

Development of a Safety Analysis  
For the  
Los Alamos National Laboratory Beryllium Technology Facility  
(LAUR 00-261)

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Paper Session

Los Alamos National Laboratory refurbished an existing industrial facility to house a state-of-the-art facility for consolidation of much of the research activities involving beryllium. During the course of this development the hazard classification of the facility was incrementally changed from industrial, to low, to moderate, and now perhaps high. The safety analysis process that accompanied the development was impacted by the changes in classification and DOE expectation.

As a significant non-nuclear facility, the Beryllium Technology Facility (BTF) posed interesting challenges for its safety analysis. Key to this challenge is the nature of the hazard, beryllium powder. Chronic beryllium disease is a non-recoverable illness leading to significant consequence including untimely death. DOE has established new expectations for beryllium safety including significantly reduced permissible occupational exposures. However, the analysis of upsets and accidents usually focuses in acute exposures that occur infrequently. Beryllium does not have an established “dose” based consequence as the worst case consequence is historically a chronic worker exposure problem.

How then are accidents assessed to determine the consequence of the event and the relative importance or worth of the controls? The lack of a dose metric makes it difficult to classify the effectiveness of control or to select those operations that pose the most significant potential for unwanted physical consequences. As concentrations of only milligrams per cubic meter exceed allowable exposures, it takes only grams of beryllium powder to produce these results. Consequently, the quantity of beryllium powder is a small driver in analyzing the conditions of interest.

Furthermore, the BTF is in the process of development and processes are not defined in detail. Most processes to be transferred to the BTF are currently performed in the DOE complex, with many of them presently operational at LANL. This results in a less rigorous analysis process than is possible for an existing facility as failures and errors are difficult to postulate except in gross terms. Such lack of detail is a difficult proposition for development of an authorization basis and has posed problems for both the Laboratory and DOE in their review processes.

The approach taken to identify key controls, establish objectives, and guide planning for safe operations provides some insight into the new problems that might be posed as we attempt to apply nuclear based analytical expectations to significant non-nuclear facilities.

## **Introduction**

### **Evolution of the Beryllium Technology Facility**

The BTF is a heavily renovated existing industrial facility within the main technical area of the Laboratory providing about 16,000 sq. ft of office and work area. The design concept relied heavily on beryllium control and management concepts developed for a similar facility in Great Britain. The facility features a PC-2 seismic design, an extremely capable ventilation system with a both cartridge and HEPA filtering, and isolation of the beryllium processes. Most of the features were included as best practices and were not the outcome of a structured safety analysis.

Operations to be performed in the new facility include machining, beryllium powder production, inspection, foundry, near-net shape (hydrostatic isotropic press), and mechanical test. These operations are housed in separate areas with ventilation to support contamination isolation and management. Some operations, such as the powder production and machining, use high flow ventilation to manage beryllium effluents.

The operations at the BTF are a consolidation of those that were performed at Rocky Flats and Los Alamos National Laboratory. New developmental operations are added for high quality beryllium powder production. The facility will be the primary research area within DOE for beryllium and will provide limited specialty production and test capability while maintaining a level of beryllium technical capability as a hedge against the loss of commercial production.

### **Evolution of the Safety Analysis**

The BTF was developed as part of the non-nuclear reconfiguration process. As such, the normal project development process at the Laboratory was by-passed. However, many planning documents addressed the beryllium hazard and its management. Even so, no in-depth evaluation was made until the facility was already designed and in the process of being constructed and the process for transition to operation was being considered. To provide a safety basis for readiness to operate, a safety evaluation was performed to consolidate several hazard assessments.

The near-term result of this analysis was the determination that the hazard classification, “common industrial facility,” was inaccurate. This hazard classification, no longer used at LANL, indicated that all safety issues were adequately addressed in consensus standards. However, only a few beryllium facilities handling beryllium powder exist in the free world. This hardly constitutes the millions of man-years experience captured in the blood stained standards of the steel, gas and oil, and similar industries where standards for safe operation are common.

The lowest hazard category for an industrial facility, excluding the one determined to be inappropriate, was low. However, upon further review of the nature of the beryllium hazard, it became increasingly clear that a moderate hazard (indicating potential for severe injury or death to worker from non-standard industrial hazard sources) was

appropriate. This assessment was further supported by the publication of DOE N 440.1 that covered Chronic Beryllium Disease, the consequence of interest noted heretofore. DOE conducted several reviews of the BTF project to ensure that the requirements of this notice were addressed. The notice focused on worker safety under normal operations.

With the new moderate hazard classification, the formality of the safety analysis and its rigor increased. LANL did not have a good non-nuclear safety basis expectation in its DOE contract. DOE AL 5481.1B was included, but not DOE O 5481.1B which established the hazard categories upon which the AL order was predicated. Additionally, the safety documentation that had been prepared was focusing on the requirements for a new facility in the process of development rather than examination of an existing facility with well defined operations.

A safety document was produced that addressed the hazards, particularly the beryllium powder hazard, the facility design, and the proposed operations. Detailed analysis of proposed operations was not performed because the operational schedule did not provide for the same. LANL had adopted a work control process called Safe Work Practices that was the more appropriate forum for examining the details of the specific operations and defining their safety requirements within the more general safety framework for which the facility was designed. Hence, the safety analysis was a mostly as designed (detailed interfaces for the operational systems were undefined) as proposed to operate document. Unfortunately, this kind of document was unfamiliar to the DOE reviewers more accustomed to the backward looking analysis characteristic of the nuclear analyses of the past decade and so its premise was hard to deal with.

Furthermore, the public impact assessment was hampered due to the lack of criteria associated with determining the level of impact coupled with no standard for computation of the impact. Laboratory guidance through Integrated Safety Management provided a framework, but no generally agreed upon thresholds coupled to ERPG or other recognized measures were included in either DOE or LANL standards. The latter was further hampered by no beryllium specific release data, particularly for fires, upon which to base the release analysis.

As time progressed, the notoriety beryllium hazard prompted DOE to require that the BTF be governed by an authorization agreement, similar to the Laboratory's nuclear facilities. The safety basis document, which we termed a Safety Analysis or SA, is a key element of that process.

Over time the issues and uncertainties were addressed by interaction between the Laboratory and DOE to establish a common framework leading to an authorization basis. The public impact issue was addressed through a white paper produced by the Laboratory for the DOE that outlined the level of understanding of consequence assessment, airborne release fraction ranges, and major accident types that could lead to off-site exposure. From the white paper came a set of additional analyses that were required to address more fully the issues addressed and to identify potential controls.

With this writing, the accident analysis has been completed and presented for both internal Laboratory and DOE review. Some issues remain open, particularly the right airborne release fraction to apply to beryllium powder fires. It does appear that the beryllium facility with only slight changes in its proposed operation can be operated in an acceptably safe manner although DOE approval is yet to be obtained.

It is interesting to note that some beryllium operations continue at the Laboratory in their current, less capable, facilities. The new BTF is a quantum leap in safety for these operations, but the safety analysis process and the lack of clear expectations for the analysis in support of a developing non-nuclear facility prevents transition of these operations to the new facility.

## **The Beryllium Hazard**

The beryllium hazard is somewhat unusual compared to those familiar with nuclear safety analyses are concerned. There is no explicit dose function. There is no direct link between exposure and consequence. There is no established level associated with acute exposure (accident condition) where the likelihood of contracting the condition of interest is established.

For both workers and the public, the significant consequence of beryllium exposure is Chronic Beryllium Disease (CBD). CBD typically manifest itself over time and is mostly associated with workers and others exposed chronically to beryllium dusts. The effects of CBD are generally decreased lung function resulting in untimely death. CBD is not recoverable. Acute Beryllium Disease can result from high exposures, but ABD is recoverable.

Beryllium is also classified as a weak explosive powder and a flammable metal. Unoxidized beryllium is pyrophoric. Burning beryllium, when exposed to water, will disassociate the water producing hydrogen gas that can lead to an explosion. Such an explosion occurred in the then Soviet Union. Solid or bulk beryllium (defined as not powder) is rather inert. Some beryllium salts are absorbed through the skin, but such salts are used in the BTF.

Most established thresholds for adverse consequences associated with beryllium are low with a short term exposure limit of  $10\mu\text{g}/\text{m}^3$  for a 15 minute exposure. If we assume puff releases, as are typical of an accident, and similar hazardous thresholds of 10's of  $\mu\text{g}/\text{m}^3$  we see that source terms of 10's of grams are important. In fact, there is no functional safety difference between kilograms and grams at risk for a worker. This characteristic limits the application of screening tools common in nuclear hazard analysis and most of the chemical analysis methodologies. Contamination inside process machines presents as much a hazard as a 25 pound container of beryllium powder to workers.

## Public Impact Analysis

The public impact analysis was performed using Emergency Response Planning Guide level 3 (ERPG-3) as the key measure for significant impact. Bounding accident analyses were performed using 95 percentile weather conditions, unlike that usually for estimating consequences for emergency planning that focuses on 50 percentile weather. The analysis was further complicated by the lack of beryllium specific transport characteristics. The specific behavior of beryllium powder, particularly in a fire scenario, is unknown. DOE Handbook 3010 does address a variety of release conditions involving powders. However, these powders are virtually all denser than the beryllium powder used or produced in the facility.

Furthermore, ERPG is computed using the airborne release fraction (ARF) rather than the ARF times the respirable fraction (RF). Personnel knowledgeable in beryllium disease know that the respirable fraction is truly the parameter of interest, but ARF is the basis for the standard at this point in time. ERPG also uses two time frames, a short term release and a long term release. For short term releases, the concentration is averaged over 15 minutes while a long term release is averaged over 60 minutes. The level of concern is unchanged so it takes one fourth the material at risk (MAR) for the short term release to produce the condition of interest.

With the above in mind, the question is what set of accident conditions may lead to public impact at the ERPG-3 level ( $100 \mu\text{g}/\text{m}^3$ ). Knowing the bounding weather conditions and the distance to the closest public maximally exposed individual (MOI) allows formulation of the set of accident conditions that must be considered. The concentration,  $\Pi$  (Greek chi) is related to the release rate,  $Q$ , and the dispersion conditions for a ground level (worst case) as show in Equation 1.

$$X = \frac{Q}{2 \cdot p \cdot s_y \cdot s_z} \quad \text{Equation 1}$$

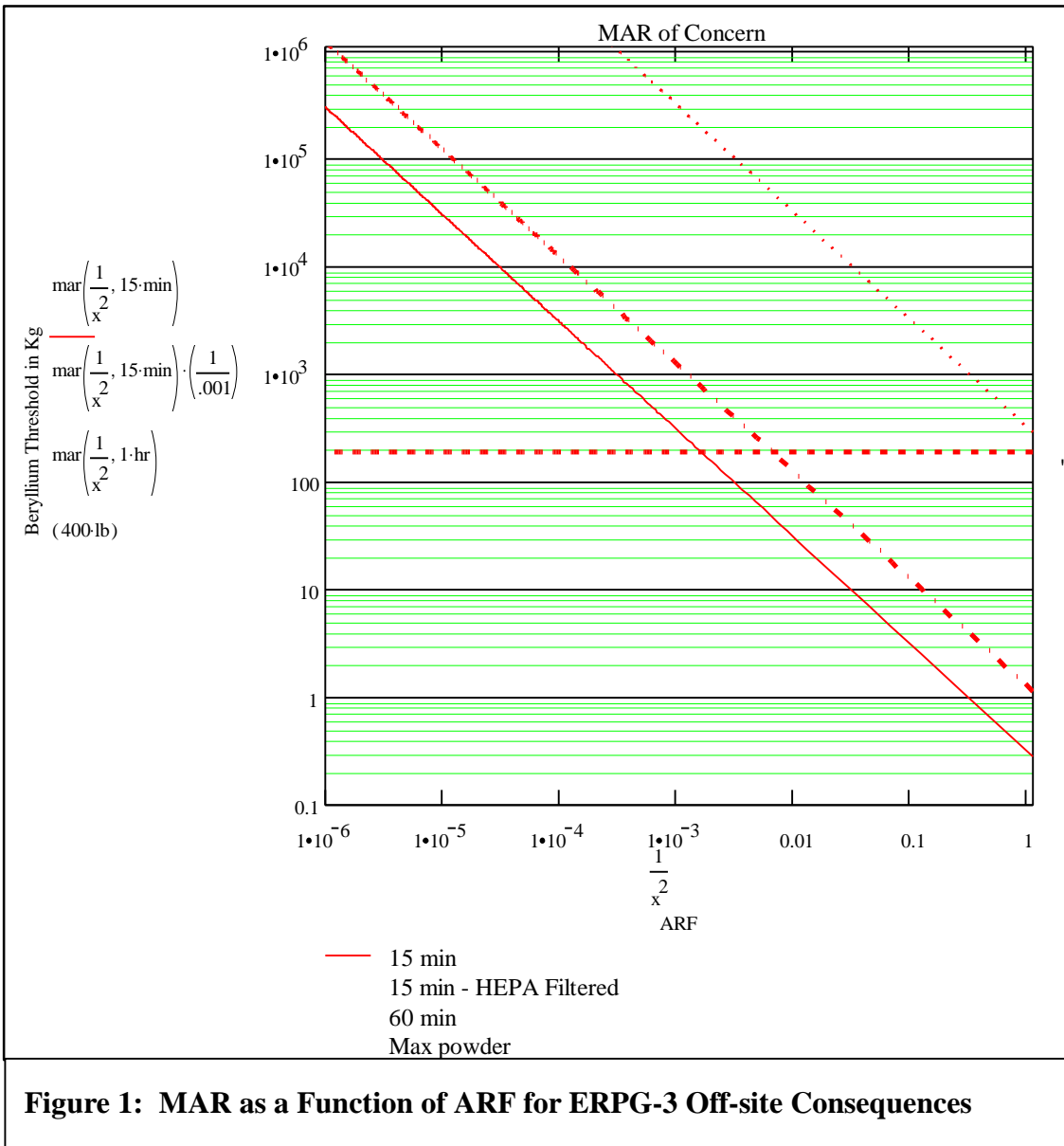
Where  $\Phi_y$  and  $\Phi_z$  are the dispersion coefficients.

Using the five factor formula for the source term and restraining the MAR to be totally released during the 15 or 60 minute release interval, one can express this equation in terms of the MAR and ARF where leak path factor (LPF), damage ratio (DR), and RF are 1. The representation of the relationship of MAR to ARF for the release conditions is shown in Figure 1 representation of the equation listed below. In Figure 1 the leftmost diagonal line represents the 15 minute release, the middle line the 60 minute release, and the rightmost line a 0.999 HEPA filtered release. The horizontal line represents a planning MAR limit. The region of the diagonal line below the MAR limit line represents the set of ARF values that can produce the ERPG-3 levels for a ground level release.

$$\text{mar}(\text{ARF}, t) := \frac{X \cdot t}{\text{Be}_{\text{disp}} \cdot \text{ARF}}$$

MAR as a function of concentration, dispersion, release time and ARF where  $Q := \text{mar} \frac{\text{ARF}^2}{t}$

From this information and using the information in DOE Handbook 3010, a set of release conditions with associated MAR can be developed and compared to the facility and its operations and potential upset conditions that might lead to the ERPG-3 off-site consequences. This information is shown in Table 1 for a limited set of release conditions.



**Figure 1: MAR as a Function of ARF for ERPG-3 Off-site Consequences**

**Table 1: MAR of Interest for Candidate ARF Values**

<b>ARF</b>	<b>DOE Hdbk 3010 ref.</b>	<b>MAR</b>	<b>Release condition</b>	<b>Release points</b>
1E0	4.4.2.2	0.28 Kg (0.6 lb)	Explosion acting directly onto powder, puff release	Water placed on a beryllium metal fire presents the potential for hydrogen generation and explosion.
1E-1	4.4.2.3.1	2.8 Kg (6 lb)	Venting of pressurized gas >25psig through powder, puff release	Beryllium containers that are air tight and subject to high compressive forces and high temperatures. Assumes gas overflow. Vacuum fill not applicable.
1E-2	4.4.1.2	28 Kg (62 lb)	Entrainment for chemically reactive compounds, puff release	Unoxidized beryllium is reactive. Transport from atomizer processes through exhaust with initial inert gas background. Oxidized beryllium at temperatures above 600C (burning).
6E-3	4.4.1.1	46.8 Kg (104 lb)	Entrainment at high velocities (>1.17m/sec) with unreactive powder, puff release.	Filter breakthrough of both bag and HEPA filters with Be loading > 11.7 Kg and exhaust operating. Note 1.
5E-3	4.4.2.3.2	56 Kg (124 lb)	Venting of pressurized gases <25 psig through powder, puff release.	Similar to high pressure release. Poorly sealed containers that fail under crush conditions with small openings.
5E-3	4.4.2.2	56 Kg (124 lb)	Blast from large volume explosion, not directly impinging on the powder (shielded), puff release	Large explosion from hydrogen produced due to water on beryllium fire inside building.

An examination of Figure 1 shows that no release that is filtered by the building ventilation system can lead to an off-site condition that exceeds ERPG-3. Therefore, the accidents of interest are those that challenge the HEPA filters, the building structure, or beryllium containing parts of the ventilation system physically outside the structure, specifically the cartridge filter house.

A public impact analysis addressing fire, seismic failure, and explosion are adequate to identify the key safety systems and assess their effectiveness and associated controls. Note that a subsequent analysis, based on this bounding concept, produces somewhat

different results. However, the approach to determining the credible accidents was applied with success as subsequent review found the analysis to be sufficient to characterize public impact and the associated controls to prevent or mitigate the conditions of interest.

## **Analysis Difficulties**

The analysis of the beryllium hazard as an health impact to both the public and the workers presented many difficulties not normally encountered in nuclear facilities. These difficulties can be characterized as follows:

Public impact – ERPG is used as a measure for chemicals. Beryllium, and other particulate chemicals that have an ERPG established, use the ARF for determining consequences. However, virtually everyone recognizes that the hazard is realized because of the respirable fraction. Assumedly, the ERPG-3 level accommodates the respirable fraction by some factor that considers the distribution of particles where the 100 :g/m<sup>3</sup> threshold is inclusive of worst case respirable fraction. Even if the latter is true, there is no substantiated evidence that acute exposures lead to chronic beryllium disease.

Worker impact – like public impact, worker exposure is assessed by measuring the airborne fraction although a particle distribution can be determined by subsequent analysis of air samples. Again, the exposure levels are established based on ARF. The real issue is acknowledged to be respirable fraction. Acute exposure does not necessarily lead to chronic beryllium disease. Unlike radiation exposure which is measured in dose, the analysis is forced to consider a concentration threshold above a level designed for normal operations to be equally dangerous with the most severe outcome assumed. Therefore, gram level quantities of beryllium powder are as significant, from an analysis point of view, kilogram quantities. Virtually all operations involving where there is a potential for beryllium powder to be present become viable analysis candidates for significant worker exposure accidents.

## **Selection of Controls**

Within the framework established above, the selection of controls is actually straight forward. Analyses subsequently performed using the release data and appropriate weather conditions associated with the various release scenarios pointed to the ventilation system and fire protection and management for protection of the public. Programmatic activities including configuration management and rigorous maintenance programs and worker training were already anticipated even without the potential for significant worker impact. Worker safety issues fall into work practices, engineered controls consisting of the ventilation system and process enclosures where practical, and PPE and monitoring. Specific process controls that support defense-in-depth and best practices are still in the process of being developed through detailed analysis of the process and process equipment.

## **Future Issues**

Several issues to be addressed and perhaps resolved in the future may have significant impact on the assessment of the beryllium facility, its hazards, and controls. These include a better measure for the hazard of acute exposure as expected in an accident condition, better data in support of dispersion behavior in fires and other energetic events, and more accurate metrics for public impact threshold assessment. The very conservative nature of the analysis produces very low thresholds for beryllium powder material at risk under certain public impact scenarios. Better data may allow the downgrading of these impacts with an associated lessening of the rigor of the controls with attendant cost of operation reductions and added operational flexibility.

## **Conclusion**

The LANL Beryllium Technology Facility poses unique and difficult analytical difficulties. The evolution of the recognition of the beryllium hazard and its metrics within DOE has led to an evolution of the assessment of the facility and its hazards in a more rigorous manner. The methods established for analysis of the hazards and their control based on the nuclear model are not a good fit because acute exposure information is lacking as most consequences are the result of chronic exposures. LANL applied best information to assess the public hazard and appropriate controls resulting in the development of an analysis that supports that the facility can be operated safely. Uncertainties in the behavior of beryllium powder under accident conditions and limited acute exposure consequence data exacerbate the process and make meaningful analysis difficult. Future development of better data may allow the significant relaxation of management of safety systems and processes consistent with the real nature of the hazard.