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Leak Path Factor Evaluation Methodology For Nonreactor Nuclear Facilities

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Abstract – The Leak Path Factor (LPF) for a nonreactor nuclear facility is a critical component for the evaluation of the source term used to evaluate the on-site and off-site consequences when an accident produces aerosols containing radioactive powders that propagate through the facility and finally to the outside environment. The Leak Path Factor is defined as the fraction of the airborne radioactive particulate material that is in the respirable size range within the building that escapes via available pathways to the outside environment. This paper presents a methodology to evaluate the LPF for various accident conditions (e.g., seismic event, fire) that could take place in a nonreactor nuclear facility using MELCOR computer code. The methodology presented could enable analysts to efficiently model facilities to assess the magnitude of the LPF by evaluating its various components.

I. INTRODUCTION

This paper presents a methodology to evaluate the Leak Path Factor (LPF) for a postulated accident scenario in a building containing plutonium powder when the resulting outside release is partly through the ventilation/filtration system and partly through other pathways such as building access doorways. When analyzing an accident scenario involving the release of radioactive powders inside a building, various pathways for the release to the outside environment can exist.

This work is presented to show how the multiple building leak path factors (combination of filtered and unfiltered releases) can be evaluated in an integrated manner to assess the magnitude of the source term (ST) to be used in the subsequent consequence analysis.

The source term is defined as the product of five terms:

$$ST = MAR \times DR \times ARF \times RF \times LPF \tag{1}$$

Where

MAR	=	Material at risk
DR	=	Damage Ratio
ARF	=	Airborne Release Fraction
RF	=	Respirable fraction
LPF	=	Leak Path Factor

Together the MAR and DR terms represent the amount of radiological material (assumed to be in powder form for the purposes of this paper) that is exposed to an accident-generated stress. The ARF and RF product represents the fraction of this material that is made airborne in the respirable size range (generally considered to be 10 micron or less aerodynamic equivalent diameter) in response to the accident-generated stress and is generally experimentally based [2]. Thus taken collectively, the first four terms represent the amount radioactive powder material that is made airborne in the respirable size range inside the building.

The core of the analysis and the focus of this paper is the calculation of the LPF, which represents the fraction of respirable radioactive powder material that is made airborne that leaves the building through the various pathways. The computer code of choice for this determination is MELCOR. The analysis results can be used for the transport and dispersion of powder material released to the atmosphere and to estimate the resulting dose that is received by the downwind receptors of interest.

The methodology presented can be used as a model for performing analyses for systems similar in nature where releases can propagate to the outside environment via filtered and/or unfiltered pathways. This work provides guidance to analysts outlining the essential steps needed to perform a sound and defensible analysis.

II. OVERVIEW OF MELCOR COMPUTER CODE

MELCOR 1.8.5 was developed by Sandia National Laboratories under support of the United Stated Nuclear Regulatory Commission (USNRC). MELCOR is a fully integrated, engineering-level computer code whose primary purpose is to model the progression of accidents in light water reactor nuclear power plants. MELCOR is a mature code with worldwide use for a wide spectrum of applications. MELCOR can be intelligently adapted to evaluate the Leak Path Factor for accident conditions in nonreactor nuclear facilities using its robust built-in models capabilities in aerosol dynamics.

MELCOR modeling is general and flexible, making use of a "control volume" approach in describing the plant/facility system. The various code packages have been written using a modular structure with well-defined interfaces between them.

The MELCOR code is composed of a large number of modules that together model the major systems of a nuclear reactor. The great majority of these models are not required for Leak Path Factor analyses, and when performing LPF studies for non-reactor nuclear facilities the modules used are then reduced to those which will enable the modeling of the release and transport of aerosolized materials.

III.ANALYSES

An ideal nonreactor nuclear facility is the subject of this study. A two-floor building is analyzed where two rooms are selected to have post seismic fire-induced release of plutonium oxide powder. The two fire locations are selected to show how the analysis results can be affected by the location of the fire with respect to other rooms and proximity to outside doors. The first step to be taken in this analysis is the creation of a MELCOR mathematical model of the facility to analyze, and then the assessment of the LPF results.

There are various steps that must be taken prior to the creation of a MECLOR model. For cases where a seismic event is an accident condition, it is important to assess the results of the structural analyses. This example only models those structures that survived the seismic event, and all the doors between the internal volumes are fire doors with relatively loose gaps. All the doors leading to the outside environment are kept open for a predetermined time to allow for evacuation of the building.

A schematic arrangement of the facility subject of this analysis is shown in Figures 1 and 2.

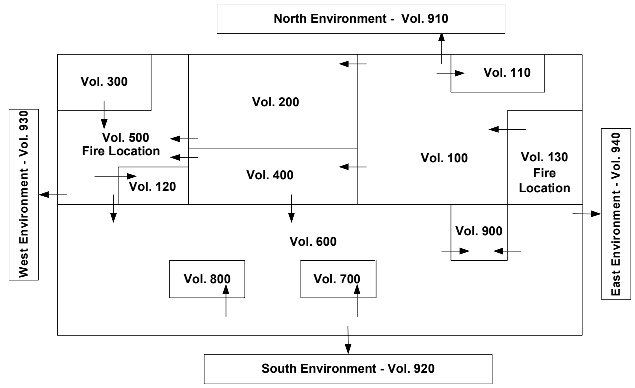

Fig. 1. Sketch of Building First Floor.

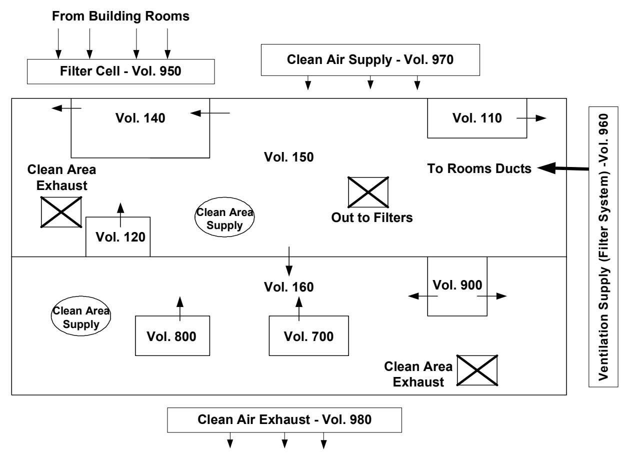

Fig. 2. Sketch of Building Second Floor.

The figures above show also the various building external volume will be used to simulate the building external environment and ventilation sources and sinks.

The locations selected for the two fires are volumes 500 and 130 as shown in Figure 1. These are also the location where the fire-induced release of plutonium oxide takes place. A simple block diagram shown in Figure 3 is generated to synthesize the two sketches for used in the MELCOR analysis.

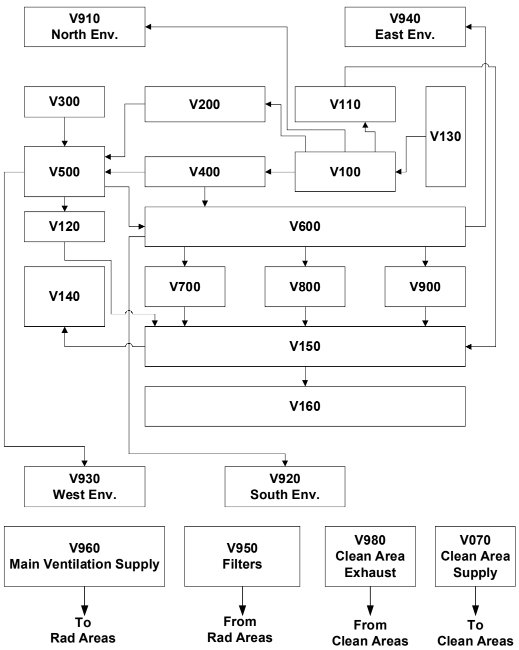

Fig.3. Building Block Diagram.

It has to be noted that the direction of the flow shown in Figure 3 is an assumed positive direction for MELCOR to initialize the simulation. The code will assign the proper flow direction based on the computed actual flow.

The building internal air temperature used in the analysis is 299 K (78 °F), and the building outside environment temperature used is 283 K (50 °F). The wind speed and direction used to simulate an overall pressure differential across the building are 2.24 m/s (5 mph) and wind from the south. Since wind speed is an input parameter to both the LPF calculation and the subsequent calculation for atmospheric plume transport and dispersion, it is desirable that the wind speed be specified consistently in both calculations to maintain the proper level of conservatism. While the LPF tends to increase with increasing wind speed, downwind plume concentrations and receptor doses decrease with increasing wind speed. Since the plume-concentration and receptor-dose calculations tend to be more sensitive to the wind speed than the LPF calculations, wind speeds on the low side are generally used to support proper conservatism in the analysis.

The wind pressure effects on the building are evaluated using the ASHRAE [3] methodology and are applied to model environmental influence. The building wind pressure is calculated from the dynamic head equation written in the form:

$$\Delta P_w = c_w \rho \frac{V_w^2}{2} \qquad (2)$$

Where:

$\Delta P_w =$ Localized air pressure change due to wind

$c_w =$ Wind pressure coefficient

$V_w =$ Wind speed

$\rho =$ Air density

The wind coefficient c_w varies with wind direction relative to building surfaces. With wind impinging normally on a wall $c_w = +0.7$. Wind parallel to a wall produces a wind coefficient of –0.35 and on the downwind side of the building a coefficient of –0.4 is used. Using these wind pressure coefficients, the pressure difference across the facility can be calculated.

The effective fire power used in both volumes is given in Figure 4. This is simulated by input of mass and energy into a control volume (very small mass with large specific energy vs. time)

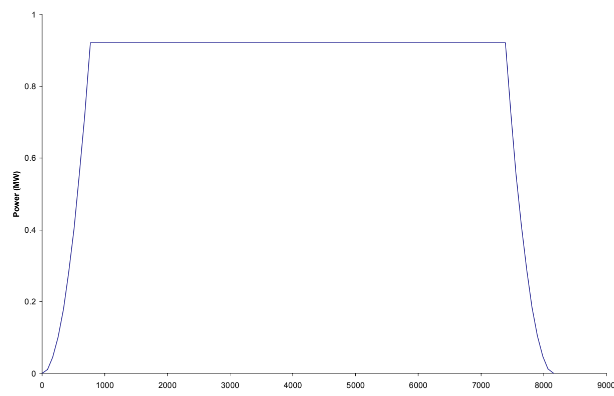

Fig.4. Fire Power Profile.

The release of the plutonium oxide powder is modeled to take place 3000 s after the fire start to assure the fire has already released energy into the volumes where the fire is located. The amount of powder released for the MELCOR simulation is 1.0 g of Pu^{238}. Releasing a small amount of material is generally in the conservative direction [4]. The calculated value of the LPF can decrease for a larger amount of material released because of enhanced agglomeration of smaller particles. Figure 5 shows the results of a parametric study on agglomeration effects for this type of situation. Specifically, Figure 5 shows the increased effects of agglomeration through lower LPF values that occur as the quantity of airborne mass of plutonium powder increases.

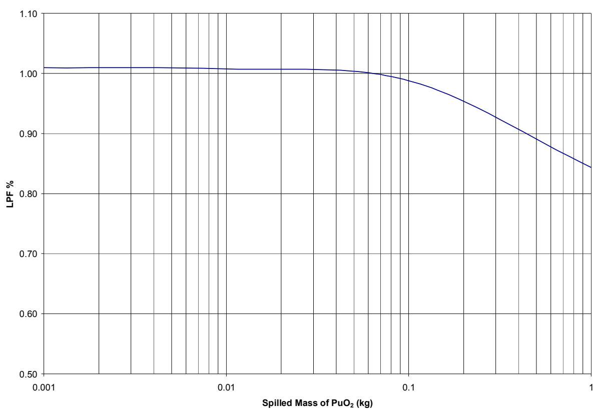

Fig.5. Influence of spilled mass on LPF.

The plutonium oxide powder particle size distribution used is obtained from experimental data for free fall spills in static air which is deemed to be conservative for fires that would have considerable updraft [5],[6].

Maximum aerosol particle diameter = 3 µm
Minimum aerosol particle diameter = 0.003 µm
Vol.-equivalent mass median particle diameter = 2.3 µm
Geometric standard deviation of the particle size distribution = 2

With the parameters described above approximately 63% of the airborne particles distribution is smaller than 3 µm (10 µm Aerodynamic Equivalent Diameter) and respirable.

The Probability Density Function for a lognormal distribution used in MELCOR is

$$PDF = \frac{1}{\sqrt{2\pi}\, d_p \ln(\sigma)} e^{-\frac{1}{2}\frac{\ln^2(d_p/d_m)}{\ln^2(\sigma)}} \qquad (3)$$

Where:

d_p is the distributed variable particle diameter,
d_m is the volume-equivalent mass median particle diameter, and
σ is the geometric standard deviation

Figure 6 shows the initial distribution of Pu^{238} powder particles used in the analyses.

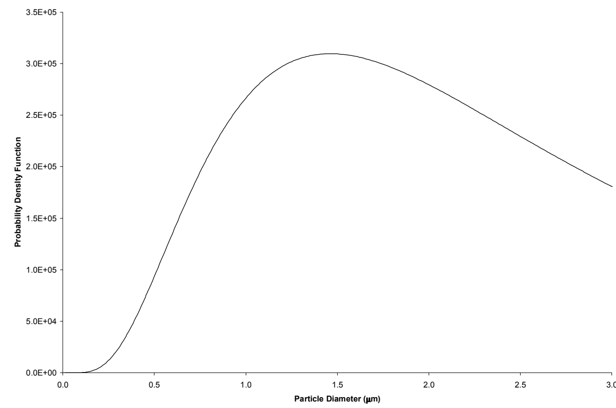

Fig.6. Lognormal distribution of Pu^{238} Powder Particles.

A total of 1 g of Pu^{238} powder with this particle size distribution is initially made airborne in the analyses. The accident analysis that is required to estimate the amount of respirable material that is made airborne during the fire is outside the scope of this paper.

The filtration system selected for this study is set to be resistant to hot gases generated by fires (sand filter type) and the release fraction for the system is assumed to be 0.005, with ventilation remaining operational during the fire event.

With all this information at hand, the MELCOR building model can be built to evaluate the various contributors to the building overall leak path factor.

It is advisable to have individual environmental volumes for each pathway leading out of the building. This is important to assess the contribution to the overall LPF from the various flow paths.

For both fire locations (volumes 500 and 130) the ventilation flow rates used in the analysis are 0.6 m^3/s for the air supply and 0.7 m^3/s for the air exhaust.

A MELCOR analysis is performed separately for each fire location and the results provided show how the total building LPF is accounted for.

Figure 7 shows the MELCOR calculated LPF (total LPF and individual contributions) for a fire in volume 500.

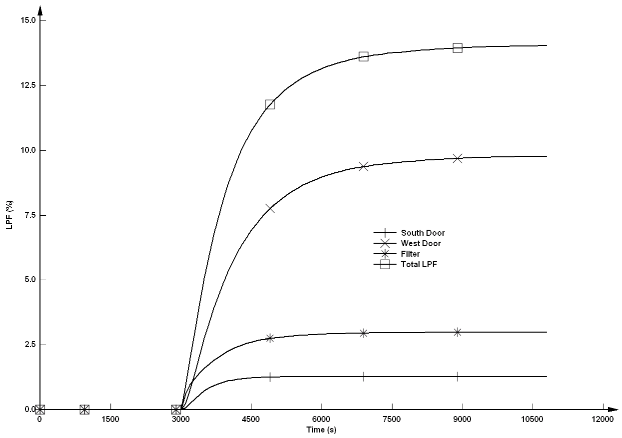

Fig.7. Leak Path Factor Summary – Fire in Volume 500.

Figure 7 shows that the contribution to the LPF due to the doors (West + South) is larger than the contribution due to the filter system release. That is caused by the model geometry and flows established by the MELCOR simulation for the given boundary conditions. The volume 500 area has a pathway closely connected to the outside environment through the West door, consequently the fire induced pressure inside the volume 500 space causes most of the aerosolized release to occur through the West door (much less goes out the South door). The filter in the ventilation system significantly reduces the amount of aerosolized material that exits the building through this pathway. All other pathways not shown contribute negligibly to the atmospheric release. It is expected that a larger amount of aerosolized material would leave the volume 500 area and reach the outside through the West door than through the filter system and the South door because of the fire-induced energy inside the volume 500 area and the proximity of the volume 500 area to the West door.

Figure 8 combines the unfiltered and unfiltered contributions of the leak path factor.

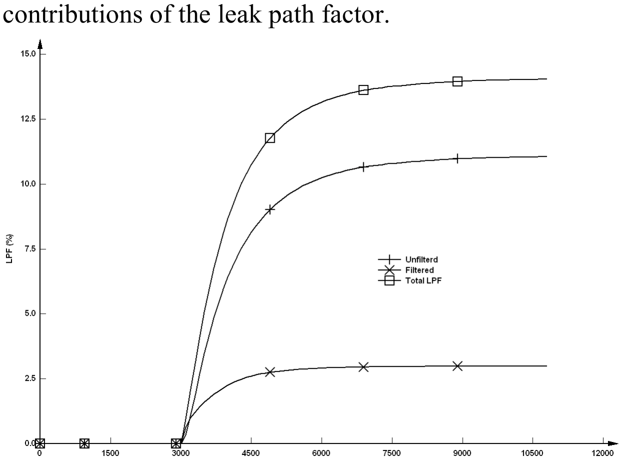

Fig.8. **U**nfiltered and Filtered Contribution to the LPF - Fire in Volume 500.

A new analysis is now performed where the fire is in volume 130, the north east side of the building. In this case, volume 130 is not closely connected to a door leading to the outside of the building. All the parameters used in this new analysis are the same. This new arrangement shows how the results change with a different fire location.

Figure 9 shows the MELCOR calculated LPF (total LPF and individual contributions) for a fire in volume 130. The value of the calculated LPF is much smaller.

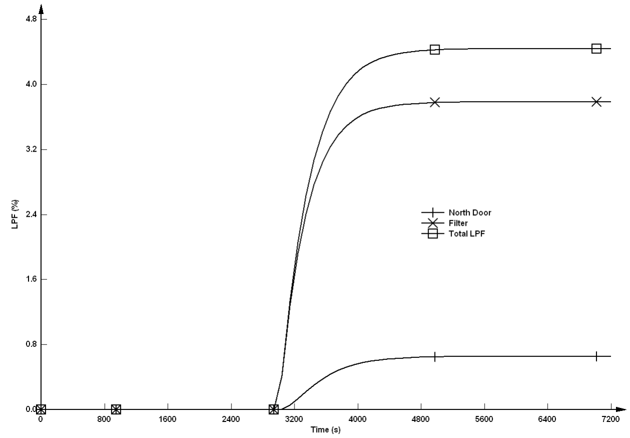

Fig.9. Leak Path Factor Summary – Fire in Volume 130.

Figure 9 also shows that the contribution to the LPF due to the filter system release is larger than the contribution due to the release from the North door. That is caused by the model geometry and flows established by the MELCOR simulation for the given boundary conditions. Volume 130 has doors closely connected to the building inside, and the North door is not closely connected to volume 130. As a consequence the amount of aerosolized material leaving the volume 130 toward the filter system is larger than the amount exiting by the North door. All other pathways not shown contribute negligibly to the atmospheric release.

III. CONCLUDING REMARKS

The results given in this paper is time-dependent Leak Path Factor for a fire-induced release of plutonium powder. The approach used in the analysis is simple and it is based on a careful evaluation of the various contributions to the leak path factor for the facility. The use of a time-dependent LPF is a viable methodology to evaluate a time-dependent source term for the subsequent consequence analysis. More realistic estimations of downwind plume concentrations and receptor doses are accomplished through:

- Analysis-supported estimates of the amount of the airborne material that actually leaves the building by taking credit for material that stays inside the building either as the result of natural deposition mechanisms or removal by ventilation filters.

- Analysis-supported estimates of the fraction of the airborne material that leaves through the ventilation system and through a stack so that an elevated release can be modeled for the atmospheric transport and dispersion calculation for this component of the release.
- Analysis-supported estimates of the time-history and duration of the release components so that the proper averaging time can be used for the basis of the dispersion coefficients in order to reasonably account for plume meander effects.

The use of MELCOR offers a robust method to assess the amount of material that can be released because of accidents found in non-reactor nuclear facilities. Using the methodology presented in this paper, the chief benefit that can be found is the possible integration of source term evaluation and its consequence analysis. This work can be used as model for performing analyses for systems similar in nature where releases can propagate to the outside environment via filtered and unfiltered pathways. The methodology provides guidance to analysts outlining the essential steps needed to perform a sound and defensible analysis.

REFERENCES

1. R.O. Gauntt et al., "MELCOR Computer Code Manuals," Version 1.8.5, NUREG/CR-6119 Rev. 2, SAND2000-2417/1, May 2000.

2 DOE, "Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities," DOE-HDBK-3010-94, Change Notice 1, US Department of Energy, Washington DC, 2000

3. American Society of Heating, Refrigerating and Air-Conditioning Engineers, "Handbook of Fundamentals," 1997 Edition.

4. L. M. Polizzi, N. Flouras, "Leak Path Factor Study at Savannah River Site," Safety Analysis Working Group (SAWG) Workshop 2000, Santa Fe, NM, April 28 – May 4, 2000.

5. S. L. Sutter, J. W. Johnson, J. Mishima, "Aerosols Generated by Free Fall Spill of Powders and Solutions in Static Air," NUREG/CR-2139, Battelle Pacific Northwest Laboratory, Richland, WA, December 1981.

6 Transuranic Package Transporter, TRUPACT-1, SARP, SAND 830-7077, Sandia National Laboratories, GA Technologies, San Diego, CA, Nov. 1983.