APPENDIX G
ACCIDENT ANALYSIS

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ACRONYMS

ARF	airborne release fraction
ARR	airborne release rate
ASR	auditable safety record
CEDE	committed effective dose equivalent
Ci	Curie
DAC	derived air concentration
DCF	dose conversion factor
DOE	U.S. Department of Energy
EBA	evaluation basis accident
EG	evaluation guideline
ERPG	Emergency Response Planning Guide
FCP	Fernald Closure Project
HC	hazard category
HEPA	high-efficiency particulate air
MOI	maximally exposed off-site individual
OU	operable unit
pCi	picocurie
PHAR	Preliminary Hazard Analysis Report
RF	Respirable fraction
STD	Standard
TPQ	Threshold planning quantity
UCL	Upper confidence level
WL	Working level
WLM	Working level-month

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EXECUTIVE SUMMARY

The purpose of this accident analysis is to determine if any safety-class structures, systems, and components or technical safety requirements are needed for protection of the public. The analysis quantifies the consequences of potential hazards associated with the activities supporting the Silo 3 project and compares the consequences to U.S. Department of Energy (DOE) Evaluation Guidelines.

Analysis of six accident scenarios produced the radiological dose estimates for collocated workers and off-site populations. The nearest off-site point on the Fernald Environmental Management Project site boundary is approximately 350 m west of the silos. The maximally exposed off-site individual is assumed to be located 350 m downwind of the accident location. The committed effective dose equivalents are estimated in this appendix for individuals located at 30, 100, and 350 m from the point of the release. The values at 350 m are compared to the Evaluation Guidelines (EGs) established by DOE-STD-3009-94, Appendix A.

The conclusion that can be drawn from the analyses is that none of the accident scenarios analyzed yield consequences that would require "safety-class" controls per DOE-STD-3009-94, Appendix A.

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G-1.0 INTRODUCTION

The purpose of this Accident Analysis is to support the final hazard categorization and to determine if any safety-class structures, systems, and components (SSC) or technical safety requirements are needed for protection of the public. Safety-class SSCs will not normally be associated with Hazard Category 2 or 3 facilities due to their limited potential for offsite impact. The analysis quantifies the consequences of potential hazards associated with the retrieval and packaging of the material in Silo 3 including construction and operation of the processing areas and storage of retrieved material. The bounding accidents for the Silo 3 project are fully analyzed and reported in this document for comparison to the DOE-STD-3009-94, Appendix A (Ref. 1) Evaluation Guideline (EG). Safety-class SSCs are required for consequences exceeding an EG of 25 rem total effective dose equivalent to a maximally exposed off-site individual (MOI).

Safety-significant SSCs are those important to defense in depth or onsite worker safety. Although EGs are not used for designating safety-significant SSCs, the onsite impacts are determined in this analysis.

Within this analysis, consequences are determined for:

- Workers at 30 m, which represents the distance for determining the dose threshold criteria of DOE Hazard Category (HC) 3 facilities;
- Workers at 100 m, which represents the distance for determining the dose threshold criteria of DOE HC-2 facilities;
- Public at 350 m, which is the distance to the MOI. This distance corresponds to the nearest site boundary. The MOI distance is used for comparison with off-site EG.

The scope of the analysis is focused on the accidents most likely to be encountered during the construction, operation, and maintenance of the Silo 3 project.

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G-2.0 ACCIDENT ANALYSIS METHODS

This section presents the results and major assumptions for the analysis of six evaluation basis accident (EBA) scenarios associated with the facility. As determined by the hazard category calculations (Ref. 3, Section 3.2), the Silo 3 activities constitute, at most, a "radiological" facility, and accident analyses are not essential. However, these analyses are presented to demonstrate that consequences of accidents would not exceed thresholds. The accident scenarios considered are:

- EBA-1, Hose rupture during pneumatic retrieval
- EBA-2, Silo wall containment failure during cutting an opening in the silo wall
- EBA-3, Spill of material from a conveyor failure
- EBA-4, Breach of full soft-sided package
- EBA-5, Failure of the collectors/filters in the pneumatic retrieval system
- EBA-6, Spill contents of a Cargo Container

The locations of scenarios are described in Section 3.0.

G-2.1 BASIC CALCULATION METHOD FOR SOLIDS RELEASE

The methods used to determine the dose consequence or committed effective dose equivalent (CEDE) for each accident scenario use variations of the following general equation (Ref. 4):

$$CEDE = \Sigma\ (MAR * DCF * DR * BR * ARF \text{ or } ARR * LPF * RF * (\chi/Q) * T)_i$$

where:

MAR	=	amount of a radionuclide available to be acted upon by a physical stress (pCi)
DCF	=	dose conversion factor in mrem/pCi
DR	=	damage ratio or the fraction of the MAR actually impacted by accident conditions
BR	=	breathing rate of a reference person considered 3.33×10^{-4} m^3/sec
ARF	=	airborne release fraction
ARR	=	airborne release rate
LPF	=	leak path factor or the fraction of material transported through some confinement
RF	=	respirable fraction
χ/Q	=	long-term dispersion factor in sec/m^3
T	=	exposure time in hours
i	=	each radionuclide

The dispersion factor (χ/Q) for a straight line, ground level release, is determined from a Gaussian plume model for continuous point source emission from the *Handbook of Health Physics and Radiological Health* (Ref. 5). A wind speed of 1.0 m/second and D stability

class was used at a distance of 30 m, which is consistent with the recommendations of DOE-STD-1027-92 (Ref. 6), for HC 3 criteria. A wind speed of 4.5 m/second and D stability class was used at 100 m, which is consistent with the recommendations of DOE-STD-1027-92 for HC-2 calculations. A wind speed of 1.0 m/second and F stability class was used at 330 m, which is consistent with the requirements of DOE G 151.1-1, DOE Emergency Management Guide, *Hazard Surveys and Hazard Assessments*.

For a continuous release, the receptor is assumed to be exposed for 24 hrs at 30 m and 2 hrs at 100 m and 330 m. For an instantaneous release, the material is assumed to be completely released within 1 hour. The receptor is exposed during this hour to the instantaneous release, and for the entire exposure period to resuspended solids that are emitted continuously.

In some accident scenarios, contaminants are released to the environment from a 125-ft stack that will be built as part of the Silo 3 project. To estimate the upper bound of the effect of such releases, a "fumigation" model is adopted from the *Handbook of Health Physics and Radiological Health*. Under this model, releases from the stack are constrained to mix under an inversion layer with a "lid" assumed at a height of 100 m. The model specifies a stability class G and wind speed of 1 mph (0.5 m/second) to reflect an extreme nighttime inversion.

For evaluation of chemical consequences, the hazard category calculations (Ref. 3, Section 3.3) have indicated that only five hazardous chemicals exceeded the 40 CFR 355 threshold planning quantities. These include arsenic, cadmium, mercury, thallium, and vanadium. Therefore, for EBAs in which solids are assumed dispersed, the concentration of each of these contaminants at the receptor is determined for comparison with evaluation guidelines by the following equation:

$$C\ (mg/m^3) = MAR * ARF * RF * DR * LPF * (\chi/Q)/\text{time of release}$$

G-2.2 BASIC CALCULATION METHOD FOR RADON RELEASE

Fluor Fernald, Inc., developed a predictive tool, *The Fernald Radon Model,* to estimate radon air concentrations at different site locations for various release scenarios. The model, which reasonably fits existing site monitoring data, is described in the *Radon Modeling Report for the OU4 Safety Analysis Plan* (Ref. 8). The model predicts the radon concentrations downwind from a release and allows inclusion of a "lag" term. The "lag" model is more complex, and provides a more accurate depiction of radon transport when compared to existing monitoring data. This is because the model accounts for the persistence of radon in the vicinity closest to the release point. The nonlag model is used for the accident analyses. The model, embodied in Equation 16 of Reference 8, is based on F Class meteorological stability. A wind speed of 1.8 m/second is used in the accident analysis, since this speed is a basic assumption of the model and is based on the F Class stability. Once the radon air concentrations are determined at different receptor locations, the dose consequence can be determined.

The concentrations of radon progeny are calculated in working levels (WLs) in the manner specified by Evans (Ref. 9). Exposures to these radionuclides are expressed in working level months (WLMs), that is, the time integrated concentration at the point of interest.

In several accident scenarios, the radiological source term released is initially pure ^{222}Rn, which by itself is not a great hazard. However, the radon quickly produces a chain of radionuclides, each the progeny of the previous parent. The conservative data provided by Fluor Fernald in Figure 8 of *An Evaluation of the Need for Personnel Radon Monitoring at the FEMP* (Ref. 10) shows that in a matter of a few hours, 100 pCi/L of ^{222}Rn will produce approximately one WL.

For the purpose of comparison with thresholds and limits, the dose equivalence of working levels must be determined. As shown in 10 *Code of Federal Regulations* (CFR) 835 (Ref. 11), the Derived Air Concentration (DAC) for Rn-222 is 30 pCi/L, corresponding to 5 rem in one year, which is equivalent to 2.5 mrem in one hour. Therefore, an individual exposed to 100 pCi/L Rn-222 (or 1 WL) for one hour would receive a dose of 7.5 mrem, assuming 100 percent progeny equilibrium.

G-2.3 COMMON ASSUMPTIONS

The accident scenarios were analyzed using several common assumptions:

- The Silo 3 material is assumed to contain 3,870 pCi/g of ^{226}Ra and its progeny are in complete equilibrium unless otherwise noted in the scenario.
- The Silo 3 material bulk density ranges from 29 to 58 lb/ft^3. The average bulk density is 42.4 lb/ft^3 (0.68 g/cm^3). A bulk density of 50 lb/ft^3 was used in the analyses, conservatively bounding the average. This ensures that an operational condition does not occur in which the safety basis may be inadequate, or results in a "potential inadequacy of the safety analysis".
- All Silo 3 material is in powder form. The airborne release fraction (ARF) and respirable fraction (RF) of the solid powder material is obtained from DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (Ref. 5). The inputs are summarized in Table G.2-1. The bounding ARF for a free-fall spill of uncontained powders, page 4-77 of Ref. 5, is 2×10^{-3}. An RF of 0.3 was used for free fall spill of powders. These values were obtained from experiments performed using up to 1,000 g. TiO_2, material density 4.2 g/cm^3, from a spill height of 3 m. Recalculation of EBAs where free-fall spills were modeled was performed with more conservative bounding values, as discussed in Section 3.0.
- The ARF for powders impacted by a falling object is 1×10^{-3} and the RF is 0.1. DOE-HDBK-3010-94, page 4-85, provides a basis for choosing an ARF and RF from impacts due to large falling objects and induced air turbulence. Tests were performed on a variety of materials to simulate the release of powders. All the tested materials were free-flowing (non-cohesive) powders, the most dispersible of which was Al_2O_3, with an ARF of 1×10^{-3}. The nature of this release scenario is to provide some confinement of its inner volume. DOE-HDBK-3010-94 also considers other material configurations in which some material protection is available. Additional tests were performed by

dropping heavy objects on cans of powder. The highest RF value from the contained set was 0.07. DOE-HDBK-3010-94 concludes that, in cases where some material protection is afforded, the appropriate bounding ARF*RF is the highest ARF from the uncontained data set (1×10^{-3} for uncontained Al_2O_3) used in conjunction with the largest RF from the contained experiments (rounded to 0.1). As a result, an ARF of 1×10^{-3} with a RF of 0.1 was assessed to be appropriate for this release scenario.

- The airborne release rate (ARR) due to aerodynamic resuspension of spilled powders due to ambient wind stresses is detailed on page 4-96 of Ref. 5. The ARR is assumed to be 4×10^{-5}/hr and the RF is 1.0.
- The summation of CEDEs for each radionuclide results in a CEDE for Silo 3 material of 19.8 rem/g inhaled (without radon and daughters). This is shown in Table G.2-2. The DCFs were obtained from Federal Guidance Report No. 11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion* (Ref. 13), which is based on ICRP 30. The selected lung clearance class was based on the presence of oxides. The Ra226 DCF, lung clearance class Y, is obtained from CAP88-PC Version 2.1, which was determined using the RADRISK code. Short-lived radionuclides are not included because of the negligible dose contribution.

Radon will continue to emanate from silo material that is involved in spills or is open to the environment. The radon emanation rate from a solid material is 35 percent of the generation rate, based on experimental studies presented in References 17 and 18. The measured values for emanation fraction are derived or measured from mill tailings, which are similar to Silo 1 and 2 material in terms of composition, particle size, density, and porosity. However, Silo 3 contains calcined material that has a significantly different porosity, density, and particle size distribution. Since an experimentally determined emanation rate does not exist for Silo 3 material, 35 percent was used. The 35 percent emanation rate is the best experimentally based value available, although it may not be conservative.

Table G.2-1. Dispersion Analysis Inputs

Release Mode or Type	Distance (m)	Application	Wind Speed (m/sec)	Stability Class	ARF	RF
Gaussian Ground Level Solids Release	30	HC-3	1.0	D	2E-3	0.3
	100	HC-2	4.5	D		
	350	MOI	1.0	F		
Gaussian Stack Solids Release	30	HC-3	1.0	D	2E-3	0.3
	100	HC-2	4.5	D		
	350	MOI	1.0	F		
Radon Release	30	HC-3	1.8	F	1	1
	100	HC-2				
	350	MOI				

Notes:
1. An ARF of 1×10^{-3} and an RF of 0.1 is used for EBA-2.
2. An ARR of 4×10^{-5}/hr and an RF of 1.0 is used for resuspension during EBA-6.

Table G.2-2. Silo 3 Material Dose Conversion

Nuclides	95% UCL Specific Activity [a] (pCi/g)	Fed Guide 11 Inhalation DCF [b] (mrem/pCi)	Silo 3 CEDE without radon (mrem/g)
Actinium-227	**925**	1.29E+00	1,194
Actinium-228	406	1.25E-04	<0.1
Bismuth-210	3,480	1.96E-04	1
Bismuth-212	367	1.91E-05	<0.1
Bismuth-214	3,870	6.22E-06	<0.1
Francium-223	13	6.22E-06	<0.1
Protactinium-231	**627**	8.58E-01	538
Protactinium-234	2	8.14E-07	<0.1
Protactinium-234m	1,778	8.14E-07	<0.1
Lead-210	**3,480**	1.36E-02	47
Lead-211	925	8.70E-06	<0.1
Lead-212	367	1.69E-04	<0.1
Lead-214	3,870	7.81E-06	<0.1
Polonium-210	3,480	8.58E-03	30
Radium-223	925	7.84E-03	7
Radium-224	**367**	3.16E-03	1
Radium-226	**3,870**	1.4E-01	542
Radium-228	**406**	4.77E-03	2
Thorium-227	925	1.62E-02	15
Thorium-228	**747**	3.42E-01	255
Thorium-230	**60,200**	2.62E-01	15,748
Thorium-231	117	8.77E-07	<0.1
Thorium-232	**842**	1.15E+00	969
Thorium-234	1,780	3.50E-05	<0.1
Uranium-234	**1,730**	1.32E-01	229
Uranium-235/236	**117**	1.23E-01	14
Uranium-238	**1,780**	1.18E-01	211
TOTAL			**19,805**

a. Actual measured values are in bold type.
b. Reference 13 for all values except Ra226. The Ra226 DCF is from CAP88-PC, Version 2.1, class Y.

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G-3.0 ACCIDENT ANALYSES

The accidents analyzed include (1) hose rupture during pneumatic transfer, (2) silo wall containment failure while cutting an opening, (3) spill of material due to conveyor failure, (4) breach of a full soft-sided package, (5) failure of the collectors in the pneumatic retrieval system, and (6) spill contents of a cargo container. These accident scenarios and analysis results are described in the following sections.

Safety analysis presented here relies on DOE-HDBK-3010-94 for established values for airborne release fractions (ARF) for free-fall spills and respirable fractions (RF). The dose consequences presented in this Appendix were derived applying the factors presented in DOE-HDBK-3010-94 for solid powders. The factors presented in this reference guide were developed in part on empirical testing of the properties of the oxides of the elements aluminum, silicon, titanium and uranium. The materials present in Silo 3, largely oxides or sulfates of magnesium, iron, sodium, calcium and aluminum, were byproducts of the extraction of uranium from milled ores and ore concentrates. Following extraction, the residues were subsequently calcined in the presence of lime and pneumatically conveyed into the silo. As a result of the waste generating process, concern was expressed by some internal reviewers that the application of the factors recommended in DOE-HDBK-3010-94 may not be appropriately representative of the characteristics of the waste. The most significant difference is the unusually low bulk density of the Silo 3 waste, e.g., about half the bulk density of sand. At this lower bulk density it is possible that a larger airborne release fraction could occur as the result of an accident than indicated in the experiments reported in the HDBK.

To ensure that the dose consequences derived through the hazard calculations for the selected accident scenarios were appropriately representative of the waste materials involved and present reasonable bounding values, the total dose was calculated twice. First, by applying the experimentally determined factors reported in DOE-HBDK-3010-94, and then separately by utilizing the bounding values given in the HDBK. The bounding values used were an airborne release fraction of 0.01 for free-fall spills of powder, and a respirable fraction of 0.36. The results of these analyses are a simple linear increase by a factor of 6 (2E-3x0.3 versus 0.01x0.36); however, the increase was not significant enough to result in any change to the Hazard Categorization conclusions. These results are presented in each affected EBA Table (EBA 1, 3, 4, 5 and 6) under "Solids Results", along with those derived utilizing the factors presented in DOE-HBDK-3010-94. For EBA 2 the results of using a bounding RF of 0.36 (ARF was not questioned) is presented in Table G.3.2 along with those derived utilizing the factors presented in DOE-HBDK-3010-94.

G-3.1 EBA-1, HOSE RUPTURE DURING PNEUMATIC RETRIEVAL

In this accident scenario, the Pneumatic Retrieval System has been in use for two hours when the hose carrying Silo 3 material to the Pneumatic Retrieval Collector, DCL-10-5002, breaks at a location inside the fabric structure. A conservative assumption is used that the fabric structure is open to the environment. When the line breaks, the motive force for material removal is stopped. However, all the material in the line between the vacuum

wand and the pneumatic retrieval collector is assumed to be released to the atmosphere inside the fabric structure. All solids and radon present are assumed to be released to the environment.

The vacuum line is 150-ft long by 6 in. in diameter. With an airflow of 1,200 cfm and a solids removal rate of 10 yd^3 per hour, and based on a bulk density of 50 lb/ft^3, the air will have a density of 0.188 lb/ft^3:

50 lb/ft^3 x 10 yd^3/hr x min/1200 ft^3 x 27ft3/yd3 x hr/60min = 0.188 lb/ft^3

Therefore, 5.56 lb will be released from the 150-ft length.

The initial radon release is conservatively assumed as 0.0475 Ci, which is the headspace inventory based on 300,000 pCi/L and a headspace volume of 5,600 ft^3. In addition to the initial radon release, radon will be released from the remaining silo material at a rate of 6.26 x 10^6 pCi/minute over the next 24 hours. The emission rate is based on the headspace inventory, where emission rate equals decay rate. The decay rate is 0.0475 Ci x 0.693/5500 min.

The solids dispersion is modeled using the Gaussian plume model for ground-level releases. The radon dispersion is modeled using the Fernald radon model (Ref. 8). The receptors are assumed to be within the airborne solids plume for 1 hour. The receptors are assumed to be in the initial radon release plume for 1 hour and in the residual flux radon plume for 24 hours. Table G.3-1 summarizes the scenario results; the spreadsheets are provided in Attachment 1.

Table G.3-1. Hose Rupture during Transfer Scenario Results

Receptor Distance	Solids Results			Radon Results for Initial Release		Radon Results for Flux		Total[1] CEDE (mrem)	Total[2] CEDE (mrem)
	X/Q	Dose[1] (mrem)	Dose[2] (mrem)	Conc. (pCi/L)	Dose (mrem)	Conc. (pCi/L)	Dose (mrem)		
30 m (HC-3)	1.77E-2	0.176	1.06	291	24	2.1	4	28	29
100 m (HC-2)	1.05E-3	0.01	0.06	60	5	0.4	0.07	5	5
350 m (MOI)	9.0E-4	0.009	0.054	12	1	0.1	0.01	1	1

1 Based on ARF of 2E-3, RF of 0.3 from HDBK 3010. See Section 3.0 for explanation.
2 Based on ARF of 0.01, RF of 0.36, bounding. See Section 3.0 for explanation.

G-3.2 EBA-2, SILO WALL CONTAINMENT FAILURE

In this accident scenario, the Pneumatic Retrieval System has been used to remove enough Silo 3 material to allow removal of a portion of the silo wall. The wall section removal allows the use of a mechanical excavator. A calculation performed by Parsons determined that during a seismic event, the higher stressed lower portion of the walls would crack at approximately 5 to 10 ft above floor level (Ref. 14). Continued seismic shaking would propagate the crack sufficiently for the dome to fall downward, allowing some solid material to spill out from the full silo. For this accident scenario, either during

the cutting operation or during excavation, an unanticipated relief of stress in the silo wall occurs adjacent to the concrete cut, a crack propagates, and the dome collapses inward impacting the remaining material.

The solids release from this accident is estimated in a similar manner to the previously analyzed seismic event. It was determined that under the unmitigated release conditions from a catastrophic silo structural failure, approximately 5.5 percent of the total silo inventory would be released (Ref. 3). For this accident scenario, the material has been removed in the vicinity of the wall cut before performing the wall cut operation; therefore, the silo material volume is less for this accident. It is assumed that 25 percent of the original silo material volume has been removed before the collapse. The configuration of the remaining silo material is such that the angle of repose from the floor area at the wall opening to the high solids level at the center of the silo is less than 45 degrees. Material release at the time of collapse would result from material falling toward the wall opening. The Silo 3 solid metal oxides will not slough more than 45 degrees, as documented in WSRC-TR-2000-0053, *Characterization of Fernald Silo 3 Wastes* (Ref. 15). Therefore, the material spilling out of the collapsed region would be minimal and it is conservatively assumed that 1 percent of the silo material volume, at the time of collapse, spills outside the silo and into either the excavator area or fabric structure, depending upon the nature of the failure.

The solids release is 5,100 yd^3 x 0.75 x 0.01, which equals 38.3 yd^3 (1,033 ft^3). The initial radon release is conservatively assumed as 0.0356 Ci, which assumes that no silo ventilation was in operation. In addition to the initial radon release, radon would be released from the remaining silo material at a rate of 4.7×10^6 pCi/minute over the next 24 hours. These values are 75% of the values obtained with the original material volume.

The solids dispersion is modeled using the Gaussian plume model for ground-level releases. The radon dispersion is modeled with the Fernald radon model. Table G.3-2 summarizes the scenario results; the spreadsheets are provided in Attachment 2.

Table G.3-2. Silo Wall Failure Scenario Results

Receptor Distance	Solids Results			Radon Results for Initial Release		Radon Results for Flux		Total[1] CEDE (mrem)	Total[2] CEDE (mrem)
	X/Q	Dose[1] (mrem)	Dose[2] (mrem)	Conc. (pCi/L)	Dose (mrem)	Conc. (pCi/L)	Dose (mrem)		
30 m (HC-3)	1.77E-2	273	983	217	18	1.6	3	294	1004
100 m (HC-2)	1.05E-3	16	58	45	4	0.4	0.1	20	62
350 m (MOI)	9.0E-4	14	50	9	1	0.1	<0.1	15	51

Chemicals	Concentration				ERPG-1 (mg/m³)	ERPG-2 (mg/m³)	ERPG-3 (mg/m³)
	On-site [1] (mg/m³)	On-site [2] (mg/m³)	Off-site [1] (mg/m³)	Off-site [2] (mg/m³)			
Arsenic trioxide	6.62E-02	2.38E-01	6.56E-03	2.36E-02	0.03	1.4	5
Cadmium oxide	2.31E-03	8.32E-03	2.29E-04	8.24E-04	0.03	0.05	12.5
Mercuric oxide	1.11E-02	4.00E-02	1.10E-03	3.96E-03	0.025	0.1	10
Thallium sulfate	1.42E-03	5.11E-03	1.40E-04	5.04E-03	0.3	2	15
Vanadium pentoxide	1.16E-01	4.18E-01	1.15E-02	4.14E-02	0.15	0.5	35

1 Based on ARF of 1E-3, RF of 0.1 from HDBK 3010. See Section 3.0 for explanation.
2 Based on RF of 0.36, bounding. See Section 3.0 for explanation.

Of the chemical constituents in the waste, five exceed the threshold planning quantity (TPQ) values in 40 CFR 355 (Ref. 16). After further evaluation of these five compounds, none exceed the criteria for a "low" chemical hazard classification based on Emergency Response Planning Guide (ERPG) values. The criteria for "low" chemical hazard on-site is less than ERPG-3 and off-site is less than ERPG-2.

G-3.3 EBA-3, SPILL OF MATERIAL FROM CONVEYOR FAILURE

In this accident scenario, there is a total break in conveyor containment while removing material with the excavator at the intersection of the inclined conveyor and the transfer conveyor. The conveyed material is released directly into the interior of the process building packaging area for 15 minutes before action is taken to stop the conveyor. The transfer rate for the conveyor is 10 yd^3 per hour; therefore, 2.5 yd^3 or 3,375 lb of material is released. The solids that become airborne are released to the ventilation system. It is conservatively assumed that the filter system fails to remove the material and all materials are passed through the ventilation system and released from the 125-ft stack.

Radon present in the spilled material void spaces and radon generated over the next 24 hours is released to the ventilation system. The 2.5 yd^3 spilled material contains 0.0059 Ci Ra^{226}. Assuming 35 percent of the radon generated emanates to the void spaces, the

spill will result in a release of 2.07 x 10^{-3} Ci instantaneously. The radon emanation from the remaining solids will be 260,000 pCi/min over the next 24 hours.

The solids dispersion is modeled using the Gaussian plume model for stack releases, with stability class G and wind speed of 0.5 m/second. The radon release is significantly lower than that released in EBA-1; therefore, the radon dose is negligible. Table G.3-3 summarizes the scenario results; the spreadsheets are provided in Attachment 3.

Table G.3-3. Spill of Material from Conveyor Scenario Results

Receptor Distance	Solids Result			Total [1] CEDE (mrem)	Total [2] CEDE (mrem)
	X/Q	Dose [1] (mrem)	Dose [2] (mrem)		
30 m (HC-3)	2.75E-2	167	1002	167	1002
100 m (HC-2)	7.8E-3	47.4	284	47	284
350 m (MOI)	2.24E-3	13.6	81.6	14	82

1 Based on ARF of 2E-3, RF of 0.3 from HDBK 3010. See Section 3.0 for explanation.
2 Based on ARF of 0.01, RF of 0.36, bounding. See Section 3.0 for explanation.

G-3.4 EBA-4, BREACH OF FULL PACKAGE

In this accident scenario, a bridge crane is assumed to be transferring a full soft-sided package between the off-loading conveyor and the cargo container. The package is caught on the edge of the cargo container and is ripped open. The material in the soft-sided container spills out and lands in a pile on the floor.

The cargo container bay is effectively open to the environment so that what little radon is present and the airborne solids leak from the room. It is assumed that the package volume spilled to the ground is 96 ft^3, having a bulk density of 56.3 lb/ft^3 for the treated material, for a total spill of 5,405 lb. Assuming untreated material has a density of 50 lb/ft^3, the silo 3 material comprises 89 percent of the total treated material mass. Therefore, the mass of silo 3 material released is 4810 lb (2.18 x 10^6 g).

Radon present in the spilled material void spaces and radon generated over the next 24 hours is released to the ventilation system. The 96 ft^3 of spilled material contains 0.0084 Ci Ra^{226}. Assuming 35 percent of the radon generated emanates to the void spaces, the spill will result in a release of 2.94 x10^{-3} Ci instantaneously. The radon emanation from the remaining solids will be 370,400 pCi/min over the next 24 hours.

The solids dispersion is modeled using the Gaussian plume model for ground-level releases. The radon release is significantly lower than that released in EBA-1; therefore, the radon dose is negligible. Table G.3-4 summarizes the results; the spreadsheets are provided in Attachment 4.

Table G.3-4. Breach a Waste Package

Receptor Distance	Solids Result			Total [1] CEDE (mrem)	Total [2] CEDE (mrem)
	X/Q	Dose [1] (mrem)	Dose [2] (mrem)		
30 m (HC-3)	1.77E-2	152	912	152	912
100 m (HC-2)	1.05E-3	9.1	54.6	9	55
350 m (MOI)	9.0E-4	7.8	46.8	8	47

1 Based on ARF of 2E-3, RF of 0.3 from HDBK 3010. See Section 3.0 for explanation.
2 Based on ARF of 0.01, RF of 0.36, bounding. See Section 3.0 for explanation.

G-3.5 EBA-5, FAILURE OF COLLECTORS IN PNEUMATIC RETRIEVAL SYSTEM

Ordinarily, the material collected by the Pneumatic Retrieval System is removed from the airstream using several unit operations in series. First is the Pneumatic Retrieval Collector consisting of a bag-house. The collector is followed by a cartridge filter and a filter housing, which contains a high-efficiency particulate air (HEPA) filter, two graded prefilters, and an ultra-low-penetrating air filter.

During extraction, an abrupt pressure change causes a blowout of the downstream filters and disables the Pneumatic Retrieval Collector. The extracted material flows directly to the stack and is emitted to the atmosphere. The material and associated radon are released at the design flow-rate of 1,200 ft^3/minute of air containing 0.188 lb solids/ft^3.

50 lb/ft^3 x 10 yd^3/hr x min/1200 ft^3 x 27ft3/yd3 x hr/60min = 0.188 lb/ft^3

The accident is unmitigated for 15 minutes, resulting in a release of 3,384 lbs of solids.

The initial radon release is conservatively assumed as 0.0475 Ci, which is the headspace inventory based on 300,000 pCi/L and a volume of 5,600 ft^3. In addition to the initial radon release, radon will be released from the remaining silo material at a rate of 6.26 x 10^6 pCi/minute over the next 15 minutes. The total radon release is 0.048 Ci.

The solids dispersion is modeled using the Gaussian plume model for stack releases, with stability class G and wind speed of 0.5 m/second. The radon dispersion is modeled with the Fernald radon model. Table G.3-5 summarizes the scenario results; the spreadsheets are provided in Attachment 5.

Table G.3-5. Failure of Collectors Results

Receptor Distance	Solids Results			Radon Results for Initial Release		Total [1] CEDE (mrem)	Total [2] CEDE (mrem)
	X/Q	Dose [1] (mrem)	Dose [2] (mrem)	Concentration (pCi/L)	Dose (mrem)		
30 m (HC-3)	2.75E-2	167	1002	294	24	191	1026
100 m (HC-2)	7.8E-3	47.5	285	61	5	53	290
350 m (MOI)	2.24E-3	13.6	81.6	12	1	15	83

1 Based on ARF of 2E-3, RF of 0.3 from HDBK 3010. See Section 3.0 for explanation.
2 Based on ARF of 0.01, RF of 0.36, bounding. See Section 3.0 for explanation.

G-3.6 EBA-6, SPILL OF CONTENTS FROM A CARGO CONTAINER

Bags are transferred from the Container Management and Packaging System into cargo containers with lids, via the following steps:

1. Move the cargo container into place using a forklift.
2. Remove/open the top of the cargo container using the bridge crane.
3. Use the Bridge Crane and lifting frame to pick up the bags by their straps, transport them to the cargo container, and set them in place. Up to 8 bags can physically be placed in each container.
4. Once a cargo container is loaded with bags, replace/close the top of the cargo container using the Bridge Crane. Use a heavy-duty forklift to transport the cargo container to a staging area, where either a crane or forklift places the cargo containers on a rail car or a truck for transport.

During transport with the forklift outside the building, the cargo container tips over, the container opens, every bag falls out and opens, exposing the contents to atmosphere. The 8 bags, at 96 ft^3 each, have a bulk density of 56.3 lbs/ft^3 for the treated material. Assuming untreated material has a density of 50 lbs/ft^3, the total volume of 768 ft^3 has a total Silo 3 material mass of 38,400 lbs. The fraction of bags that open (damage ratio) is assumed as 100%. The fraction of material that leaks from the packages (leakpath factor) is assumed as 50%. The ARF for the spill of material is 2×10^{-3}. The ARR due to resuspension of powder due to wind stress is 4×10^{-5}.

Radon present in the spilled material void spaces and radon generated over the next 24 hours is released to the atmosphere. The 768 ft^3 of spilled material contains 0.0674 Ci Ra^{226}. Assuming 35 percent of the radon generated emanates to the void spaces, the spill will result in a release of 0.024 Ci instantaneously. The radon emanation from the remaining solids will be 2.97×10^6 pCi/min over the next 24 hours.

The solids dispersion is modeled using the Gaussian plume model for ground-level releases. The radon dispersion is modeled with the Fernald radon model. Table G.3-6 summarizes the scenario results; the spreadsheets are provided in Attachment 6.

Table G.3-6. Spill of Cargo Container Results

Receptor Distance	Solids Results				Radon Results		Total [1] CEDE (mrem)	Total [2] CEDE (mrem)
	X/Q	Initial Release Dose [1] (mrem)	Initial Release Dose [2] (mrem)	Re-suspension Dose (mrem)	Initial Release (mrem)	Flux Release (mrem)		
30 m (HC-3)	1.77E-2	610	3660	975	12	2	1600	4649
100 m (HC-2)	1.05E-3	36.4	218	5	3	<0.1	44	224
350 m (MOI)	9.00E-4	31	186	4	0.5	<0.1	36	191

1 Based on ARF of 2E-3, RF of 0.3 from HDBK 3010. See Section 3.0 for explanation.
2 Based on ARF of 0.01, RF of 0.36, bounding. See Section 3.0 for explanation.

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G-4.0 CONCLUSIONS

Analysis of five accident scenarios produced the radiological dose estimates for workers, co-located workers, and off-site populations that are presented in Tables G.4-1 and G.4-2. Workers are defined as any personnel performing work on the Silo 3 project within the boundaries of the facility (30 m receptor). Co-located workers are defined as other workers located within the boundaries of the FCP site, but not performing work on the Silos 3 project (100 m receptor). The off-site population is defined as all non-workers who reside or are otherwise located outside the FCP site boundaries. The nearest off-site point for the MOI is approximately 350 m west of the silos. Table G.4-1 provides calculated internal dose estimates for individuals located at 30, 100, and 350 m from the point of the release. The offsite dose estimate is compared to the 25 rem EG established by DOE-STD-3009-94.

Tables G.4-1 and G.4-2 provide calculated internal dose estimates for individuals located at 30, 100, and 350 m from the point of the release. The offsite dose estimate is compared to the 25 rem EG established by DOE-STD-3009-94. Table G.4.1 presents the dose estimates using ARF and RF values from DOE-STD-3010-94, and Table G.4-2 presents the dose estimates using the more bounding ARF and RF values. As expected, the bounding ARF and RF factors resulted in higher dose consequences; however both sets of dose estimates support the conclusion that the final hazard categorization of Radiological is appropriate, and no safety-class structures, systems, and components (SSC) or technical safety requirements are needed, since the off-site EGs are not challenged.

Of the chemicals present, five exceed the TPQ values in 40 CFR 355. Further evaluation of these five compounds determined that none exceed the on-site and off-site criteria for a "low" chemical hazard classification based on ERPG values.

Table G.4-1. Dose for Comparison to Dose to Emergency Guideline

EVENT	Radiological Dose CEDE @ various distances (mrem)		
	30 m	100 m	350 m*
EBA-1	28	5	1
EBA-2	294	20	15
EBA-3	167	47	14
EBA-4	152	9	8
EBA-5	191	53	15
EBA-6	1600	44	36

* Nearest off-site location is 350 m, which is the MOI. DOE-STD-3009-94 Public EG is 25 rem.

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Table G.4-2. Dose for Comparison to Emergency Guideline Using Conservative Assumptions

EVENT	Radiological Dose CEDE @ various distances (mrem)		
	30 m[a]	100 m[a]	350 m[b]
EBA-1	29	5	1
EBA-2	1004	62	51
EBA-3	1002	284	82
EBA-4	912	55	47
EBA-5	1026	290	83
EBA-6	4649	224	191

[a] ARF = 0.01 and RF = 0.36 for free fall spill of powders
[b] Nearest off-site location is 350 m, which is the MOI. DOE-STD-3009-94 Public EG is 25 rem.

The conclusion that can be drawn from the analyses is that none of the accident scenarios analyzed yield consequences that would require "safety-class" controls as DOE-STD-3009-94, since the off-site EGs are not challenged.

G-5.0 REFERENCES

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5. Shleien, B., L. Slayback, Jr., and B. Birky, 1998, *Handbook of Health Physics and Radiological Health*, Third Edition, Williams & Wilkins, Baltimore, MD, 1998.
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17. C. Yu, J.J. Cheng, et al., *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil,* Argonne National Laboratory, ANL/EAIS-8, April 1983.

18. Rogers, V.C., et al., *Radon Attenuation Handbook for Uranium Mill Tailings Cover Design*, prepared for the U.S. Nuclear Regulatory Commission, Washington D.C., NUREG/CR-3533, PNL-4878, April 1984.

ATTACHMENT 1
EBA-1 SPREADSHEETS

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Accident Dose Calculations for Silo 3 Project - Solids Ground Release

References:

Dose conversion factors for inhalation are from Table 2.1, EPA-520/1-88-020 (Federal Guidance Report 11).
The DCF lung clearance class was selected for oxides.
The values for ARF and RF from DOE-HDBK-3010
Atmospheric stability D: Ref. DOE-STD-1027-92, Attachment 1, pages A-6 and A-7, for hazard categorization.

Dose Methodology:

DOSE = Q * X/Q * BR * DCF * t

where:

BR =	3.33E-04 m^3/s	Breathing Rate (a constant)
DCF =	rem/Ci	Dose Conversion Factor (varies)
t =	exposure time	
Q =	Airborne Source Term	

Q = MAR * DR * LPF * ARF * RF

where:

MAR =	material at risk of release	
DR =	1	damage ratio
LPF =	1	leak path factor
ARF*RF=		airborne release fraction x respirable fraction

X/Q Methodology:

A Gaussian dispersion model is used to determine the dispersion loss between the release and receptor.
The methodology allows a comparison of the effects of plume meander and wake effects. (Ref. NRC Reg Guide 1.145)

Equation 1 X/Q = 1/(U *(pi * sig-y * sig-z +(A/2)))
Equation 2 X/Q = 1/(U * (3 * pi * sig-y * sig-z))
Equation 3 X/Q = 1/(U * pi * E-y * sig-z)

The higher value from equation 1 and 2 is selected. This value is compared with the value from equation 3 and the lower value is selected as the appropriate X/Q value.

A =		cross-sectional area of structure, m^2	
d =		downwind distance to evaluation point, m	User Input
		Atmospheric stability class (D, E, F, G)	
sig-y =		lateral plume spread, m	Constant
sig-z =		vertical plume spread, m	
E-y =		lateral plume spread with wake effects, m	Calculated
U =		10 meter above grade wind speed, m/sec	

Dispersion Calculations:

A =	100	m^2
pi =	3.14159	
d =	30	m
	D	
sig-y =	3.67	m
sig-z =	1.63	m
E-y =	7.35	m
U =	1	m/s

X/Q	sec/m^3
(Eqn.1) =	1.45E-02
(Eqn.2) =	1.77E-02
(Eqn.3) =	2.65E-02
Selected EQN =	Eqn.2
X/Q =	1.77E-02

A =	100
pi =	3.14159
d =	100
	D
sig-y =	10.34
sig-z =	4.95
E-y =	12.39
U =	4.5

X/Q	sec/m^3
(Eqn.1) =	1.05E-03
(Eqn.2) =	4.61E-04
(Eqn.3) =	1.15E-03
Selected EQN =	Eqn.1
X/Q =	1.05E-03

A =	100
pi =	3.14159
d =	350
	F
sig-y =	14.04
sig-z =	6.30
E-y =	56.18
U =	1

X/Q	sec/m^3
(Eqn.1) =	3.05E-03
(Eqn.2) =	1.20E-03
(Eqn.3) =	9.00E-04
Selected EQN =	Eqn.3
X/Q =	9.00E-04

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Accident Dose Calculations for Solids Release

Dose Calculation:

EBA-1 Solids Release

Solids Activity (pCi/cc) equals solids activity (pCi/g) x solids density
Source Term (MAR) equals solids activity (pCi/cc) x solids volume
Airborne Source Term (Q) equals the MAR x ARF x RF x DR x LPF
The DCF is listed for each isotope.
DOSE = Q * X/Q * BR * DCF * t

Dry Solid Density 0.8 g/cm^3
wt % solids 100 g solid/g slurry
Solid Density = 0.188 lb/ft^3
Release Volume = 0.8 m^3
29.5 cf

50 lb/ft3 x 10 yd3/hr x min/1200 ft3 x 27ft3/yd3 x hr/60min = 0.188 lb/ft3

ARF =	2.00E-03	
RF =	0.3	
DR =	1.0	
LPF =	1.0	
BR =	3.33E-04	m^3/s

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
30	D	1	1.77E-02	1
100	D	4.5	1.05E-03	1
350	F	1	9.00E-04	1

Radionuclide	Solids activity pCi/g	Solids activity pCi/cc	Source Term (MAR) pCi	Airborne Source Term (Q) pCi/s	DCF (mrem/pCi)	Dose @ 30 (mrem)	Dose @ 100 (mrem)	Dose @ 350 (mrem)
Ac-227	925	2.79E+00	2.33E+06	3.88E-01	1.29E+00	1.06E-02	6.33E-04	5.40E-04
Ac-228	406	1.22E+00	1.02E+06	1.70E-01	1.25E-04	4.51E-07	2.69E-08	2.30E-08
Bi-210	3,480	1.05E+01	8.76E+06	1.46E+00	1.96E-04	6.06E-06	3.62E-07	3.09E-07
Fr-223	13	3.92E-02	3.27E+04	5.46E-03	6.22E-06	7.19E-10	4.29E-11	3.66E-11
Pa-231	627	1.89E+00	1.58E+06	2.63E-01	8.58E-01	4.78E-03	2.85E-04	2.43E-04
Pa-234	2	6.03E-03	5.04E+03	8.39E-04	8.14E-07	1.45E-11	8.63E-13	7.37E-13
Pb-210	3,480	1.05E+01	8.76E+06	1.46E+00	1.36E-02	4.21E-04	2.51E-05	2.14E-05
Po-210	3,480	1.05E+01	8.76E+06	1.46E+00	8.58E-03	2.65E-04	1.58E-05	1.35E-05
Ra-223	925	2.79E+00	2.33E+06	3.88E-01	7.84E-03	6.45E-05	3.85E-06	3.28E-06
Ra-224	367	1.11E+00	9.24E+05	1.54E-01	3.16E-03	1.03E-05	6.15E-07	5.25E-07
Ra-226	3,870	1.17E+01	9.74E+06	1.62E+00	1.40E-01	4.82E-03	2.87E-04	2.45E-04
Ra-228	406	1.22E+00	1.02E+06	1.70E-01	4.77E-03	1.72E-05	1.03E-06	8.77E-07
Th-227	925	2.79E+00	2.33E+06	3.88E-01	1.62E-02	1.33E-04	7.95E-06	6.78E-06
Th-228	747	2.25E+00	1.88E+06	3.13E-01	3.42E-01	2.27E-03	1.36E-04	1.16E-04
Th-230	60,200	1.81E+02	1.52E+08	2.53E+01	2.62E-01	1.40E-01	8.37E-03	7.14E-03
Th-231	117	3.53E-01	2.95E+05	4.91E-02	8.77E-07	9.12E-10	5.44E-11	4.64E-11
Th-232	842	2.54E+00	2.12E+06	3.53E-01	1.15E+00	8.61E-03	5.14E-04	4.38E-04
Th-234	1,780	5.36E+00	4.48E+06	7.47E-01	3.50E-05	5.54E-07	3.30E-08	2.82E-08
U-234	1,730	5.21E+00	4.36E+06	7.26E-01	1.32E-01	2.03E-03	1.21E-04	1.03E-04
U-235/236	117	3.53E-01	2.95E+05	4.91E-02	1.23E-01	1.28E-04	7.63E-06	6.51E-06
U-238	1,780	5.36E+00	4.48E+06	7.47E-01	1.18E-01	1.87E-03	1.11E-04	9.51E-05
TOTAL	8.62E+04	2.60E+02	2.17E+08	3.62E+01	4.47E+00	**1.76E-01**	**1.05E-02**	**8.97E-03**

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Silo 3 Project
EBA-1 Hose Rupture - Instantaneous Radon Release

Spreadsheet EBA 1 Radon Inst

FERNALD RADON MODEL

$\ln C = A_0 + A_1\ln(Q) + A_2DW + A_3XW + A_4\ln(u_s) + A_5\ln(C_{lag})$

Where:
- C = concentration (pCi/L)
- Q = uniform emissions rate (uCi/sec)
- DW = $\ln(x^2)$ = downwind dilution term
- XW = $(y/x)^2$ = crosswind dilution term
- u_s = the mean wind speed (m/s)
- x = the downwind distance (m)
- y = the crosswind distance (m)

Coefficients		Inputs			
A0	8.1624	Q =	1.32E+01	uCi/sec	0.0475 Ci/hr
A1	1.0158	Wind Speed	1.8	m/s	
A2	-0.6537	y (m) =	0		
A3	-0.9789	x (m)	30		
A4	-1.1262	C lag =	0	pCi/L	
A5	N/A				

Result: C = 2.91E+02 pCi/L @ 30 m.

Dose Conversion:

The ^{222}Rn DAC = 3×10^{-8} uCi/mL, resulting in 5 rem, for 2000 hrs exposure (Ref. 10 CFR 835, Appendix A)

The ALI for ^{222}Rn is 4 WLM. 4 WLM = 5 rem, 1 WLM = 1.25 rem.

Approach 1

WLM =	CFT	C =	2.91E+02	pCi/L
	KN	Equilibrium Factor (F) =	1	
		Time =	1	hr
WLM =	1.71E-02	K =	17000	pCi/L /WL hr/mo
Dose =	2.14E-02 rem	N =	1	
		1 WLM =	1.25	rem

Approach 2

# of DAC =	C/DAC	C =	2.91E+02	pCi/L
# of DAC	9.71E+00	1 DAC =	3.00E-08	uCi/mL
Dose =	# DAC*F*DF*T	1 DAC =	30	pCi/L
Dose =	2.43E-02 rem	Equilibrium Factor (F) =	1	
		DAC DF =	2.5	mrem/hr
		Time =	1	hr

x (m)	Wind Speed (m/s)	C (pCi/L)	X/Q	#DAC	Ingrowth Time (min)	F equil	Time (hr)	Dose (mrem)
30	1.8	2.91E+02	2.21E-02	9.71E+00	N/A	1	1	2.43E+01
100	1.8	6.04E+01	4.57E-03	2.01E+00	N/A	1	1	5.03E+00
350	1.8	1.17E+01	8.89E-04	3.91E-01	N/A	1	1	9.78E-01

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Silo 3 Project
EBA-1 Hose Rupture - Radon Flux

Spreadsheet EBA 1 Radon Flux

FERNALD RADON MODEL

$\ln C = A_0 + A_1\ln(Q) + A_2DW + A_3XW + A_4\ln(u_s) + A_5\ln(C_{lag})$

Where:
- C = concentration (pCi/L)
- Q = uniform emissions rate (uCi/sec)
- DW = $\ln(x^2)$ = downwind dilution term
- XW = $(y/x)^2$ = crosswind dilution term
- u_s = the mean wind speed (m/s)
- x = the downwind distance (m)
- y = the crosswind distance (m)

Coefficients		Inputs		
A0	8.1624	Q =	1.04E-01 uCi/sec	6.26E+06 pCi/min
A1	1.0158	Wind Speed	1.8 m/s	
A2	-0.6537	y (m) =	0	
A3	-0.9789	x (m)	30	
A4	-1.1262	C lag =	0 pCi/L	
A5	N/A			

Result: C = 2.13E+00 pCi/L @ 30 m.

Dose Conversion:

The ^{222}Rn DAC = 3×10^{-8} uCi/mL, resulting in 5 rem, for 2000 hrs exposure (Ref. 10 CFR 835, Appendix A)

The ALI for ^{222}Rn is 4 WLM. 4 WLM = 5 rem, 1 WLM = 1.25 rem.

Approach 1

WLM =	CFT / KN	C =	2.13E+00 pCi/L
		Equilibrium Factor (F) =	1
		Time =	1 hr
WLM =	1.26E-04	K =	17000 pCi/L /WL hr/mo
Dose =	1.57E-04 rem	N =	1
		1 WLM =	1.25 rem

Approach 2

# of DAC =	C/DAC	C =	2.13E+00 pCi/L
# of DAC	7.11E-02	1 DAC =	3.00E-08 uCi/mL
Dose =	# DAC*F*DF*T	1 DAC =	30 pCi/L
Dose =	1.78E-04 rem	Equilibrium Factor (F) =	1
		DAC DF =	2.5 mrem/hr
		Time =	1 hr

x (m)	Wind Speed (m/s)	C (pCi/L)	X/Q	#DAC	Ingrowth Time (min)	F equil	Time (hr)	Dose (mrem)
30	1.8	2.13E+00	2.05E-02	7.11E-02	N/A	1	24	4.27E+00
100	1.8	4.42E-01	4.24E-03	1.47E-02	N/A	1	2	7.37E-02
350	1.8	8.59E-02	8.24E-04	2.86E-03	N/A	1	2	1.43E-02

ATTACHMENT 2
EBA-2 SPREADSHEETS

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Accident Dose Calculations for Solids Release

Dose Calculation: **EBA-2 Solids Release**

Solids Activity (pCi/cc) equals solids activity (pCi/g) x solids density
Source Term (MAR) equals solids activity (pCi/cc) x solids volume
Airborne Source Term (Q) equals the MAR x ARF x RF x DR x LPF
The DCF is listed for each isotope.
DOSE = Q * X/Q * BR * DCF * t

Dry Solid Density 0.80 g/cm^3
wt % solids 100 g solid/g slurry
Solid Density = 50.0 lb/ft^3
Solid Volume = 3900.8 m^3 5100 cy 137700 cf

ARF =	1.00E-03	
RF =	0.1	
DR =	0.75	
LPF =	0.01	
BR =	3.33E-04	m^3/s

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
30	D	1	1.77E-02	1
100	D	4.5	1.05E-03	1
350	F	1	9.00E-04	1

Radionuclide	Solids activity pCi/g	Solids activity pCi/cc	Source Term (MAR) pCi	Airborne Source Term (Q) pCi/s	DCF (mrem/pCi)	Dose @ 30 (mrem)	Dose @ 100 (mrem)	Dose @ 350 (mrem)
Ac-227	925	7.41E+02	2.89E+12	6.02E+02	1.29E+00	1.65E+01	9.82E-01	8.38E-01
Ac-228	406	3.25E+02	1.27E+12	2.64E+02	1.25E-04	7.00E-04	4.18E-05	3.56E-05
Bi-210	3,480	2.79E+03	1.09E+13	2.27E+03	1.96E-04	9.40E-03	5.61E-04	4.79E-04
Fr-223	13	1.04E+01	4.06E+10	8.46E+00	6.22E-06	1.11E-06	6.65E-08	5.68E-08
Pa-231	627	5.02E+02	1.96E+12	4.08E+02	8.58E-01	7.42E+00	4.43E-01	3.78E-01
Pa-234	2	1.60E+00	6.25E+09	1.30E+00	8.14E-07	2.24E-08	1.34E-09	1.14E-09
Pb-210	3,480	2.79E+03	1.09E+13	2.27E+03	1.36E-02	6.53E-01	3.89E-02	3.32E-02
Po-210	3,480	2.79E+03	1.09E+13	2.27E+03	8.58E-03	4.12E-01	2.46E-02	2.10E-02
Ra-223	925	7.41E+02	2.89E+12	6.02E+02	7.84E-03	1.00E-01	5.97E-03	5.09E-03
Ra-224	367	2.94E+02	1.15E+12	2.39E+02	3.16E-03	1.60E-02	9.54E-04	8.14E-04
Ra-226	3,870	3.10E+03	1.21E+13	2.52E+03	1.40E-01	7.47E+00	4.46E-01	3.80E-01
Ra-228	406	3.25E+02	1.27E+12	2.64E+02	4.77E-03	2.67E-02	1.59E-03	1.36E-03
Th-227	925	7.41E+02	2.89E+12	6.02E+02	1.62E-02	2.07E-01	1.23E-02	1.05E-02
Th-228	747	5.98E+02	2.33E+12	4.86E+02	3.42E-01	3.52E+00	2.10E-01	1.79E-01
Th-230	60,200	4.82E+04	1.88E+14	3.92E+04	2.62E-01	2.17E+02	1.30E+01	1.11E+01
Th-231	117	9.37E+01	3.66E+11	7.62E+01	8.77E-07	1.41E-06	8.44E-08	7.20E-08
Th-232	842	6.74E+02	2.63E+12	5.48E+02	1.15E+00	1.34E+01	7.97E-01	6.80E-01
Th-234	1,780	1.43E+03	5.56E+12	1.16E+03	3.50E-05	8.59E-04	5.13E-05	4.37E-05
U-234	1,730	1.39E+03	5.41E+12	1.13E+03	1.32E-01	3.15E+00	1.88E-01	1.60E-01
U-235/236	117	9.37E+01	3.66E+11	7.62E+01	1.23E-01	1.98E-01	1.18E-02	1.01E-02
U-238	1,780	1.43E+03	5.56E+12	1.16E+03	1.18E-01	2.90E+00	1.73E-01	1.47E-01
TOTAL	8.62E+04	6.91E+04	2.69E+14	5.61E+04	4.47E+00	**2.73E+02**	**1.63E+01**	**1.39E+01**

Silo 3 Project
EBA-2 Silo Failure - Instantaneous Radon Release

Spreadsheet EBA 2 Radon Inst

FERNALD RADON MODEL

$\ln C = A_0 + A_1\ln(Q) + A_2DW + A_3XW + A_4\ln(u_s) + A_5\ln(C_{lag})$

Where:
- C = concentration (pCi/L)
- Q = uniform emissions rate (uCi/sec)
- DW = $\ln(x^2)$ = downwind dilution term
- XW = $(y/x)^2$ = crosswind dilution term
- u_s = the mean wind speed (m/s)
- x = the downwind distance (m)
- y = the crosswind distance (m)

Coefficients		Inputs			
A0	8.1624	Q =	9.90E+00	uCi/sec	0.035625 Ci/hr
A1	1.0158	Wind Speed	1.8	m/s	
A2	-0.6537	y (m) =	0		
A3	-0.9789	x (m)	30		
A4	-1.1262	C lag =	0	pCi/L	
A5	N/A				

Result: C = 2.17E+02 pCi/L @ 30 m.

Dose Conversion:

The ^{222}Rn DAC = 3×10^{-8} uCi/mL, resulting in 5 rem, for 2000 hrs exposure (Ref. 10 CFR 835, Appendix A)

The ALI for ^{222}Rn is 4 WLM. 4 WLM = 5 rem, 1 WLM = 1.25 rem.

Approach 1

WLM =	CFT / KN	C =	2.17E+02	pCi/L
		Equilibrium Factor (F) =	1	
		Time =	1	hr
WLM =	1.28E-02	K =	17000	pCi/L /WL hr/mo
Dose =	1.60E-02 rem	N =	1	
		1 WLM =	1.25	rem

Approach 2

# of DAC =	C/DAC	C =	2.17E+02	pCi/L
# of DAC	7.25E+00	1 DAC =	3.00E-08	uCi/mL
Dose =	# DAC*F*DF*T	1 DAC =	30	pCi/L
Dose =	1.81E-02 rem	Equilibrium Factor (F) =	1	
		DAC DF =	2.5	mrem/hr
		Time =	1	hr

x (m)	Wind Speed (m/s)	C (pCi/L)	X/Q	#DAC	Ingrowth Time (min)	F equil	Time (hr)	Dose (mrem)
30	1.8	2.17E+02	2.20E-02	7.25E+00	N/A	1	1	1.81E+01
100	1.8	4.51E+01	4.55E-03	1.50E+00	N/A	1	1	3.75E+00
350	1.8	8.76E+00	8.85E-04	2.92E-01	N/A	1	1	7.30E-01

Silo 3 Project
EBA-2 Silo Failure - Radon Flux

Spreadsheet EBA 2 Radon Flux

FERNALD RADON MODEL

$\ln C = A_0 + A_1\ln(Q) + A_2DW + A_3XW + A_4\ln(u_s) + A_5\ln(C_{lag})$

Where:
- C = concentration (pCi/L)
- Q = uniform emissions rate (uCi/sec)
- DW = $\ln(x^2)$ = downwind dilution term
- XW = $(y/x)^2$ = crosswind dilution term
- u_s = the mean wind speed (m/s)
- x = the downwind distance (m)
- y = the crosswind distance (m)

Coefficients	
A0	8.1624
A1	1.0158
A2	-0.6537
A3	-0.9789
A4	-1.1262
A5	N/A

Inputs			
Q =	7.83E-02	uCi/sec	4.70E+06 pCi/min
Wind Speed	1.8	m/s	
y (m) =	0		
x (m)	30		
C lag =	0	pCi/L	

Result: C = 1.59E+00 pCi/L @ 30 m.

Dose Conversion:

The ^{222}Rn DAC = 3×10^{-8} uCi/mL, resulting in 5 rem, for 2000 hrs exposure (Ref. 10 CFR 835, Appendix A)

The ALI for ^{222}Rn is 4 WLM. 4 WLM = 5 rem, 1 WLM = 1.25 rem.

Approach 1

WLM = CFT / KN

WLM = 9.38E-05

Dose = 1.17E-04 rem

C =	1.59E+00	pCi/L
Equilibrium Factor (F) =	1	
Time =	1	hr
K =	17000	pCi/L /WL hr/mo
N =	1	
1 WLM =	1.25	rem

Approach 2

# of DAC =	C/DAC
# of DAC	5.32E-02
Dose =	# DAC*F*DF*T
Dose =	1.33E-04 rem

C =	1.59E+00	pCi/L
1 DAC =	3.00E-08	uCi/mL
1 DAC =	30	pCi/L
Equilibrium Factor (F) =	1	
DAC DF =	2.5	mrem/hr
Time =	1	hr

x (m)	Wind Speed (m/s)	C (pCi/L)	X/Q	#DAC	Ingrowth Time (min)	F equil	Time (hr)	Dose (mrem)
30	1.8	1.59E+00	2.04E-02	5.32E-02	N/A	1	24	3.19E+00
100	1.8	3.30E-01	4.22E-03	1.10E-02	N/A	1	2	5.51E-02
350	1.8	6.42E-02	8.20E-04	2.14E-03	N/A	1	2	1.07E-02

Accident Dose Calculations for Chemical Release for Silo Failure During Wall Cutting

EBA-2 Chemical Release

Dose Calculation:

The MAR is 3825 cy (75% of 5100 cy at time of wall failure during cutting)
Chemical inventory equals concentration x solids mass
Concentration = (Compound mass x ARF x RF x DR x LPF x X/Q) / t

MAR =	3825 cy
Solid Density =	50 lb/ft^3
Solid Mass =	4.4.E+06 lb
Solid Mass =	2.0.E+06 kg

ARF =	1.00E-03	
RF =	0.1	
DR =	1.0	
LPF =	0.01	

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
100	F	1	9.08E-03	1
350	F	1	9.00E-04	1

Chemical	Concentration (mg/kg)	Chemical Inventory (mg)	Chemical Compound	Compound Mass (mg)	Concentration @ 100 (mg/m3)	Concentration @ 350 (mg/m3)
Arsenic	7.27E+03	1.70E+10	Arsenic Pentoxide	2.62E+10	6.62E-02	6.56E-03
Cadmium	3.43E+02	8.04E+08	Cadmium Oxide	9.17E+08	2.31E-03	2.29E-04
Mercury	1.74E+03	4.08E+09	Mercuric Sulfate	4.41E+09	1.11E-02	1.10E-03
Thallium	1.63E+02	3.82E+08	Thallium Sulfate	5.62E+08	1.42E-03	1.40E-04
Vanadium	1.09E+04	2.56E+10	Vanadium Pentoxide	4.60E+10	1.16E-01	1.15E-02

Accident Dose Calculations for Ferrous Sulfate Release

MAR =	4500 gal
Solid Density =	1.9 g/ml
Solid Mass =	3.2.E+04 kg

ARF =	5.00E-05	
RF =	0.8	
DR =	1.0	
LPF =	1.00	

Chemical	Concentration mg/kg	Chemical Inventory mg		Concentration @ 100 (mg/m3)	Concentration @ 350 (mg/m3)
Ferrous Sulfate	1.00E+06	3.24E+10		3.26E+00	3.24E-01

ATTACHMENT 3
EBA-3 SPREADSHEETS

5004

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Accident Dose Calculations for Silo 3 Project - Solids Stack Release

References:

DOE-STD-3009-94
EPA-520/1-88-020
DOE-HDBK-3010
US Nuclear Regulatory Commission Reg Guide 1.145
DOE-STD-1027-92, December 1992, Change notice 1, September 1997

Dose Methodology:

DOSE = Q * X/Q * BR * DCF * t

where:

BR =	3.33E-04 m^3/s	Breathing Rate (a constant)
DCF =	rem/Ci	Dose Conversion Factor (varies)
t =	exposure time	
Q =	Airborne Source Term	

Q = MAR * DR * LPF * ARF * RF

where:

MAR =		material at risk of release
DR =	1	damage ratio
LPF =	1	leak path factor
ARF*RF=		airborne release fraction x respirable fraction

X/Q Methodology:

A Gaussian dispersion model is used to determine the dispersion loss between the release and receptor.

For fumigation conditions:

X/Q = 1/((2*pi)^0.5 *U*sig-y*h)

Where the variables are defined as follows:

pi =	3.14159	
d =		downwind distance to evaluation point, m
		Atmospheric stability class (D, E, F, G)
h =		effective stack height, m
sig-y =		lateral plume spread, m
U =		wind speed, m/sec, at the release height

Dispersion Calculations:

	User Input	Constant	Calculated
pi =	3.14159	3.14159	3.14159
d =	30	100	350
	G	G	G
h =	38.1	38.1	38.1
sig-y =	0.76	2.68	9.36
U =	0.5	0.5	0.5
X/Q (sec/m3) =	2.75E-02	7.80E-03	2.24E-03

5004

Accident Dose Calculations for Solids Release

Dose Calculation: **EBA-3 Solids Stack Release**

Solids Activity (pCi/cc) equals solids activity (pCi/g) x solids density
Source Term (MAR) equals solids activity (pCi/cc) x solids volume
Airborne Source Term (Q) equals the MAR x ARF x RF x DR x LPF
The DCF is listed for each isotope.
DOSE = Q * X/Q * BR * DCF * t

Dry Solid Density 0.80 g/cm^3
wt % solids 100 g solid/g slurry
Solid Density = 50.0 lb/ft^3
Solid Volume = 1.9 m^3 67.5 cf

ARF =	2.00E-03	
RF =	0.3	
DR =	1.0	
LPF =	1.0	
BR =	3.33E-04	m^3/s

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
30	G	0.5	2.75E-02	1
100	G	0.5	7.80E-03	1
350	G	0.5	2.24E-03	1

Radionuclide	Solids activity pCi/g	Solids activity pCi/cc	Source Term (MAR) pCi	Airborne Source Term (Q) pCi/s	DCF (mrem/pCi)	Dose @ 30 (mrem)	Dose @ 100 (mrem)	Dose @ 350 (mrem)
Ac-227	925	7.41E+02	1.42E+09	2.36E+02	1.29E+00	1.00E+01	2.85E+00	8.17E-01
Ac-228	406	3.25E+02	6.22E+08	1.04E+02	1.25E-04	4.27E-04	1.21E-04	3.47E-05
Bi-210	3,480	2.79E+03	5.33E+09	8.88E+02	1.96E-04	5.74E-03	1.63E-03	4.67E-04
Fr-223	13	1.04E+01	1.99E+07	3.32E+00	6.22E-06	6.80E-07	1.93E-07	5.53E-08
Pa-231	627	5.02E+02	9.60E+08	1.60E+02	8.58E-01	4.52E+00	1.28E+00	3.68E-01
Pa-234	2	1.60E+00	3.06E+06	5.11E-01	8.14E-07	1.37E-08	3.89E-09	1.11E-09
Pb-210	3,480	2.79E+03	5.33E+09	8.88E+02	1.36E-02	3.98E-01	1.13E-01	3.24E-02
Po-210	3,480	2.79E+03	5.33E+09	8.88E+02	8.58E-03	2.51E-01	7.13E-02	2.04E-02
Ra-223	925	7.41E+02	1.42E+09	2.36E+02	7.84E-03	6.10E-02	1.73E-02	4.96E-03
Ra-224	367	2.94E+02	5.62E+08	9.37E+01	3.16E-03	9.75E-03	2.77E-03	7.94E-04
Ra-226	3,870	3.10E+03	5.93E+09	9.88E+02	1.40E-01	4.56E+00	1.29E+00	3.71E-01
Ra-228	406	3.25E+02	6.22E+08	1.04E+02	4.77E-03	1.63E-02	4.63E-03	1.33E-03
Th-227	925	7.41E+02	1.42E+09	2.36E+02	1.62E-02	1.26E-01	3.58E-02	1.03E-02
Th-228	747	5.98E+02	1.14E+09	1.91E+02	3.42E-01	2.15E+00	6.10E-01	1.75E-01
Th-230	60,200	4.82E+04	9.22E+10	1.54E+04	2.62E-01	1.33E+02	3.77E+01	1.08E+01
Th-231	117	9.37E+01	1.79E+08	2.99E+01	8.77E-07	8.63E-07	2.45E-07	7.02E-08
Th-232	842	6.74E+02	1.29E+09	2.15E+02	1.15E+00	8.14E+00	2.31E+00	6.63E-01
Th-234	1,780	1.43E+03	2.73E+09	4.54E+02	3.50E-05	5.24E-04	1.49E-04	4.26E-05
U-234	1,730	1.39E+03	2.65E+09	4.42E+02	1.32E-01	1.92E+00	5.45E-01	1.56E-01
U-235/236	117	9.37E+01	1.79E+08	2.99E+01	1.23E-01	1.21E-01	3.44E-02	9.85E-03
U-238	1,780	1.43E+03	2.73E+09	4.54E+02	1.18E-01	1.77E+00	5.02E-01	1.44E-01
TOTAL	8.62E+04	6.91E+04	1.32E+11	2.20E+04	4.47E+00	**1.67E+02**	**4.74E+01**	**1.36E+01**

ATTACHMENT 4
EBA-4 SPREADSHEETS

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Accident Dose Calculations for Solids Release

Dose Calculation: **EBA-4 Solids Release**

Solids Activity (pCi/cc) equals solids activity (pCi/g) x solids density
Source Term (MAR) equals solids activity (pCi/cc) x solids volume
Airborne Source Term (Q) equals the MAR x ARF x RF x DR x LPF
The DCF is listed for each isotope.
DOSE = Q * X/Q * BR * DCF * t

Dry Solid Density 0.80 g/cm^3
wt % solids 100 g solid/g slurry
Solid Density = 50.0 lb/ft^3
Solid Volume = 2.7 m^3 1 sacks
96 cf

ARF =	2.00E-03	
RF =	0.3	
DR =	1.0	
LPF =	1.0	
BR =	3.33E-04	m^3/s

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
30	D	1	1.77E-02	1
100	D	4.5	1.05E-03	1
350	F	1	9.00E-04	1

Radionuclide	Solids activity pCi/g	Solids activity pCi/cc	Source Term (MAR) pCi	Airborne Source Term (Q) pCi/s	DCF (mrem/pCi)	Dose @ 30 (mrem)	Dose @ 100 (mrem)	Dose @ 350 (mrem)
Ac-227	925	7.41E+02	2.01E+09	3.36E+02	1.29E+00	9.18E+00	5.48E-01	4.67E-01
Ac-228	406	3.25E+02	8.84E+08	1.47E+02	1.25E-04	3.90E-04	2.33E-05	1.99E-05
Bi-210	3,480	2.79E+03	7.58E+09	1.26E+03	1.96E-04	5.25E-03	3.13E-04	2.67E-04
Fr-223	13	1.04E+01	2.83E+07	4.72E+00	6.22E-06	6.22E-07	3.71E-08	3.17E-08
Pa-231	627	5.02E+02	1.37E+09	2.28E+02	8.58E-01	4.14E+00	2.47E-01	2.11E-01
Pa-234	2	1.60E+00	4.36E+06	7.26E-01	8.14E-07	1.25E-08	7.47E-10	6.38E-10
Pb-210	3,480	2.79E+03	7.58E+09	1.26E+03	1.36E-02	3.64E-01	2.17E-02	1.85E-02
Po-210	3,480	2.79E+03	7.58E+09	1.26E+03	8.58E-03	2.30E-01	1.37E-02	1.17E-02
Ra-223	925	7.41E+02	2.01E+09	3.36E+02	7.84E-03	5.58E-02	3.33E-03	2.84E-03
Ra-224	367	2.94E+02	7.99E+08	1.33E+02	3.16E-03	8.92E-03	5.32E-04	4.54E-04
Ra-226	3,870	3.10E+03	8.43E+09	1.41E+03	1.40E-01	4.17E+00	2.49E-01	2.12E-01
Ra-228	406	3.25E+02	8.84E+08	1.47E+02	4.77E-03	1.49E-02	8.89E-04	7.58E-04
Th-227	925	7.41E+02	2.01E+09	3.36E+02	1.62E-02	1.15E-01	6.88E-03	5.87E-03
Th-228	747	5.98E+02	1.63E+09	2.71E+02	3.42E-01	1.96E+00	1.17E-01	1.00E-01
Th-230	60,200	4.82E+04	1.31E+11	2.19E+04	2.62E-01	1.21E+02	7.24E+00	6.18E+00
Th-231	117	9.37E+01	2.55E+08	4.25E+01	8.77E-07	7.89E-07	4.71E-08	4.02E-08
Th-232	842	6.74E+02	1.83E+09	3.06E+02	1.15E+00	7.45E+00	4.44E-01	3.79E-01
Th-234	1,780	1.43E+03	3.88E+09	6.46E+02	3.50E-05	4.79E-04	2.86E-05	2.44E-05
U-234	1,730	1.39E+03	3.77E+09	6.28E+02	1.32E-01	1.76E+00	1.05E-01	8.94E-02
U-235/236	117	9.37E+01	2.55E+08	4.25E+01	1.23E-01	1.11E-01	6.60E-03	5.64E-03
U-238	1,780	1.43E+03	3.88E+09	6.46E+02	1.18E-01	1.62E+00	9.64E-02	8.22E-02
TOTAL	8.62E+04	6.91E+04	1.88E+11	3.13E+04	4.47E+00	**1.52E+02**	**9.10E+00**	**7.76E+00**

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ATTACHMENT 5
EBA-5 SPREADSHEETS

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Accident Dose Calculations for Solids Release

Dose Calculation: **EBA-5 Solids Stack Release**

Solids Activity (pCi/cc) equals solids activity (pCi/g) x solids density
Source Term (MAR) equals solids activity (pCi/cc) x solids volume
Airborne Source Term (Q) equals the MAR x ARF x RF x DR x LPF
The DCF is listed for each isotope.
DOSE = Q * X/Q * BR * DCF * t

Solid Density = 0.188 lb/ft^3
Release Volume = 509.9 m^3
18000 cf

ARF =	2.00E-03	
RF =	0.3	
DR =	1.0	
LPF =	1.0	
BR =	3.33E-04	m^3/s

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
30	G	0.5	2.75E-02	1
100	G	0.5	7.80E-03	1
350	G	0.5	2.24E-03	1

Radionuclide	Solids activity pCi/g	Solids activity pCi/cc	Source Term (MAR) pCi	Airborne Source Term (Q) pCi/s	DCF (mrem/pCi)	Dose @ 30 (mrem)	Dose @ 100 (mrem)	Dose @ 350 (mrem)
Ac-227	925	2.79E+00	1.42E+09	2.37E+02	1.29E+00	1.01E+01	2.86E+00	8.19E-01
Ac-228	406	1.22E+00	6.24E+08	1.04E+02	1.25E-04	4.28E-04	1.22E-04	3.48E-05
Bi-210	3,480	1.05E+01	5.35E+09	8.91E+02	1.96E-04	5.75E-03	1.63E-03	4.68E-04
Fr-223	13	3.92E-02	2.00E+07	3.33E+00	6.22E-06	6.82E-07	1.94E-07	5.55E-08
Pa-231	627	1.89E+00	9.63E+08	1.61E+02	8.58E-01	4.54E+00	1.29E+00	3.69E-01
Pa-234	2	6.03E-03	3.07E+06	5.12E-01	8.14E-07	1.37E-08	3.90E-09	1.12E-09
Pb-210	3,480	1.05E+01	5.35E+09	8.91E+02	1.36E-02	3.99E-01	1.13E-01	3.25E-02
Po-210	3,480	1.05E+01	5.35E+09	8.91E+02	8.58E-03	2.52E-01	7.15E-02	2.05E-02
Ra-223	925	2.79E+00	1.42E+09	2.37E+02	7.84E-03	6.12E-02	1.74E-02	4.98E-03
Ra-224	367	1.11E+00	5.64E+08	9.40E+01	3.16E-03	9.78E-03	2.78E-03	7.96E-04
Ra-226	3,870	1.17E+01	5.95E+09	9.91E+02	1.40E-01	4.57E+00	1.30E+00	3.72E-01
Ra-228	406	1.22E+00	6.24E+08	1.04E+02	4.77E-03	1.63E-02	4.64E-03	1.33E-03
Th-227	925	2.79E+00	1.42E+09	2.37E+02	1.62E-02	1.26E-01	3.59E-02	1.03E-02
Th-228	747	2.25E+00	1.15E+09	1.91E+02	3.42E-01	2.15E+00	6.12E-01	1.75E-01
Th-230	60,200	1.81E+02	9.25E+10	1.54E+04	2.62E-01	1.33E+02	3.78E+01	1.08E+01
Th-231	117	3.53E-01	1.80E+08	3.00E+01	8.77E-07	8.65E-07	2.46E-07	7.04E-08
Th-232	842	2.54E+00	1.29E+09	2.16E+02	1.15E+00	8.17E+00	2.32E+00	6.65E-01
Th-234	1,780	5.36E+00	2.73E+09	4.56E+02	3.50E-05	5.25E-04	1.49E-04	4.28E-05
U-234	1,730	5.21E+00	2.66E+09	4.43E+02	1.32E-01	1.93E+00	5.47E-01	1.57E-01
U-235/236	117	3.53E-01	1.80E+08	3.00E+01	1.23E-01	1.21E-01	3.45E-02	9.88E-03
U-238	1,780	5.36E+00	2.73E+09	4.56E+02	1.18E-01	1.77E+00	5.03E-01	1.44E-01
TOTAL	8.62E+04	2.60E+02	1.32E+11	2.21E+04	4.47E+00	**1.67E+02**	**4.75E+01**	**1.36E+01**

Silo 3 Project
EBA-5 Collector Failure - Instantaneous Radon Release

Spreadsheet EBA 5 Radon Inst

FERNALD RADON MODEL

$\ln C = A_0 + A_1\ln(Q) + A_2DW + A_3XW + A_4\ln(u_s) + A_5\ln(C_{lag})$

Where:
- C = concentration (pCi/L)
- Q = uniform emissions rate (uCi/sec)
- DW = $\ln(x^2)$ = downwind dilution term
- XW = $(y/x)^2$ = crosswind dilution term
- u_s = the mean wind speed (m/s)
- x = the downwind distance (m)
- y = the crosswind distance (m)

Coefficients		Inputs			
A0	8.1624	Q =	1.32E+01	uCi/sec	0.0475 Ci/hr
A1	1.0158	Wind Speed	1.8	m/s	
A2	-0.6537	y (m) =	0		
A3	-0.9789	x (m)	30		
A4	-1.1262	C lag =	0	pCi/L	
A5	N/A				

Result: C = 2.91E+02 pCi/L @ 30 m.

Dose Conversion:

The ^{222}Rn DAC = 3×10^{-8} uCi/mL, resulting in 5 rem, for 2000 hrs exposure (Ref. 10 CFR 835, Appendix A)
The ALI for ^{222}Rn is 4 WLM. 4 WLM = 5 rem, 1 WLM = 1.25 rem.

Approach 1

WLM =	CFT / KN	C =	2.91E+02	pCi/L
		Equilibrium Factor (F) =	1	
		Time =	1	hr
WLM =	1.71E-02	K =	17000	pCi/L /WL hr/mo
Dose =	2.14E-02 rem	N =	1	
		1 WLM =	1.25	rem

Approach 2

# of DAC =	C/DAC	C =	2.91E+02	pCi/L
# of DAC	9.71E+00	1 DAC =	3.00E-08	uCi/mL
Dose =	# DAC*F*DF*T	1 DAC =	30	pCi/L
Dose =	2.43E-02 rem	Equilibrium Factor (F) =	1	
		DAC DF =	2.5	mrem/hr
		Time =	1	hr

x (m)	Wind Speed (m/s)	C (pCi/L)	X/Q	#DAC	Ingrowth Time (min)	F equil	Time (hr)	Dose (mrem)
30	1.8	2.91E+02	2.21E-02	9.71E+00	N/A	1	1	2.43E+01
100	1.8	6.04E+01	4.57E-03	2.01E+00	N/A	1	1	5.03E+00
350	1.8	1.17E+01	8.89E-04	3.91E-01	N/A	1	1	9.78E-01

ATTACHMENT 6
EBA-6 SPREADSHEETS

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Accident Dose Calculations for Solids Release

Dose Calculation:

Solids Activity (pCi/cc) equals solids activity (pCi/g) x solids density
Source Term (MAR) equals solids activity (pCi/cc) x solids volume
Airborne Source Term (Q) equals the MAR x ARF x RF x DR x LPF
The DCF is listed for each isotope.
DOSE = Q * X/Q * BR * DCF * t

EBA-6 Solids Release
Release from Spill of Powders

Dry Solid Density 0.80 g/cm^3
wt % solids 100 g solid/g slurry
Solid Density = 50.0 lb/ft^3
Solid Volume = 22 m^3 8 bags
768 cf

ARF =	2.00E-03	
RF =	0.3	
DR =	1.0	
LPF =	0.5	
BR =	3.33E-04	m^3/s

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
30	D	1	1.77E-02	1
100	D	4.5	1.05E-03	1
350	F	1	9.00E-04	1

Radionuclide	Solids activity pCi/g	Solids activity pCi/cc	Source Term (MAR) pCi	Airborne Source Term (Q) pCi/s	DCF (mrem/pCi)	Dose @ 30 (mrem)	Dose @ 100 (mrem)	Dose @ 350 (mrem)
Ac-227	925	7.41E+02	1.61E+10	1.34E+03	1.29E+00	3.67E+01	2.19E+00	1.87E+00
Ac-228	406	3.25E+02	7.08E+09	5.90E+02	1.25E-04	1.56E-03	9.32E-05	7.95E-05
Bi-210	3,480	2.79E+03	6.06E+10	5.05E+03	1.96E-04	2.10E-02	1.25E-03	1.07E-03
Fr-223	13	1.04E+01	2.27E+08	1.89E+01	6.22E-06	2.49E-06	1.48E-07	1.27E-07
Pa-231	627	5.02E+02	1.09E+10	9.11E+02	8.58E-01	1.65E+01	9.87E-01	8.43E-01
Pa-234	2	1.60E+00	3.49E+07	2.90E+00	8.14E-07	5.01E-08	2.99E-09	2.55E-09
Pb-210	3,480	2.79E+03	6.06E+10	5.05E+03	1.36E-02	1.46E+00	8.69E-02	7.41E-02
Po-210	3,480	2.79E+03	6.06E+10	5.05E+03	8.58E-03	9.18E-01	5.48E-02	4.68E-02
Ra-223	925	7.41E+02	1.61E+10	1.34E+03	7.84E-03	2.23E-01	1.33E-02	1.14E-02
Ra-224	367	2.94E+02	6.40E+09	5.33E+02	3.16E-03	3.57E-02	2.13E-03	1.82E-03
Ra-226	3,870	3.10E+03	6.74E+10	5.62E+03	1.40E-01	1.67E+01	9.95E-01	8.49E-01
Ra-228	406	3.25E+02	7.08E+09	5.90E+02	4.77E-03	5.96E-02	3.55E-03	3.03E-03
Th-227	925	7.41E+02	1.61E+10	1.34E+03	1.62E-02	4.61E-01	2.75E-02	2.35E-02
Th-228	747	5.98E+02	1.30E+10	1.08E+03	3.42E-01	7.86E+00	4.69E-01	4.00E-01
Th-230	60,200	4.82E+04	1.05E+12	8.74E+04	2.62E-01	4.85E+02	2.90E+01	2.47E+01
Th-231	117	9.37E+01	2.04E+09	1.70E+02	8.77E-07	3.16E-06	1.88E-07	1.61E-07
Th-232	842	6.74E+02	1.47E+10	1.22E+03	1.15E+00	2.98E+01	1.78E+00	1.52E+00
Th-234	1,780	1.43E+03	3.10E+10	2.58E+03	3.50E-05	1.92E-03	1.14E-04	9.76E-05
U-234	1,730	1.39E+03	3.01E+10	2.51E+03	1.32E-01	7.02E+00	4.19E-01	3.58E-01
U-235/236	117	9.37E+01	2.04E+09	1.70E+02	1.23E-01	4.43E-01	2.64E-02	2.25E-02
U-238	1,780	1.43E+03	3.10E+10	2.58E+03	1.18E-01	6.46E+00	3.86E-01	3.29E-01
TOTAL	8.62E+04	6.91E+04	1.50E+12	1.25E+05	4.47E+00	**6.10E+02**	**3.64E+01**	**3.11E+01**

Accident Dose Calculations for Solids Release

Dose Calculation:

Solids Activity (pCi/cc) equals solids activity (pCi/g) x solids density
Source Term (MAR) equals solids activity (pCi/cc) x solids volume
Airborne Source Term (Q) equals the MAR x ARF x RF x DR x LPF
The DCF is listed for each isotope.
DOSE = Q * X/Q * BR * DCF * t

EBA-6 Solids Release
Resuspension of Solids

Dry Solid Density 0.80 g/cm^3
wt % solids 100 g solid/g slurry
Solid Density = 50.0 lb/ft^3
Solid Volume = 22 m^3 8 bags
768 cf

ARF =	4.00E-05	
RF =	1.0	
DR =	1.0	
LPF =	0.5	
BR =	3.33E-04	m^3/s

Distance (m)	Stability Class	Wind Spd (m/s)	X/Q (s/m3)	Time (hours)
30	D	1	1.77E-02	24
100	D	4.5	1.05E-03	2
350	F	1	9.00E-04	2

Radionuclide	Solids activity pCi/g	Solids activity pCi/cc	Source Term (MAR) pCi	Airborne Source Term (Q) pCi/s	DCF (mrem/pCi)	Dose @ 30 (mrem)	Dose @ 100 (mrem)	Dose @ 350 (mrem)
Ac-227	925	7.41E+02	1.61E+10	8.96E+01	1.29E+00	5.87E+01	2.92E-01	2.49E-01
Ac-228	406	3.25E+02	7.08E+09	3.93E+01	1.25E-04	2.50E-03	1.24E-05	1.06E-05
Bi-210	3,480	2.79E+03	6.06E+10	3.37E+02	1.96E-04	3.36E-02	1.67E-04	1.42E-04
Fr-223	13	1.04E+01	2.27E+08	1.26E+00	6.22E-06	3.98E-06	1.98E-08	1.69E-08
Pa-231	627	5.02E+02	1.09E+10	6.07E+01	8.58E-01	2.65E+01	1.32E-01	1.12E-01
Pa-234	2	1.60E+00	3.49E+07	1.94E-01	8.14E-07	8.01E-08	3.98E-10	3.40E-10
Pb-210	3,480	2.79E+03	6.06E+10	3.37E+02	1.36E-02	2.33E+00	1.16E-02	9.88E-03
Po-210	3,480	2.79E+03	6.06E+10	3.37E+02	8.58E-03	1.47E+00	7.31E-03	6.24E-03
Ra-223	925	7.41E+02	1.61E+10	8.96E+01	7.84E-03	3.57E-01	1.77E-03	1.51E-03
Ra-224	367	2.94E+02	6.40E+09	3.55E+01	3.16E-03	5.71E-02	2.84E-04	2.42E-04
Ra-226	3,870	3.10E+03	6.74E+10	3.75E+02	1.40E-01	2.67E+01	1.33E-01	1.13E-01
Ra-228	406	3.25E+02	7.08E+09	3.93E+01	4.77E-03	9.53E-02	4.74E-04	4.04E-04
Th-227	925	7.41E+02	1.61E+10	8.96E+01	1.62E-02	7.38E-01	3.67E-03	3.13E-03
Th-228	747	5.98E+02	1.30E+10	7.23E+01	3.42E-01	1.26E+01	6.25E-02	5.34E-02
Th-230	60,200	4.82E+04	1.05E+12	5.83E+03	2.62E-01	7.76E+02	3.86E+00	3.29E+00
Th-231	117	9.37E+01	2.04E+09	1.13E+01	8.77E-07	5.05E-06	2.51E-08	2.14E-08
Th-232	842	6.74E+02	1.47E+10	8.15E+01	1.15E+00	4.77E+01	2.37E-01	2.02E-01
Th-234	1,780	1.43E+03	3.10E+10	1.72E+02	3.50E-05	3.07E-03	1.52E-05	1.30E-05
U-234	1,730	1.39E+03	3.01E+10	1.67E+02	1.32E-01	1.12E+01	5.59E-02	4.77E-02
U-235/236	117	9.37E+01	2.04E+09	1.13E+01	1.23E-01	7.08E-01	3.52E-03	3.01E-03
U-238	1,780	1.43E+03	3.10E+10	1.72E+02	1.18E-01	1.03E+01	5.14E-02	4.39E-02
TOTAL	8.62E+04	6.91E+04	1.50E+12	8.35E+03	4.47E+00	**9.76E+02**	**4.85E+00**	**4.14E+00**

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Silo 3 Project
EBA-6 Spill of Cargo Container - Instantaneous Radon Release

Spreadsheet EBA 6 Radon Inst

FERNALD RADON MODEL

$\ln C = A_0 + A_1\ln(Q) + A_2DW + A_3XW + A_4\ln(u_s) + A_5\ln(C_{lag})$

Where:
- C = concentration (pCi/L)
- Q = uniform emissions rate (uCi/sec)
- DW = $\ln(x^2)$ = downwind dilution term
- XW = $(y/x)^2$ = crosswind dilution term
- u_s = the mean wind speed (m/s)
- x = the downwind distance (m)
- y = the crosswind distance (m)

Coefficients		Inputs			
A0	8.1624	Q =	6.67E+00	uCi/sec	0.024 Ci/hr
A1	1.0158	Wind Speed	1.8	m/s	
A2	-0.6537	y (m) =	0		
A3	-0.9789	x (m)	30		
A4	-1.1262	C lag =	0	pCi/L	
A5	N/A				

Result: C = 1.46E+02 pCi/L @ 30 m.

Dose Conversion:

The ^{222}Rn DAC = 3×10^{-8} uCi/mL, resulting in 5 rem, for 2000 hrs exposure (Ref. 10 CFR 835, Appendix A)
The ALI for ^{222}Rn is 4 WLM. 4 WLM = 5 rem, 1 WLM = 1.25 rem.

Approach 1

WLM =	CFT / KN	C =	1.46E+02	pCi/L
		Equilibrium Factor (F) =	1	
		Time =	1	hr
WLM =	8.56E-03	K =	17000	pCi/L /WL hr/mo
Dose =	1.07E-02 rem	N =	1	
		1 WLM =	1.25	rem

Approach 2

# of DAC =	C/DAC	C =	1.46E+02	pCi/L
# of DAC	4.85E+00	1 DAC =	3.00E-08	uCi/mL
Dose =	# DAC*F*DF*T	1 DAC =	30	pCi/L
Dose =	1.21E-02 rem	Equilibrium Factor (F) =	1	
		DAC DF =	2.5	mrem/hr
		Time =	1	hr

x (m)	Wind Speed (m/s)	C (pCi/L)	X/Q	#DAC	Ingrowth Time (min)	F equil	Time (hr)	Dose (mrem)
30	1.8	1.46E+02	2.18E-02	4.85E+00	N/A	1	1	1.21E+01
100	1.8	3.02E+01	4.52E-03	1.01E+00	N/A	1	1	2.51E+00
350	1.8	5.86E+00	8.80E-04	1.95E-01	N/A	1	1	4.89E-01

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Silo 3 Project
EBA-6 Storage Container - Radon Flux

Spreadsheet EBA 6 Radon Flux

FERNALD RADON MODEL

$\ln C = A_0 + A_1\ln(Q) + A_2DW + A_3XW + A_4\ln(u_s) + A_5\ln(C_{lag})$

Where:
- C = concentration (pCi/L)
- Q = uniform emissions rate (uCi/sec)
- DW = $\ln(x^2)$ = downwind dilution term
- XW = $(y/x)^2$ = crosswind dilution term
- u_s = the mean wind speed (m/s)
- x = the downwind distance (m)
- y = the crosswind distance (m)

Coefficients	
A0	8.1624
A1	1.0158
A2	-0.6537
A3	-0.9789
A4	-1.1262
A5	N/A

Inputs			
Q =	4.95E-02	uCi/sec	2.97E+06 pCi/min
Wind Speed	1.8	m/s	
y (m) =	0		
x (m)	30		
C lag =	0	pCi/L	

Result: C = 1.00E+00 pCi/L @ 30 m.

Dose Conversion:

The ^{222}Rn DAC = 3×10^{-8} uCi/mL, resulting in 5 rem, for 2000 hrs exposure (Ref. 10 CFR 835, Appendix A)
The ALI for ^{222}Rn is 4 WLM. 4 WLM = 5 rem, 1 WLM = 1.25 rem.

Approach 1

WLM =	CFT	C =	1.00E+00	pCi/L
	KN	Equilibrium Factor (F) =	1	
		Time =	1	hr
WLM =	5.88E-05	K =	17000	pCi/L /WL hr/mo
Dose =	7.36E-05 rem	N =	1	
		1 WLM =	1.25	rem

Approach 2

# of DAC =	C/DAC	C =	1.00E+00	pCi/L
# of DAC	3.33E-02	1 DAC =	3.00E-08	uCi/mL
Dose =	# DAC*F*DF*T	1 DAC =	30	pCi/L
Dose =	8.34E-05 rem	Equilibrium Factor (F) =	1	
		DAC DF =	2.5	mrem/hr
		Time =	1	hr

x (m)	Wind Speed (m/s)	C (pCi/L)	X/Q	#DAC	Ingrowth Time (min)	F equil	Time (hr)	Dose (mrem)
30	1.8	1.00E+00	2.02E-02	3.33E-02	N/A	1	24	2.00E+00
100	1.8	2.07E-01	4.19E-03	6.91E-03	N/A	1	2	3.45E-02
350	1.8	4.03E-02	8.14E-04	1.34E-03	N/A	1	2	6.72E-03