A Discussion on Unmitigated Accident Scenario Modeling and Assumptions

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1. Introduction

1.1 Background and Overview

The concept of the "unmitigated event" has been developed to (1) conservatively estimate the consequence potential from postulated scenarios, (2) aid with the identification of evaluation basis accidents (EBAs), and (3) aid with defining the safety function of needed safety controls. The underlying basis of this concept is the lack of preventative or mitigative actions performed by any safety controls (i.e., administrative and engineered). Hence, the analysis of "unmitigated event(s)" allows the safety analyst insights into the effects of candidate safety controls.

DOE-STD-3009-94 required the evaluation of unmitigated events to be included as a key component of the evaluation of potential accident scenarios. In an effort to comply with this guidance, DOE contractors have implemented, the concept of the "unmitigated event" with much creativity and inconsistency. DOE has responded to this situation with the issuance of additional guidance that provides additional clarification on this subject. DOE-STD-3009-94 Appendix A (herein referred to as Appendix A) provides this guidance.

This paper, which is based on the authors' experiences, discusses how DOE contractors have implemented the "unmitigated event" concept while performing hazard (i.e., qualitative) and accident (quantitative) analysis. The analysis of the "unmitigated event" is performed by initially identifying the unmitigated frequency of the event followed by the determination of its unmitigated consequences. Through examples of proper and improper implementation of the 'unmitigated event" concept, adherence to the guidance of Appendix A, as well as recommendations for better adaptation of Appendix A's guidance will be discussed.

1.2 Summary of DOE-STD-3009-94 Appendix A's Approach

The purpose of Appendix A, is to provide guidance for (1) determining the effectiveness of a safety control's preventative or mitigative action during postulated event scenarios and (2) performing the calculations necessary for evaluating consequences from releases from these events.

Appendix A specifies that for operational accidents there should not be an explicit need for a frequency component to the unmitigated release calculation, since the determination of need is solely driven by the bounding consequence potential. That is, there should not be a screening of accident scenarios based on the frequency of occurrence of the scenario. For natural phenomena events, the unmitigated frequency of occurrence is defined in terms of the frequency of the initiating event, or the return period for the postulated natural phenomena event. While for external (man-made) events, the unmitigated frequency is bound within the cutoff frequency of 10^{-6}/yr (conservatively calculated) or 10^{-7}/yr (realistically calculated). Furthermore, Appendix A states that the unmitigated consequence should consider material quantity, form, location, dispersability, and interaction with available energy source, but should not consider safety features which would mitigate the release, and thus the consequences.

Additionally, Appendix A specifies that the calculation of unmitigated releases should represent a theoretical bounding limit to scenario consequences. Key assumptions[1] that should be applied while performing these calculations are:

1. All active safety features have failed;

2. Passive safety features, which are needed in order to define a realistic scenario, that are assessed to survive the postulated accident scenario may perform their safety function[2] (e.g., external confinement barriers that can survive evaluation basis natural phenomena events);

3. Passive safety features that contribute to any leakpath reduction in source terms (e.g., building filtration) have failed; and

4. Passive features that are not affected by the postulated accident scenario have performed their intended safety function.

By applying these precepts to evaluating the 'unmitigated event," the guidance contained within Appendix A ensures that the release potential for a given operation is conservatively estimated.

2. Unmitigated Hazard Analysis

This section presents a discussion of the unmitigated frequency and consequences as it relates to the hazard analysis, how they are implemented or interpreted throughout the DOE complex, and a discussion of their merit.

2.1 Frequency of Occurrence Estimates

Following is examples of typical assumptions or interpretations to the frequency estimates for unmitigated accident scenarios.

a. Misinterpretation of Accident Scenarios Based on Frequency

A frequent implementation strategy for identifying the unmitigated frequency in the hazard analysis is to screen out accident scenarios based on the postulated accident scenario's low frequency of occurrence. Specifically, operational accident scenarios are screened out based on the assumption that the scenario frequency falls below a 10^{-6}/yr (incredible).

In light of Appendix A's guidance that operational accidents should be evaluated independent of their frequency of occurrence (see Section 1.2), this is inconsistent with the Standard. When this misguided approach is implemented, the analyst may fail to capture the importance of those controls that made the scenario low frequency (less than credible) in the first place.

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[1]These assumptions may have potential impact on the designation of safety systems, structures, or components (SSSCs) or Technical Safety Requirements (TSRs).

[2] In some instances, these passive features may warrant a safety class (SC) or safety significant (SS) designation to ensure that the assumptions, with respect to survivability, of the safety features are preserved.

b. Misinterpretation of Coverage of Natural and External Events

Analysts at some sites still try to evaluate credible natural phenomena events in both the hazard and accident analysis. That is, natural phenomena with return periods of up to 10^6 years (frequency of occurrence of $>10^{-6}$/yr). As indicated by the Appendix, natural phenomena events should only be evaluated to the frequency of occurrence or return periods that correspond to the performance categorization (PC) assigned to the facility at a given site. The determination of the appropriate PC for a given facility should be performed in accordance with the guidance contained within DOE-STD-1021-93.

External events are often missed in the hazard analysis altogether or with the natural phenomena screened from further evaluation with no-adequate analytical bases to support this decision. It is important to realize that this type of events correspond to man-made events such as those created by airplane crashes, transportation accidents immediately outside the facility that may have impact on the facility, brush/forest fires, etc. As stated within the Appendix, these events include those that have a frequency of occurrence of 10^{-6}/yr or higher if calculated conservatively, or 10^{-7}/yr if realistically calculated.

With respect to the hazard analysis, some of these events may not have sound analytical bases to screen out these events. As such, the analyst should at least consider such scenarios for further analysis to develop the analytical bases for eliminating them from further analysis with respect to source term and consequence analysis. For example, the DOE-STD-3014 methodology for airplane crashes should be applied after the hazard analysis to determine whether or not such scenarios should be analyzed further in the accident analysis.

c. Misinterpretation of the Unmitigated Accident Scenario's Frequency of Occurrence

It is often seen during the performance of the hazard analysis, that even though the unmitigated consequences are correctly provided qualitatively, the associated frequency for a scenario is provided as a mitigated scenario. That is, the frequency of occurrence of the postulated accident scenario is reduced by the performance of the intended safety function of the controls identified in the hazard analysis. The following simplified hazard analysis table illustrates this misinterpretation.

Table 1. Example of Mitigated Frequency for an Unmitigated Consequence

Accident Scenario	Initiating Event or Cause	Enabling Event	Freq.	Unmitigated Consequences		Risk		Control Type*	Controls
				W	P	W	P		
1. Fire in glovebox with release of radioactive material to the room and environment	1.1 Overheated glovebox furnace	Radioactive material present when the fire occurs	IV	A	B	4	3	PPE	1. Furnace Temperature Controller
								PPE	2. Glovebox inert system
								MPE	3. Furnace integrity
								MPA	4. Combustible control in the GB
								MFF	5. Glovebox integrity
								MFF	6. Sprinkler system
								MFF	7. GB ventilation HEPA filters
								MFF	8. GB ventilation negative pressure
								MFF	9. GB heat detectors
								MFA	10. Local manual fire detection and suppression
								-	11. Etc….

* Preventor (P) or Mitigator (M), Facility-wide (F) or Process-specific (P), and Engineering Feature (E) or Administrative Control (A).

For this postulated accident scenario, the frequency provided (i.e., IV, 10^{-4} to 10^{-6}/yr) assumed that all the controls identified in the table are present and have performed their intended safety function. In this example, the 10^{-4} to 10^{-6}/yr frequency is a mitigated frequency, rather than the needed unmitigated frequency estimate.

d. Recommended Frequency Estimates for Unmitigated Scenarios in the Hazard Analysis

Operational accidents should be evaluated independent of frequency of occurrence. In many cases, the fact that a scenario may have a low frequency of occurrence is because the analyst has taken into account the successful performance of the intended safety function of the safety control under the assumed accident conditions.

In order to properly implement the guidance of Appendix A, the frequency of occurrence should be based solely on the product of the frequency of the initiating event and the enabling event, without taking into account the existing controls identified in the table. Reconsidering the above example in light of these guidelines, a higher frequency should be assigned based on the occurrence of the initiating event and the conditional probability of having radioactive material in the glovebox at the time of the fire. By doing a truly unmitigated frequency evaluation of such scenario, the importance of each or set of controls could be evaluated with respect to the contribution in reducing the frequency of occurrence of the postulated scenario. This is illustrated by Table 2 below.

Table 2. Example of Mitigated Hazard Analysis Table

Scenario and Cause	Unmitigated Scenario					Control Description	Control Type	Mitigated Scenario					Control Category*
	Cons.		Freq.	Risk				Cons.		Freq.	Risk		
	P	W		P	W			P	W		P	W	
1 (1.1) Fire in glovebox with release of radioactive material to the room and environment, due to overheated glovebox furnace	B	A	II	3	4	1. Furnace Temperature Controller	PPE	B	A	II	3	4	DD**
						2. Glovebox inert system	PPE	B	A	III	3	3	SS
						3. Furnace integrity	MPE	B	B	II	3	3	SS
						4. Combustible control in the GB	PPA	B	A	III	3	3	DD
						5. Glovebox integrity	MFF	B	B	II	3	2	SS
						6. Room Sprinkler system	MFF	C	B	II	3	3	SS
						7. GB ventilation HEPA filters	MFF	D	A	II	2	3	SS
						8. GB ventilation negative pressure	MFF	B	A	II	3	4	DD
						9. GB heat detectors	MFF	B	A	II	3	4	DD
						10. Local manual fire detection and suppression	MFA	B	A	II	3	4	DD
	Control set						-	D	D	IV	1	1	-

* SS for safety significant designation, DD a defense-in-depth control
** If no special design requirements or reliability is required

2.2 Consequence Estimates in Hazard Analyses

The following types of consequence estimates are routinely encountered in hazard analyses performed throughout the DOE complex:

a. Mitigated Consequences

Even though, the body of DOE-STD-3009-94 requires the evaluation of unmitigated consequences, some hazard analyses still evaluate mitigated consequences taking into account the intended safety function of controls in place, which leads to smaller consequence estimates. This approach contradicts to intent of the Standard. As stated in Appendix A, the unmitigated consequence may consider material quantity, form, location, dispersability, and interaction with available energy source, but should not to consider safety features which would mitigate the release, and thus the consequences unless they meet the criteria of previously discussed in Section 1.2.

b. Misinterpretation of the Unmitigated Accident Scenario's Consequences

This type of analysis assumes a true "parking lot" scenario, in which even the material forms, locations, dispersibilities, and passive controls that are likely to survive the postulated initiated event are assumed to be subject to unrealistic or physically impossible phenomena. This of course leads to overly conservative inflated consequences that tend to raise a negative risk perception for such scenarios and corresponding facilities or activities.

c. Recommended Consequence Estimates for Unmitigated Scenarios in the Hazard Analysis

By default, the unmitigated consequences for the hazard analysis should represent a more conservative set of assumptions than those used in the accident analysis, the reason for this is to ensure that potentially high consequence scenarios are identified and evaluated further as part of the accident analysis or appropriate safety designation are given to controls to prevent or mitigate such scenarios. The consequences for such unmitigated scenarios should take into account the intended safety function of passive engineered safety controls that clearly are not impacted by the initiating event or the postulated scenario, and for the inherent physical forms of the material-at-risk (MAR).

An example of this concept may be illustrated by considering a failed valve that leads to a postulated release of an extremely hazardous chemical from a tank within a facility. It is legitimate to only consider the maximum pipe diameter connected to the valve as the means to determine the maximum leak rate from the tank, and it is not necessary to assume that the tank contents are released instantaneously. The analyst could take into account a berm, if one is present, to contain the released liquid thus lowering the evaporation rate by limiting the surface area available for evaporation. The reason for this assumption is that the spill from a valve should not affect the availability of the berm, however, as stated in the Appendix, such passive controls may still warrant a SSSC designation based on the results of the unmitigated consequences. It is fair to consider the chemical and physical properties of the chemical in question in limiting the evaporation rate, but environmental conditions (i.e., ambient temperature) should be assumed to be conservative worst-case (e.g., relative humidity, wind speed, etc.) for the site.

3. Unmitigated Accident Analysis

As part of the EBA calculations, the body of DOE-STD-3009-94 specifies that for each scenario in the Safety Analysis Report (SAR), sufficient documentation of the analysis for both the unmitigated and mitigated accident scenarios be provided so that the process of determining the SCSSCs is well understood. In all cases, the preventative or mitigative action provided by the identified SCSSCs should be evident. However, this does not require explicit reporting of unmitigated consequences in the SAR, if it is evident that the unmitigated release consequences are large, i.e., well above the Evaluation Guideline (EG) of 25 rem. Comparison of the unmitigated consequences for a limited subset of potential accidents to the EG is performed to determine the need for any SCSSCs. If the unmitigated consequences of a release scenario approach the EG values, then and only then a need for SCSSC designation is indicated.

The following assumptions and modeling approaches are often utilized in the evaluation of unmitigated consequences while performing accident analyses:

3.1 Frequencies Determinations in Accident Analysis

The approaches outlined in section 2.1 are often seen in the evaluation of the frequencies of accident scenarios in the accident analysis. Quantitative evaluation of the frequency of occurrence of accident scenarios is not required, even though under certain cases (high unmitigated consequences) they will support risk-cost/benefit evaluations that help put the risk of such scenarios in a more realistic prospective (e.g., comparison to the SEN-35 risk criteria). Frequency evaluations in accident analyses often range from qualitative estimates (based on engineering judgment) to elaborate probabilistic risk assessment (PRA) level one analyses, in which fault/event trees are developed and quantified for postulated accident scenarios. The use of such analysis should be on a case-by-case basis. That is, for postulated EBAs in which the unmitigated consequences are significant and the SSCs considered have been given a safety designation and are active, the use of PRA level 1 techniques or models may be warranted. This will support the identification of vulnerabilities and potential improvement to identified SSCs, and define mission or downtimes that could serve as basis for completion times in the development of Limiting Conditions for Operations (LCOs) contained within TSRs.

2.3 Consequence Estimates in Accident Analyses

Some of the interpretations or assumptions discussed in the hazard analysis section are often extended to the accident analysis of the SAR. Additional insights are provided below.

a. Consequences from Credible Scenarios

Accident analyses are often limited to the evaluation of credible accident scenarios (i.e., $>10^{-6}$/yr) and ignore the consequences from other scenarios that could occur if additional controls are assumed to fail. For example, the consideration of the consequences from only filtered releases may involve the assumption that HEPA filters are passive and are not impacted by the accident scenario in question. This of course contradicts the intent of the guidance contained within the body of DOE-STD-3009-94 and Appendix A. As stated previously, operational accidents should be evaluated independent of their frequency of occurrence, and no credit is to be allowed for passive safety features that could reduce the leakpath factor used to evaluate source terms (e.g., HEPA filters, penetrations).

b. Credit for Passive Features Affected by the EBA

It is not uncommon to see accident analyses in which the successful performance of a SSSC's intended safety function is given a priori to controls (e.g., passive engineering features, such as building structures), thus eliminating such scenarios from further analysis. The hazard analysis should identify these scenarios; it is the role of the accident analyst to evaluate the adequacy of such controls, or the capability of such controls to survive the postulated scenarios. (e.g., airplane crash, seismic event), if such controls are credited in the analysis for mitigating the potential releases or consequences.

It is also part of the accident analysis to evaluate the energy sources generated as part of the postulated accident scenario in order to support the evaluation of the survivability of potential safety SSCs. That is, the accident analysis needs to evaluate the mechanical, thermal, or other stresses that may result from the postulated scenario before it is assumed that the control will be able to survive the environmental stresses created by the scenario. For example, in the case in which a container is dropped, the design specification of the container and the magnitude of the impact need to be assessed before it is assumed that the drop does not challenge the container integrity. If however, there is no design specification or willingness to demonstrate the capability of the container, it may be prudent to assume that the contents were dropped in an uncontained manner.

c. Overly or Under-Conservative Consequences

Prior to issuing of the Appendix A to DOE-STD-3009, the dispersion and consequence evaluations performed in support of the accident analysis varied all over the place. Some facilities/sites reported average consequence values based on site meteorological data, others will report centerline values as a function of distance but independent of direction, others provided consequences based on fixed meteorological data, etc. These types of evaluations have led to dose-to-source ratios (rem/gram-release) for the same radionuclide that vary by as much as one order of magnitude. Thus making decisions on the designation of safety class vary difficult and inconsistent.

d. Recommended Approach for Estimating the Unmitigated Consequences in the Accident Analysis

As stated previously, the unmitigated release and consequences should characterize both the energies driving the potential release, and the release fractions in accordance with the physical realities of the accident phenomena postulated. As such, there are assumptions that are necessary in order to better define a meaningful (i.e., realistic but conservative) scenario; but which also affect the magnitude of the resultant consequences.

The mitigative actions of a passive SSSC should only be assumed to be effective when the design features are clearly not impacted by the scenario in question. (It is important to note that SSSCs associated with leakpath reduction such as the HEPA filters and penetrations are not to be considered). The unmitigated consequences need to at least evaluate the consequences of an unfiltered release or those with loss of confinement or containment in some cases, independent of frequency of occurrence for operational scenarios. For natural and external events the previous recommendations are applicable to the accident analysis as well. It is important to also evaluate as part of the accident analysis, the consequences associated with the successful response of potential SCSSCs, since it aids in defining the bases for such safety designation by providing information on the consequence reduction and ultimately the risk reduction afforded by such controls.

The unmitigated release or consequence calculations are critical in the evaluation of EBAs. Since the results of such calculations are required to be compared to the EG in order to identify potential SCSSCs and to determine the potential environmental conditions that such scenarios create. Hence the evaluation of the "unmitigated event" aids in determining the operability requirements for potential SCSSCs.

With respect to dispersion, the Appendix A to the DOE Standard, explicitly calls for the evaluation of the 95^{th} percentile of the consequences as a function of distance and direction to the site boundary (or the highest exposure location, for elavated releases). Some of the existing computer codes such as MACCS2, GENII, RSAC will have to be evaluated to ensure that they comply with the Appendix A Guidance, prior to continue their use (if compliance with the Standard is to be claimed).

4. Conclusions

The modeling and assumptions used in the evaluations of unmitigated accident scenarios in AB documentation has been implemented in some cases at various sites or facilities in a manner that is often inconsistent with DOE Guidance in DOE-STD-3009, specially in light of the new Appendix A to such Standard. It is the hope of this paper to illustrate some of these fallacies in the evaluation of unmitigated frequencies and consequences as they refer to hazard and accident analysis, and serve as a means to ensure consistency in the implementation of the Guidance through out the DOE complex in regard with the implementation of the "unmitigated event" concept in hazard and accident analysis.