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Establishment of Quantitative Consequence Analyses Criteria for the Los Alamos National Laboratory Nuclear Materials Technology Division

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Abstract

The Nuclear Materials Technology Division at the Los Alamos National Laboratory performs consequence analysis on postulated accident scenarios identified during facility hazard analyses. While a comprehensive set of qualitative criteria was established for consequence analysis, quantitative criteria have historically been exiguous. The sparsity of established quantitative criteria coupled with ambiguities in the existing qualitative criteria has contributed to inconsistencies in these analyses. This paper will detail recent changes the NMT Division has made in its consequence analysis methodology designed to increase its objectivity and to facilitate consistency. These changes include the establishment of a complete set of quantitative consequence-severity criteria for accident phenomenon common to the NMT Division facilities as applied to receptors of interest.

1 Background

The Nuclear Materials Technology (NMT) Division at the Los Alamos National Laboratory (LANL) utilizes both facility and process hazard analyses to assess the safety of its facilities and their operations. The potential consequences of each identified postulated accident scenario are separately categorized for the anticipated effects to the public, to workers, and to the environment.

LANL utilizes the hazard categories in Table 1 to rank postulated accident scenarios in terms of consequence magnitude for the purpose of

identifying potential accidents which require further evaluation. These hazard category definitions, which are derived from the U.S. Department of Energy regulations and standards, are clearly qualitative in nature.

Hazard Category	Possible Consequences		
	Public	Worker	Environment
A	Potential for long-term health effects	Immediate health effects or loss of life	Significant offsite contamination requiring clean-up
B	Irritation or discomfort but no permanent health effects	Long-term health effects, disability, or severe injury (not life-threatening)	Moderate to significant onsite contamination; minor offsite contamination
C	No significant off-site impact	Lost-time injury or work restriction, but no disability	Moderate localized contamination; no offsite contamination
D	No off-site impact	Minor injury with no disability and no work restriction	Minor localized onsite contamination; no offsite contamination

Table 1. Qualitative Hazard Categories

It should be apparent that such qualitative criteria could lead to inconsistencies and disagreements in the assignment of hazard categories. Such problems could be exacerbated at NMT Division facilities where hazards involve not only radionuclides but also toxic and carcinogenic chemicals and the potential for explosions from chemical reactions or equipment failure. Consequently, NMT Division has established a quantitative regimen of accident consequence magnitudes corresponding to "thresholds" for the qualitative hazard categories defined in Table 1. These quantitative criteria have been defined for each of the four relevant hazard types: radiological, toxicological, carcinogenic, and explosive. These thresholds were established by identifying the physical insult (exposure, dose, etc.) that would be expected to produce a physiological response corresponding to the qualitative hazard category definitions (e.g., for Hazard category A, *potential for long-term health effects* to the Public). The thresholds for environmental consequences are also ultimately dose related, but they are derived from extant governmental standards that related contamination to worst case human uptake via all pathways

2 Radiological Exposures

In general, radiological threshold values were determined by considering the type of radionuclides present, current radiation standards, established threshold values for various health effects, and dose limits set by regulating agencies for occupational, emergency, public, and environmental exposures to radionuclides. The physiological effects corresponding to ranges of acute radiation doses above the safe limits for occupational and public exposures were compiled. The characteristics of the actinides of interest at NMT

Division facilities and the facility's predominant historical and postulated accidents were considered. This led to a conclusion that the consequence of primary concern from radiological hazards in these facilities is an increase in the probability of latent excess carcinogenicity. Several examples illustrating the rationale used to establish threshold values are presented below, followed by Table 2, which gives the complete threshold values for radiological hazards in the NMT Division.

The conceptual threshold value or qualitative descriptor for Hazard Category A is a "potential for long-term health effects". 25 rem Total Effective Dose Equivalent (TEDE, 50-year basis) is generally accepted as a value indicative of no significant health effects (i.e., low risk of latent health effects and virtually no risk of prompt health effects). This was used as a basis to establish 25 rem TEDE as an appropriate threshold value for this hazard category for the Public (including sensitive subpopulations) as above this dose level, the potential for long-term (i.e., latent) health effects exists.

The acute dose threshold for Worker Hazard Category A has been established at 200 rem, as this dose is about the lower limit for lethality [the lethal dose for 50% of the population within 30 days ($LD_{50/30}$) is about 450 rem]. Therefore, 200 rem acute dose represents the threshold for *Immediate health effects or loss of life*.

The conceptual threshold value for Worker Hazard Category C is a "lost-time injury, but no disability (work restriction)". Technical sources citing doses and their commensurate physiological effects, as well as federal regulations for occupational dose limits, were used as a basis to establish a range of between 5 and 25 rem for this hazard category. In conformance with existing regulations, an event in this exposure range would constitute a lost time injury as the worker would have exceeded the annual limit, and/or, the lifetime limit. This would result in a transfer of the worker to a non-radiological area for at least the balance of the year. Technical literature substantiating that this dose range would not involve a disability would further support its appropriateness for this hazard category.

For environmental contamination, the Hazard Category A threshold is contamination that would result in a dose to the Public via all pathways exceeding 100 mrem/year, which is the Public dose limit from nuclear operations established by U.S. federal regulations. Thus, contamination at or above this level would constitute "significant offsite contamination requiring cleanup." Note that for ^{239}Pu , this contamination level has been established at 25 pCi/g for the decommissioning and decontamination of a number of nuclear facilities.

Category	Public (rem)	Worker (rem)	Environment (mrem)
A	Potential for long-term health effects	Immediate health effects or loss of life	Significant offsite contamination requiring cleanup
	> 25	> 200 acute, or > 400 50-yr. TEDE	Public: > 100/yr. dose Restricted Areas: > 500/yr.
B	Irritation or discomfort, but no permanent health effects	Long-term health effects, disability, or severe injury (not life-threatening)	Moderate to significant onsite contamination Minor offsite contamination
	5 < dose < 25	Lifetime dose limit < dose < 200 acute, or < 400 50-yr. TEDE	Onsite (external to facilities): 5X to 10X (100 dpm/100 cm ² fixed & removable contamination of transuranics) Offsite: 25/yr. < dose < 100/yr.
C	No significant offsite impact	Lost-time injury, but no disability (work restriction)	Onsite: Moderate localized contamination Offsite: No contamination
	0.1 < dose < 5	5 < dose < lifetime dose limit	Onsite: < 5X posting threshold Offsite: < Background or MDLs (Minimum Detection Limits)
D	No offsite impact	Minor injury with no disability and no work restriction	Localized: Minor contamination Offsite: No contamination
	Dose < 0.1	1 < dose < 5	Onsite: < posting threshold Offsite: < Background or MDLs

Table 2. Radiological Hazard Category Thresholds (Robinson et al., 2002)

3 Exposures to Toxins

The toxic insult threshold values are shown in Table 3. These were determined from dose/response data and inventory thresholds using U.S. federal regulations and toxicity standards and other information gleaned from U. S. regulatory agencies and research institutions such as the U.S. Occupational Safety and Health Administration, the National Institute of Occupational Safety and Health, and the National Academy of Science.

Category	Public (rem)	Worker (rem)	Environment (mrem)
A	Potential for long-term health effects	Immediate health effects or loss of life	Significant offsite contamination requiring cleanup
	≥ ERPG-2*	≥ ERPG-3	N/A
	≥ 40 CFR 68 inventories	≥ 29 CFR 1910.119 inventories	≥ 40 CFR 261.24† or 40 CFR 268.48†† concentrations in contaminated media
B	Irritation or discomfort, but no permanent health effects	Long-term health effects, disability, or severe injury (not life-threatening)	Moderate to significant onsite contamination Minor offsite contamination
	ERPG-1 ≤ exposure < ERPG-2	ERPG-2 ≤ exposure < ERPG-3	Onsite: > 40 CFR 261.24 or 40 CFR 268.48 concentrations Offsite: < 40 CFR 261.24 or 40 CFR 268.48 and > background

Category	Public (rem)	Worker (rem)	Environment (mrem)
C	No significant offsite impact	Lost-time injury, but no disability (work restriction)	Onsite: Moderate localized contamination Offsite: No contamination
	TLV-C* < exposure < ERPG-1	ERPG-1 ≤ exposure < ERPG-2	Onsite: > 40 CFR 261.24 or 40 CFR 268.48 concentrations Offsite: < Background or < MDLs
D	No offsite impact	Minor injury with no disability and no work restriction	Localized: Minor contamination Offsite: No contamination
	≤ TLV-C	< ERPG-1	Onsite: ≤ 40 CFR 261.24 or 40 CFR 268.48 concentrations Offsite: ≤ Background or < MDLs
*ERPG=emergency response planning guidelines, American Industrial Hygiene Association **TLV=threshold limit value, American Conference of Governmental Industrial Hygienists †40 CFR 261.24, <i>Toxicity Characteristic</i> ††40 CFR 268.48, <i>Universal Treatment Standards</i>			

Table 3. Toxicological Hazard Category Thresholds (Robinson et al., 2002)

4 Exposures to Carcinogens

Hazard category thresholds for exposures to carcinogens are shown in Table 4. These were established by determining the Integrated Cancer Risk (ICR) associated with radiation dose thresholds for each hazard category.

Category	Public	Worker	Environment
A	Potential for long-term health effects	Immediate health effects or loss of life	Offsite: Significant contamination requiring cleanup
	$\geq 1.25\text{E-}03$ ICR	≥ 0.08 ICR	Unrestricted use: $\geq 5.0\text{E-}05$ ICR Restricted use: $\geq 2.5\text{E-}04$
B	Irritation or discomfort, but no permanent health effects	Long-term health effects, disability, or severe injury (not life-threatening)	Onsite: Moderate to significant onsite contamination Offsite: Minor contamination
	$2.5\text{E-}03 \leq \text{ICR} < 1.25\text{E-}02$	$1.0\text{E-}02 \leq \text{ICR} < 0.08$	Onsite: $2.0\text{E-}03 < \text{ICR} < 2.0\text{E-}04$ Offsite: $1.25\text{E-}05 \leq \text{ICR} < 5.0\text{E-}05$
C	No significant offsite impact	Lost-time injury, but no disability (work restriction)	Onsite: Moderate localized contamination Offsite: No contamination
	$5.0\text{E-}05 \leq \text{ICR} < 2.5\text{E-}03$	$2.0\text{E-}03 \leq \text{ICR} < 1.0\text{E-}02$	Onsite: $4.0\text{E-}05 \leq \text{ICR} < 2.0\text{E-}04$ Offsite: $\text{ICR} < 1.25\text{E-}05$
D	No offsite impact	Minor injury with no disability and no work restriction	Onsite: Minor localized contamination Offsite: No contamination
	$\text{ICR} < 5.0\text{E-}05$	$4.0\text{E-}04 \leq \text{ICR} < 2.0\text{E-}03$	Onsite: $\text{ICR} < 4.0\text{E-}05$ Offsite: $\text{ICR} < 1.25\text{E-}05$

Table 4 Carcinogenicity Hazard Category Thresholds (Robinson et al., 2002)

5 Exposures to Pressure Waves (Explosions)

The explosion threshold values are shown in Table 5. These were determined by considering pressure wave magnitudes, extant medical data, and the inventory of explosive materials.

Category	Public	Worker	Environment
A	Potential for long-term health effects	Immediate health effects or loss of life	Offsite: Significant contamination requiring cleanup
	≥ 40 kPa (6 psi)	≥ 100 kPa (15 psi)	≥ 7 kPa (1 psi) at the site boundary
B	Irritation or discomfort, but no permanent health effects	Long-term health effects, disability, or severe injury (not life-threatening)	Onsite: Moderate to significant contamination Offsite: Minor contamination
	$7 \text{ kPa (1 psi)} \leq \text{PW}^* < 40 \text{ kPa (6 psi)}$	$40 \text{ kPa (6 psi)} < \text{PW}^* < 100 \text{ kPa (15 psi)}$	Approaching 7 kPa (1 psi) at the site boundary
C	No significant offsite impact	Lost-time injury, but no disability (work restriction)	Onsite: Moderate localized contamination Offsite: No contamination
	$< 7 \text{ kPa (1 psi)}$	$7 \text{ kPa (1 psi)} \leq \text{PW}^* < 40 \text{ kPa (6 psi)}$	N/A
D	No offsite impact	Minor injury with no disability and no work restriction	Onsite: Moderate localized contamination Offsite: No contamination
	No offsite PW*	$< 7 \text{ kPa (1 psi)}$	N/A

*PW=pressure wave

Table 5. Pressure Wave Hazard Category Thresholds (Robinson et al., 2002)

6 Conclusions

Quantitative criteria provide an authoritative basis for the classification of hazards associated with multiple phenomena. These threshold values are consistent across diverse phenomena because they represent dose, exposure, or insult magnitudes that would be expected to evoke physiological responses that correspond in terms of qualitative severity levels. These criteria provide analysts and oversight personnel with a clear sense of what each consequence category means in terms of both acute and latent injuries.

References

1. Robinson, Mark A. and Gordon, D. J., Los Alamos Controlled Publication, LA-UR-02-6229, Los Alamos National Laboratory, Los Alamos, New Mexico, USA, October, 2002.