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Removing Unreasonable Conservatisms
DOE Safety Analyses

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Removing Unreasonable Conservatisms in DOE Safety Analyses

by
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Abstract:
While nuclear safety analyses must always be conservative, invoking excessive conservatisms does not provide additional margins of safety. Rather, beyond a fairly narrow point, conservatisms skew a facility's true safety envelope by exaggerating risks and creating unreasonable bounds on what is required for safety. The conservatism has itself become unreasonable. A thorough review of the assumptions and methodologies contained in a facility's safety analysis can provide substantial reward, reducing both construction and operational costs without compromising actual safety.

Accident analyses involving a nuclear facility's radiological and chemical hazards, criticality safety, or risk management should all be examined for excessive conservatisms. Conservatisms are embedded in each step of an accident analysis. Each step should be examined and unreasonable conservatisms removed and replaced with more accurate information. Once underway, the examination naturally leads back to the facility's hazards analysis. All conservatisms are examined. The legitimacy of conservatisms can be determined by:

- comparison to similar industry analyses
- engineering assessment, or
- overall reasonableness.
Removing Unreasonable Conservatisms from Safety Analyses

Unreasonable conservatisms should be removed prior to approval of a facility's preliminary safety analysis report, and certainly by approval of the final safety analysis report.

Unreasonable conservatisms require expensive preventive or mitigative features that provide little or no real improvement in facility safety. Indeed, they are often counterproductive to real safety, diverting attention from other equipment whose actual importance to safety is greater.

Examples of such unreasonable, counterproductive conservatisms are presented.

Taking ownership of safety analyses must mean taking charge of unreasonable conservatisms lying in that analyses and removing them.

Background:
The foundation of a facility's safety basis is its hazards analysis. The hazards analysis leads to groups (families) of accidents which are further analyzed in the accident analysis. Six basic steps comprise accident analysis:

- source term development
- scenario development
- frequency (probability) development
- unmitigated accident consequences and release calculation
- preventive and mitigative features development
- mitigated/prevented accident consequences and release calculation, and technical safety requirements development.
Engineered safety features, ESF's, prevent or mitigate accidents. One or two accidents--the design basis accidents (DBA's)--usually dominate a particular family of accidents. The DBA's establish the functional requirements which the engineered safety features must meet. Unmitigated release consequences perform several functions. They establish the facility hazard category and, if DOE Order 6430.1A is applied to the facility, the safety classification of the ESF's themselves. Finally, the unmitigated accidents and their release consequences determine the nature and sophistication of the ESF's. Accident releases are a key outcome of accident analysis.

An accident's release depends directly on its calculation's assumptions and conservatisms. Generally, for non-reactor nuclear facilities, inhalation dose dominates accident releases by orders of magnitude.\(^1\) As such, the focus of any effort to remove unreasonable conservatisms from safety analyses must be to reduce the amount of respirable material released by accidents into the environment.

The classic four-factor equation to calculate the accident release (dose) to an individual at a specific location is:

\[
D = M \times \left(\frac{X}{Q}\right) \times BR \times DCF,
\]

where

- \(D\) = accident cumulative effective dose equivalent, in REM
- \(M\) = respirable airborne material released, in grams

\(^1\) Page A-6 of DOE Standard 1027-92 quotes NRC NUREG 1140 as stating: "for all materials of greatest interest for fuel cycle and other radioactive material licensees, the dose from the inhalation pathway...will dominate the dose." The NRC then dismissed other contributors (eg, direct dose) from the dose calculations supporting the license limits shown in 10 CFR 30, Schedule C.
\[ \frac{X}{Q} = \text{atmospheric dispersion factor, in sec/cubic-meter}^2 \]

\[ \text{BR} = \text{breathing rate, cubic-meter/sec} \]

\[ \text{DCF} = \text{dose conversion factor (dose/gram of inhaled material)} \]

\[ \text{REM/gram.} \]

Of the four factors in the above equation, three are essentially constants. The atmospheric dispersion factor, \( \chi/Q \), depends on specific accident release conditions (e.g., ground release or elevated release, length of accident release, etc.), distance of the point of interest from the accident's release location and the site's historical weather data. These three elements are typically fixed and are not subject to change. Atmospheric dispersion factors are, essentially, a choice of a set of constants. Breathing rates are also more or less constant. (The rate may vary a small amount if the accident release extends over many hours.) The dose conversion factor depends on the composition of the material released and seldom changes.

Thus, the only real variable for calculating accident release consequences becomes the material released, \( M \). In other words, all the facility's engineered safety features, all of its technical safety requirements, all of the staffing, training, procedures, maintenance, and drills which constitute the facility's safety envelope are provided to limit the respirable material released by an accident.

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Dispersion factors may be calculated as either time "average" (also called time-integrated) dispersion sometimes called \( \chi/Q \) prime, or "peak" dispersion. Time-average dispersion is the ratio of average air concentration at the point of interest to the release rate at the point of release. Peak dispersions are typically used to determine toxicological dose.
The equation to find the amount of respirable airborne material released by a particular accident is:

\[ M = \text{MAR} \times \text{DR} \times \text{ARF}^3 \times \text{RF} \times \text{LPF}, \]

where

- \( M \) = amount of respirable airborne material released by the accident into the environment, in grams\(^4\)
- \( \text{MAR} \) = material at risk, i.e., amount of radioactive material available for release by the accident, in grams\(^4\)
- \( \text{DR} \) = damage ratio for the accident
- \( \text{ARF} \) = airborne release fraction (or, airborne release rate multiplied by the length of time of the release)
- \( \text{RF} \) = respirable fraction for the released material
- \( \text{LPF} \) = leak path factor for the released material.

The MAR is the amount of material contained within the confinement systems that could credibly be released by the particular accident. MAR is often called the source term, although that label is misleading.\(^5\) MAR may be less than the total amount of radioactive material in the facility's confinement system, an important distinction. Material that could not be credibly released should not be considered in the MAR.\(^6\)

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\(^3\) Or, \( \text{ARR} \times t \), where \( \text{ARR} \) is the airborne release rate and \( t \) is the length of time of the release.

\(^4\) Sometimes, \( M \) and \( \text{MAR} \) are expressed in curies.

\(^5\) Refining this label, as the release path is restricted to considering only inhalation, the source term is the amount of material that could be credibly released into the air.

\(^6\) The idea here is a derivative of the facility segmentation concept presented by DOE Standard 1027-92. Hazardous material in one segment of a facility not affected by the analyzed accident or common cause initiators may be excluded from consideration in determining release.
Damage ratio is the fraction of the MAR affected and thus released by the accident. The DR is related to the MAR. Damage ratios depend on the MAR’s chemical and physical state. Different radionuclides comprising the MAR may also have different damage ratios, so that the product of MAR x DR becomes a summation of constituents:

\[ \text{Total} = \sum (\text{MAR} \times \text{DR})_{\text{isotope}} \]

The relationship between radionuclides and their damage ratios strongly depends on the accident’s energy release and the confinement system(s) and thus may not be well known. Further, excluding from the MAR a particular radionuclide that is unaffected by the accident can change the damage ratios for the remaining affected radionuclides. Determining damage ratios is therefore difficult and is predominantly a matter of engineering judgment.

Because of the uncertainty in determining (and subsequently defending) a selected DR, analysts will frequently conservatively define the DR as 1.00, in which case all the material within the confinement system is released by the accident. This is not the same as saying that all the material at risk then becomes airborne.

The Airborne Release Fraction, ARF, is the fraction of material released during the accident that goes airborne (as an aerosol). The ARF does not include dispersion of the material downwind. Technically, the ARF should be

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hazards. In a similar manner, material within a single confinement may be excluded if not affected by the accident. However, that same material may be affected by another accident within the same confinement system. For example, radioactive corrosion products tightly bound to a pipe wall need not be considered in the MAR if the accident is a low-pressure pipe leak. However, such material should be included if the accident is a pipe explosion.
applied to acute sudden releases and not a prolonged (i.e., over a period of hours) release. A prolonged release should be treated using the accident release rate (ARR).

The Respirable Fraction is the fraction of the airborne radionuclides released by the accident that could be inhaled. Thus, the product ARF x RF represents the airborne threat posed by the accident's source term, MAR x DR.

The Leak Path Factor is the fraction of the respirable radionuclides released by the accident that escapes the final confinement system(s). The LPF includes reduction in the accident release by whatever passive mitigation features exist. The LPF depends on the size and state of the respirable particulate, existing air transport mechanisms within the facility, and deposition of the particulate's cloud. Leak path factors can be considered "macroscopically"—in which a single LPF is determined for the entire confinement system, or "microscopically"—in which separate LPF's are determined for each confinement barrier through which the cloud passes. The system's LPF is then the product of the separate barrier LPF's. Different radionuclides may also have different LPF's for the same accident. As with damage ratios, determining leak path factors is predominantly a matter of engineering judgment. Like the damage ratios, analysts frequently define the

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Note use of the word passive. Credit may be taken for passive features that reduce the accident source term so long as the feature is reasonably expected to survive the accident. The particular passive feature does not have to be safety-related (i.e., safety-class or safety-significant) in order to assume the feature is there. (See DOE Standard 3009-94, section 3.4.2.) The dispersion effect of a cloud of radionuclides released within a building may be credited in a LPF for that accident.
LPF as 1.00, meaning that all the respirable MAR within the confinement system escapes into the environment.

The Case Against Unreasonable Conservatisms:

Nuclear safety analyses must always be conservative. Accident analyses use conservatisms to compensate for approximations and uncertainties in the accident model, the data base, or other unknowns. Because not everything about the accidents can be known, the analyses use conservatisms. However, contrary to widespread perception, more conservatisms do not make a safer facility.

Conservatisms may be overused. Conservatisms frequently compensate for technical uncertainties in the accident models. In other words, ignorance breeds conservatisms and the more unknowns there are in a facility's accident analysis, the more conservative that analysis will be. Unfortunately, a tendency exists to substitute conservatisms for technical information that is better obtained by conscientious accident model development or other research. Conservatisms are too-frequently used to plug holes in a facility's knowledge base that should not be allowed to exist in the first place.

A conservative analysis is often praised to the point that arguments arise over which analysis technique is the most conservative and therefore desirable. Use of conservatisms, borne of ignorance, is often considered preferable to less "conservative", more factual and realistic analyses. In choosing to apply or not to apply conservatisms, why is ignorance thought to be more safe than knowledge?
Removing Unreasonable Conservatisms from Safety Analyses

Unreasonable conservatisms are gross manifestations of this tendency. The author defines an unreasonable conservatism as an approximation for a piece of variable or conditional information not presently known that is significantly more restrictive than similar industry values or which could not withstand objective engineering assessment.

Unreasonable conservatisms lead to an unrealistic and unreasonable accident release. The release then demands unreasonably complex ESF’s to prevent or mitigate the accident. Unreasonable conservatisms thus muddy a facility’s safety picture, making determination of what is really needed for safety more difficult. Considerable time and expense is consumed designing systems of marginal or no safety benefit, but whose operation is none-the-less required by the safety analysis report. An impression is created that substantial defenses are needed to prevent or mitigate accident releases. Deficiencies in these defenses inevitably occur during facility operation, creating the appearance of risk and the conclusion that the facility’s operation is unsafe. By exaggerating the actual accident releases, the facility’s safety basis can appear seriously deficient, projecting alarming accident releases that no one really believes, yet are the basis for the facility’s operation.

Taken to extreme ends, analysts can lose track of what the safety analysis report is for. The goal of all accident analysis should be development of safety systems to prevent, not to mitigate, an accident. Unfortunately, by their nature, conservatisms work against the goal of prevention, so that many sites end up mitigating accidents with sophisticated safety features, while simpler systems that could credibly have prevented the accident in the first
place are ignored. Real safety is lost in the zeal to provide features that mitigate make-believe accidents.

For example, the author reviewed the analysis of a spray leak during backwash of a filter used to remove transuranic radionuclides from storage basin water. Even though the facility is continually manned, the analyst insisted that the accident last the entire backwash cycle--over one hour. Because prevention (discovery) of the accident was not considered, the analyst then required that a detector be mounted on the filter pipe to alarm at a preset radiation level (the detector monitored filter loading). The alarm set point protected co-located workers and the accident's dose to facility workers was substantial (> 100 REM). Essentially, the radiation detector made the accident acceptable to co-located workers. Nothing was provided to protect facility workers, nothing was provided to prevent the accident from happening (eg, enclose the filter units), and nothing was provided to discover the accident at its inception (eg, have redundant continuous air monitors in the vicinity). DOE was asked to accept the consequences of an accident that should have been mitigated by simple detection (CAM's) and prevention (filter enclosure) features.

Over-conservatisms add unneeded layers of defense to protect against accident releases. However, actual improvements in safety quickly reach a point of diminishing returns and thereafter, the author maintains that unreasonably conservative analyses reduce over-all safety. For non-reactor DOE nuclear facilities, most serious accidents causing injury or release of radiation appear to result from neglected maintenance, personnel errors usually related
Removing Unreasonable Conservatisms from Safety Analyses

to inadequate training, or management problems. Unnecessary engineered safety features, created by unreasonable conservatisms in the safety analysis, require that scarce funds be expended to keep these features operational. This is usually done at the expense of other needs, eg, maintenance and training. The result is more frequent breakdowns and accidents. Facility operation may be completely stopped. If the facility's mission is resolution of a pressing safety issue, eg, removal of corroding fuel elements from obsolete storage basins, then progress to resolve that paramount safety issue likewise stops. Thus, real safety decreases.

Indeed, a facility can become so wrapped in being "safe" that resolution of the real safety issue for which that facility was created languishes. If left unaltered by a future in which excessive conservatisms are rooted out of a facility's authorization basis, DOE will continue to pay more for less real safety, and DOE's progress to resolve its myriad safety problems will continue to be slow and uncertain.

Removing Unreasonable Conservatisms:
Unreasonable conservatisms are often buried deeply within a safety analysis and can be difficult to identify. However, a holistic review of the facility's accident analysis can uncover them. This review examines each of the six steps comprising the accident analysis.

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8. This assertion is based on review of the reported root cause of approximately 6,900 and 7,800 occurrence reports from the Richland and Savanna River Offices, respectively. The review showed that equipment failures usually caused by inadequate maintenance, personnel errors, and management problems were the root causes of 72% and 76% of the occurrences, respectively. The author believes other DOE sites would be typical of these statistics.
The path to success is clear: begin with how the accident's source term was developed. The higher an accident's release, the more sophisticated are the design features to prevent or mitigate that accident. The inverse is also true. Reducing the accident's source term directly reduces accident's release. Therefore, the need for unnecessary and cumbersome safety features diminishes with the accident's source term.

Examine the material at risk and remove unreasonable conservatisms from it. The material at risk should not include radioactive material that cannot be credibly released by the particular accident, even though that material may be present in the affected system. For example, if the accident is a leak from a pipe or tank, corrosion deposits tightly bound to the pipe or tank cannot leak out and may be excluded from the source term.

Next, determine an appropriately conservative damage ratio to apply to the material at risk. Unfortunately, the author knows of no standards or analysis codes to calculate a DR. However, such lack of published guidance should not deter a site from determining damage ratios using sound engineering judgment following an objective assessment. Other DOE sites with similar accidents should be asked if they have applied damage ratios to their analysis and if so, what values they used. A few minutes' research by telephone may provide a wealth of information. Further research by DOE to develop standards for damage ratios and leak path factors would be valuable, and would actually pay for itself by eliminating the need for expensive and unnecessary safety features.
Next, determine that an appropriately conservative leak path factor (LPF) to apply to the confinement system(s). The CONTAIN code\(^9\) may be used to calculate dispersion of a cloud of material through a building. This code can calculate the final amount of material released into the environment. Use section 3.4.2 of DOE Standard 3009-94 to credit reliable passive barriers expected to survive the particular accident. The barrier need not be safety-related to credit its existence. However, the LPF should reflect the number and nature of barriers present. Several extensive barriers (e.g., heavy concrete confinement walls) built to safety-class standards would result in a considerably lower LPF than a non-safety-related structure built to UBC standards.

Next, rigorously examine the credibility and accident path of the scenario. Determine if substantially long times are assumed prior to termination of the accident's release. The time assumed to stop a release should not be unrealistically long. The NRC allows operator response after 10 minutes. Ten minutes may be too quick for some DOE facilities. However, the accident analysis should not arbitrarily allow many hours for the release to occur, either. Determine that the propagation method is credible and reasonably developed. Finally, verify that the postulated accident ties back to a recognized hazard identified by the facility's hazard analysis. If such a tie

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\(^9\) CONTAIN is a computer code developed by Ken Murata of the Los Alamos National Lab (LANL). It models plume movement room by room through a building. Deposition factors and other information must be provided or be assumed.
Removing Unreasonable Conservatisms from Safety Analyses

to a real hazard cannot be made, then the accident should be discarded. All accidents must derive from an identified facility hazard.\(^{10}\)

For simple accidents, little can be gained by rigorously examining the accident frequency. However, if numerous simultaneous or coincident failures must occur to trigger the accident's release, then a fault tree should be developed to evaluate the credibility of the accident's stated probability. After applying reasonable probabilities for the failures leading to the accident, the fault tree may show that either the potential accident is incredible or that its overall risk is so low the accident can be accepted without further mitigation efforts.\(^{11}\)

**Atmospheric Dispersion:**

Conservatisms are frequently built into the atmospheric dispersion factor, \(\chi/Q\). In fact, the largest reductions in accident releases can often be obtained by reducing the unreasonable conservatisms in \(\chi/Q\).\(^{12}\) The dispersion factor depends strongly on meteorological data and that data, which

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\(^{10}\) To ensure that the tie between hazards and accidents actually exists may seem obvious and unavailing. However, the author has heard the expression "we threw this accident in [for analysis] just because we thought someone might ask about it sometime." When pressed, the analyst could not easily tie that accident to a recognized hazard. Accidents are sometimes developed simply as conjectures or speculations. Such are the hallmarks of a weak ineffectual hazards analysis.

\(^{11}\) DOE defines a credible accident as those accidents with an estimated probability of occurrence \(> 1E-06/\text{year} \) (DOE Order 6430.1A). An incredible accident therefore has a frequency \(< 1E-06/\text{year}\).

\(^{12}\) For example, if the damage ratio and leak path factor for an accident are both .5, the material released is reduced by 75%. However, crediting a stack release can reduce on-site \(\chi/Q\) by factors of 50 (~98% reduction) to over 250. The effect of a stack decreases with distance. The farther away from a facility the point of interest is, the less influence the stack will have.
is assumed to be accurate, should not be further manipulated. However, for local releases,\(^{13}\) chi/Q drops considerably if the release is through a stack as compared to a ground-level release. A stack may be used even though it is not safety class so long as the stack is expected to survive the particular accident. Plume meander should be included in calculating chi/Q for releases lasting longer than one hour.

Until recently, no further refinements in chi/Q were possible. Recently however, a new methodology for calculating dispersion factors, "Atmospheric Relative Concentrations in Building Wakes," NUREG/CR-6331, has been issued and accepted for use by the Nuclear Regulatory Commission. NUREG/CR-6331 uses new models that more accurately account for building wakes effects in determining the dispersion coefficient. The new code generally reduces local chi/Q by factors of 10-100. This reduction drops substantially with distance and is small (a factor of two to five) at great distance (ten kilometers or more).

Needed: More Research into Release Factors:

In the January, 1999 issue of Nuclear News, NRC Commissioner Shirley Ann Jackson cites the necessity for more research into basic safety analyses techniques when she writes:

\(^{13}\) Local here means the short distance from the facility to the co-located worker, who is typically located within 100 to 1,000 meters of the facility. Also, a stack must generally be considered to be > 2.5 to 3 times the building height in order to be considered a true elevated release point.
"the NRC research program will continue to provide the technical bases, including improved calculation tools and data, to support more realistic analyses of safety margins..."\textsuperscript{14}

In a similar manner, the DOE should conduct more research into accident release factors, namely damage ratios and leak path factors. The goal is to publish a standard or guide to calculate both factors, given the particular design configuration. This research should be modeled on the successful approach taken in preparing DOE Handbook 3010-94, "Airborne Release Fractions/Rates and Respirable Fractions for Non-Reactor Nuclear Facilities." Methods to calculate legitimate defendable accident release factors would be of invaluable service to safety analysts. Further, by obtaining more realistic accident releases, the DOE gains a more accurate view of a facility's true risks. Finally, the research would pay for itself by avoiding the design and installation of needless superfluous safety systems.

The goal of the NRC, Commissioner Jackson states, is "to apply necessary burden, but not unnecessary burden" to safety regulation. DOE's goal should be no less enlightened.

**Conclusions:**

Unreasonable conservatisms can reduce a facility's over-all safety. Expensive unnecessary safety features hobbles the facility's mission, likely slowing

Removing Unreasonable Conservatisms from Safety Analyses

resolution of the safety issue for which the facility was constructed. Funds for maintenance, training, and management are diverted to maintaining safety systems of marginal or no real benefit. The net effect is to increase the chances for break-downs and accidents.

Deliberate intensive review of the facility's accident analysis, starting with the source term derivation and continuing through to the accident release calculation, can uncover unreasonable conservatisms that should be removed.

Additional research by DOE into developing standards for damage ratios and leak path factors would be extremely beneficial. Reductions in facility operational and design costs through elimination of unneeded safety systems, made possible by removing unreasonable conservatisms in the safety analyses, would likely pay for this effort.