for use in EP.
- A straightforward but complete approach that provides a basis for determining effective protective actions.
- A set of evaluated protective action strategies that can be used as a starting point for updating and improving guidance on protective action recommendations and decisions.
- A demonstration of the margin inherent in the 10 mile EPZ.

This work is anticipated to require approximately two years to complete. It is noted that the simple consequence models which are discussed above could eventually be integrated into software that could be made available to licensees. This software could become an updated, improved version of MACCS2 or some new code. The decision as to whether this is necessary or would benefit public health and safety can wait until after the reassessment of protective action strategies is complete.