APPENDIX 8.0-5
ACCIDENT ANALYSIS

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8.0-5 ACCIDENT ANALYSIS

8.0-5.1 Potential Accidental Releases During Operations

This appendix provides analyses of potential exposures to individuals due to accidents or unusual conditions during handling, storage, and disposal of waste. The analyses provide reasonable assurance that potential exposures to individual members of the public will be within the requirements of 30 TAC §336.313, *Dose Limits for Individual Members of the Public*, and that potential exposures to facility workers will be within the requirements of 30 TAC §336.305, *Occupational Dose Limits for Adults*. The dose limits given in 30 TAC §336.305 are associated with occupational doses incurred during routine operations and are not applicable to accidents. It is also noted that the 100 mrem dose limit stipulated in 30 TAC §336.313 is the "total dose that an individual member of the public could receive from short-term liquid or gaseous effluent releases or from direct radiation from the Site due to operations." This 100 mrem limit should not be confused with the 25 mrem annual dose above background to the whole body which is based upon concentrations of radioactive material that may be released to the general environment in groundwater, surface water, air, soil, plants, or animals as given in 30 TAC §336.724, *Protection of the General Population from Releases of Radioactivity*.

Operations will be performed in a manner consistent with industry standards to ensure the accident-related risk to workers and members of the public is minimized. Risk includes consideration of both the frequency of occurrence of a given accident scenario, and the potential human health-related consequences of the given accident scenario. Hence, accidents with a relatively high likelihood of occurrence but relatively small consequences are evaluated, as well as accidents with a relatively small likelihood of occurrence but potentially large consequences. The facility design and operation was reviewed to identify the accidents presenting the largest risk. These accidents are considered to portray a proper and sufficiently comprehensive radiological accident-related risk profile for the proposed waste disposal facilities.

- Container breach
- Explosion or fire
- Tornado or severe winds
- Flooding
- Crane malfunction suspends high radiation package for extended period of time

For accident conditions involving the release of airborne radionuclides, only inhalation doses are calculated. External radiation doses from immersion in the airborne plume are generally orders of magnitude lower than the inhalation doses. This is illustrated by the comparison of inhalation and immersion dose conversion factors in Table 8.0-5-1. The table shows the dose conversion factors for a selection of the most important radionuclides. Dose conversion factors were taken from EPA's Federal Guidance Reports No. 11 and No. 12. The table contains gamma emitters (Co-60 and Cs-137), beta emitters, (C-14, Sr-90, Tc-99), and alpha emitters (Th-232, Pu-239, Am-241) that can cause the highest inhalation doses. These common radionuclides in LLRW are representative of alpha, beta, and gamma emitters and the conclusions based in these radionuclides are also true for other radionuclides.

The relative importance of external doses compared to inhalation doses is illustrated by taking the ratio of external to inhalation doses for a representative sample of radionuclides. The inhalation dose (in sieverts) for a radionuclide is:

$$\text{Inhalation Dose} = CON \times BR \times T \times DCF_{Inh}$$

where

CON = Airborne concentration (Bq/m3)

BR = Worker breathing rate (2.57E-04 m3/s)

T = Time exposed to airborne plume (s)

DCF_{Inh} = Inhalation dose conversion factor (Sv/Bq)

The external received while immersed in the airborne plume is given by:

$$\text{External Dose} = CON \times T \times DCF_{Ext}$$

where

CON = Airborne concentration (Bq/m3)

T = Time exposed to airborne plume (s)

DCF_{Ext} = External immersion dose conversion factor (Sv/s per Bq/m3)

The ratio of the external immersion dose to the inhalation dose can be expressed by the dose ratio, DR, defined as:

$$DR = \text{External dose} / \text{Inhalation dose}$$

or

$$DR = DCF_{Ext} / (BR \times DCF_{Inh})$$

Values for the dose ratio are shown in Table 8.0-5-1 for several radionuclides. For most radionuclides, the external dose is several orders of magnitude less than the inhalation dose. As expected, the most significant external doses come from the gamma emitters Co-60 and Cs-137. Even for these radionuclides, the external dose is always less than two percent of the inhalation dose. This demonstrates that the worker doses from external radiation in an airborne plume are negligible compared to inhalation doses. Therefore, the accident analysis will calculate only the inhalation doses for the accidents involving airborne releases.

Table 8.0-5-1. Comparison of External Air Immersion Doses to Inhalation Doses

RADIONUCLIDE	EXTERNAL AIR IMMERSION DCF (SV/S PER BQ/M3)	INHALATION DCF (SV/BQ)	DOSE RATIO EXTERNAL DOSE / INHALATION DOSE
Am-241	8.18E-16	1.20E-04	2.65E-08
C-14	2.24E-19	5.64E-10	1.55E-06
Co-60	1.26E-13	5.91E-08	8.30E-03
Cs-137*	2.88E-14	8.63E-09	1.30E-02
Pu-239	4.24E-18	1.16E-04	1.42E-10
Sr-90*	1.98E-16	3.51E-07	2.19E-06
Tc-99	1.62E-18	2.25E-09	2.80E-06
Th-232	8.72E-18	4.43E-04	7.66E-11

* Short-lived decay products included.

For all accident consequence assessments that involve the uncontrolled release of radionuclides to the atmosphere, the radioactivity concentrations to be associated with a given volume of waste for the Compact Facility are presented in Table 8.0-5-2, and the radioactivity concentrations to be associated with a given volume of waste for the Federal Facility are presented in Table 8.0-5-3. The radionuclide concentrations provided in Tables 8.0-5-2 and 8.0-5-3 were selected based on information contained in Appendices 8.0-1 and 8.0-2. These appendices provided details on the waste streams that are projected for disposal at the WCS CWF and FWF facilities. The waste streams selected for the accident analysis present the largest inhalation dose hazard based on consideration of radionuclide concentrations and inhalation dose conversion factor for each radionuclide. Also considered was the dispersibility of the waste form. Four Class C waste streams and one Class B waste stream present a larger inhalation dose hazard than decontamination resins from Vermont Yankee based on consideration of only radionuclide concentrations and inhalation dose conversion factors. The Class C waste streams are "SOURCES" from Texas, "D&D PWR" from Texas, "D&D BWR" from Vermont, and "NFRCOMP" from Vermont. The Class B waste stream is "D&D PWR" from Texas. These waste streams are non-combustible and are expected to have small to negligible airborne releases under energetic accident conditions, and therefore were not selected for accident analysis. One Class A waste stream, "NCTRASH" from Vermont, presents a slightly larger inhalation dose hazard than decontamination resins from Vermont Yankee based on consideration of only radionuclide concentrations and inhalation dose conversion factors. This waste stream, which is comprised of non-compactable trash, was not selected for accident analysis because it contains predominantly non-combustibles items. Additionally, there is only 27 cubic feet of this waste stream from Middlebury College.

Table 8.0-5-2. Radioactivity Concentration for Compact Facility Waste Used in Accident Consequence Assessments

RADIONUCLIDE	CONCENTRATION (CI/M^3)
Be-10	3.04E-02
C-14	3.28E-02
Cl-36	8.52E-03
Co-60	3.21E+01
Ni-63	8.83E-01
Sr-90	1.98E-02
Tc-99	7.06E-06
I-129	6.71E-08
Pu-239	1.48E-02
Pu-241	5.30E-01
Cm-242	2.37E-04

Note: The above radionuclides are associated with 38 m^3 of Class A decontamination resins from Vermont Yankee.

Table 8.0-5-3. Radioactivity Concentration for Federal Facility Waste Used in Accident Consequence Assessments

RADIONUCLIDE	CONCENTRATION (Ci/m^3)
U-234	3.96E-01
U-235	3.06E-02
U-238	2.36E+00

Note: The above radionuclides are associated with thousands of cubic meters of Class A uranium oxides from the conversion of depleted uranium hexafluoride to deplected uranium oxides, expected to be primarily in the form of depleted U3O8 powder.

8.0-5.2 Container Breach

The breaching of one or more containers is a highly credible accident scenario. Containers can be breached by various mechanisms, including dropping, collision, crushing, and container defect. Additionally, the contents of an open container can be spilled. These mechanisms for breaching or rupturing a container could occur during vehicle transport or handling activities. Seismic activity could also result in the breaching of one or more containers by causing waste container handling equipment failure/malfunction, or by toppling of a stack of containers. The envisioned accident scenario involves substantial energetics, as opposed to, for example, a forklift tine puncturing a 55-gallon drum, or localized corrosion producing a small opening in a drum.

A 55-gallon drum full of waste is assumed to be involved in the accident. As shown in the dose calculations below, larger waste containers or multiple 55-gallon drums could be involved in accidents without causing unacceptably high radiological doses. A 55-gallon drum is a convenient and common waste container to use for purposes of estimating accident doses. The accident scenario doses can be extrapolated to larger containers or multiple containers if desired.

For the Compact Facility, the critical waste stream radionuclide concentrations are as shown in Table 8.0-5-2. For the Federal Facility, the critical waste stream radionuclide concentrations are as shown in Table 8.0-5-3. Hence, the types and quantities of radioactive material involved in the accident [which is termed the material at risk (MAR)] are determined by multiplying the concentrations shown in Tables 8.0-5-2 and 8.0-5-3, respectively for each facility, by 55-gallons (0.208 m^3). To determine the potential inhalation dose to receptors of interest, the following equation is used:

$$\text{Inhalation Dose} = \text{MAR} \times \text{ARF} \times \text{RF} \times \chi/Q \times \text{BR} \times \text{DCF}$$

where

MAR = Material At Risk (Ci)

ARF = Airborne Release Fraction

RF = Respirable Fraction

χ/Q = Dispersion Factor (sec/m^3)

BR = Breathing Rate (m^3/sec)

DCF = Dose Conversion Factor (mrem/Ci).

A review of pertinent technical information and various studies show that for essentially all radionuclides and credible accident scenarios, immersion in an airborne plume of radioactive material is a negligible contributor to the total dose received by a given receptor relative to the inhalation pathway. Additionally, DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*, states "The NRC then stated that 'for all materials of greatest interest for fuel cycle and other radioactive material licensees, the dose from the inhalation pathway will dominate the dose' and dismissed the other contributors." Therefore, as previously discussed, the immersion pathway dose has not been calculated for accidents evaluated herein.

ARFs and RFs are taken from DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Non-Reactor Nuclear Facilities*. In all or nearly all instances, the fractions and rates presented in DOE-HDBK-3010-94 have been adopted by the American Nuclear Society in ANSI/ANS-5.10-1998, *Airborne Release Fractions at Non-Reactor Nuclear Facilities*. For the breach or rupture of a waste container, use of median values (instead of bounding values) for the ARF and RF for the local worker are considered appropriate since workers are trained to minimize their exposures to hazardous materials (i.e., "see and flee"), and an airborne release of powder of depleted uranium oxides is likely to be visible. For members of the public, bounding ARF and RF values are used. For the CWF waste stream being evaluated under this accident condition, median values are not provided in the cited references, and hence the bounding ARF of 1.0E-03 and RF of 1.0E-01 are used for the worker and members of the public. These values are for "free-fall and impaction stress" of surface contaminated combustible solids "for the situation where the combustible material is packaged in a relatively robust container (e.g. hard pail, drum) that is opened or fails due to impact with the floor or impaction by falling debris (shock-vibration induced by impact)." The values are "based on reasoned judgment that suspension under these circumstances will be bounded by suspension postulated for debris impacting powders in cans." DOE-HDBK-3010-94 specifically cites resins as a type of combustible material included in the evaluation. For the breach or rupture of a waste container at the FWF, the median ARF for powders is 3.0E-04 and median RF is 0.5, and the bounding ARF for powders is 2.0E-3 and bounding RF is 0.3. Subsequent to the accident at the CWF or FWF, potential additional dose due to "aerodynamic entrainment and resuspension" is not calculated because of the very small airborne release rate associated with these phenomena, which is on the order of 1.0E-05 per hour.

The calculation of χ/Q is presented in numerous technical documents and textbooks. For an individual standing in the centerline of a ground level puff release, the equation for calculating χ/Q is as follows:

$$\chi/Q = (PD)/(\pi(2\pi)^{0.5}\sigma_x\sigma_y\sigma_z)$$

where

σ_x	=	horizontal standard deviation factor in the x-direction (meters)
σ_y	=	horizontal standard deviation factor in the y-direction (meters)
σ_z	=	vertical standard deviation factor (meters)
PD	=	puff duration (assumed to be one second).

The σ_x, σ_y, and σ_z factors represent the spread and dilution of the puff as a function of distance from the point of the release. It is standard to assume that σ_x equals σ_y. The standard deviations

σ_y and σ_z vary with downwind distance, x, from the point of the release, and stability class, s, according to the following equations:

$$\sigma_y = a(s) \cdot x^{b(s)}$$

$$\sigma_z = c(s) \cdot x^{d(s)}$$

where the factors a, b, c, and d are taken from Scire 1990 and shown in Table 8.0-5-4 for relevant receptor distances. The factors are a function of atmospheric stability class. Stability class F, corresponding to very stable atmospheric conditions and a wind speed of 1 m/s, were assumed for the accidents involving workers. Accidents involving workers could occur in the disposal units while placing waste in canisters or in the waste handling buildings. Class F conditions are the most conservative and lead to the highest estimates of airborne concentrations and doses. Of all the stability classes (A-F), Class F best represents a conservative case for workers in close proximity to the accident.

For offsite doses, Class D stability conditions and the site-specific average wind speed of 3.1 m/s were assumed. Meteorological data in Section 2.3.1 show the frequency of the various atmospheric stability conditions. Class D is the most frequent, occurring 63% of the time. More stable conditions, Class E and F, occur 6% and 8% of the time, respectively. In general, stability classes E and F occur only at night when vertical temperature gradients are small. Therefore, Class D is the most stable condition that could occur during daylight (NRC 1980). Class D represents the most conservative choice of atmospheric stability during working hours.

The distance from the point of release to the on-site worker was assumed to be 10 meters. For several reasons, it is difficult to develop accurate radiological consequence assessments for workers in close proximity to an accident. The distance of 10 meters is considered reasonable, especially in consideration of other conservative aspects of the consequence assessment. At 10 meters, the above equations yield a χ/Q of 0.25 sec/m^3. Based on a review of expected operational practices and other licensing applications, the distance to an off-site individual was assumed to be 100 meters. The χ/Q at 100 meters was calculated to be 2.29E-04 sec/m^3. The nearest residence is located approximately 6000 meters from the Compact Facility and Federal Facility. To account for uncertainties in the location of person(s) associated with the nearest residence at any given time (e.g. they may be out exercising or doing other outdoor activities for a non-trivial fraction of a given year), the χ/Q associated with the nearest residence was conservatively calculated using a distance of 4000 meters. The value of χ/Q at this distance is 3.52E-08 sec/m^3.

Table 8.0-5-4. Standard Deviation Formula Parameters for a Puff Release

Receptor	Distance (meters)	Class	“a”	“b”	“c”	“d”
Worker	10	F	0.063	0.9	0.77	0.42
Off-site	100	D	0.13	0.9	0.57	0.58
Nearest Residence	6,000*	D	0.13	0.9	0.57	0.58

*For reasons stated in the text, namely to ensure a conservative analysis, the actual distance used in equations was 4,000 meters.

The breathing rate used for consequence assessment purposes is 2.57E-04 m^3/sec, which is equivalent to 22.2 m^3/day. This breathing rate for adults is given in ICRP Publication 71, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients*.

Inhalation dose conversion factors were taken from Federal Guidance Report Number 11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. When more than one inhalation DCF was provided for a given radionuclide (because of various lung clearance class values), the largest DCF was always selected.

For the breach or rupture of a 55-gallon drum at the Compact Facility, the committed effective dose equivalents to receptors at 10 meters, 100 meters, and 6000 meters are 23.9 mrem, 2.18E-02 mrem, 3.36E-06 mrem, respectively. The dose to the on-site worker is well below the annual occupational dose limit of 5 rem stipulated in 30 TAC §336.305. The dose to the off-site receptor is well below the dose limit of 100 mrem for a member of the public, as stipulated in 30 TAC §336.313. The results indicate that a volume of waste equivalent to over 1,100 times 55 gallons could be involved in a breach or rupture accident with the dose to an off-site receptor remaining below 100 mrem.

For the breach or rupture of a 55-gallon drum at the Federal Facility, the committed effective dose equivalents to receptors at 10 meters, 100 meters, and 6000 meters are 674 mrem, 2.47 mrem, and 3.79E-04 mrem, respectively. The critical FWF waste stream (depleted uranium oxide) will likely be shipped in very robust steel cylinders, such that a container drop would cause no releases. However, even under this conservative assumption that the waste is shipped in standard steel drums, the dose to the on-site worker is below the annual occupational dose limit of 5 rem stipulated in 30 TAC §336.305. The dose to the off-site receptor is well below the dose limit of 100 mrem for a member of the public, as stipulated in 30 TAC §336.313. The results indicate that a volume of waste equivalent to about 40 times 55 gallons could be involved in a breach or rupture accident with the dose to an off-site receptor remaining below 100 mrem.

8.0-5.3 Explosion or Fire

A highly energetic event such as an explosion or fire is a credible event. However, the likelihood of an explosion or fire that involves a significant quantity of waste is considered extremely unlikely. Studies have shown that a fire in one drum does not propagate to others. WHC-SD-SQA-ANAL-501, *Fire Protection Guide for Waste Drum Storage Arrays*, prepared by Hughs Associates Inc. (HAI), states that “the burning of drum contents was found to be extremely slow… Similarly, heat fluxes to neighboring drums were found to be quite low.” Hence, “horizontal drum to drum fire propagation based on the burning of drum contents within a drum is not expected. An analysis for rack storage configurations also showed that drum burning cannot support upward fire propagation in the rack.” Furthermore, even waste containers that are involved in an external fire (e.g., a “pool” fire) often do not release significant quantities of their inventory. WHC-SD-SQA-ANAL-501 states that a Sandia National Laboratory test put 12 drums filled with combustible wastes in a 10 ft diameter salt filled pan with 50 gallons of diesel fuel. “Of the 12 drums tested, one vented unlined drum failed by violently blowing the lid and some contents out of the drum. Two other lined drums vented by flaring, and one lined drum ruptured at the base of the drum late in the test. Eight other drums did not vent or fail.” The subject document also states that Westinghouse Hanford Company burned down a wooden building with four drums (loaded with combustibles) on a bi-level steel rack, two drums per tier. None of the drums experienced violent lid loss. They all vented at the lid seal. Lastly, in the HAI tests, two target drums containing 2.3 kg of paper were exposed to a fire consisting of the standard drum contents. Neither of the drums experienced lid loss failure.

A vehicle (e.g., typical commercially available forklift or truck) accident is considered to be the initiating event for a fire or explosion that involves a substantial quantity of waste. However, for the Compact Facility and Federal Facility, the likelihood of such an event is extremely small and borders on the threshold of credibility. For example, DOE/RL-2001-0036, *Hanford Site Transportation Safety Document*, provides an estimate, based on site-specific data, of 5.0E-09 per mile for a vehicle accident that involves fire. However, it is noted that Department of Energy (DOE) sites have several measures in place that reduce vehicle accident frequencies on DOE sites relative to commercial and private vehicle accident frequencies. DOE/EIS-0212, *Final Environmental Impact Statement for Safe Interim Storage of Hanford Tank Wastes*, states that the frequency of truck accidents in the State of Washington is 4.2E-07 per mile. SAND84-0062, *The Transportation of Nuclear Materials*, states “Data from summaries of accident reports filed by commercial motor carriers indicate that fires occur in approximately 1.6% of all truck accidents.” Hence, using commercial data, truck accidents that involve fires occur with a frequency of 6.7E-09 per mile. A threshold often used in the nuclear industry for assessing the credibility of a given accident or accident sequence is 1.0E-06 per year. The total vehicle miles driven per year at the Compact Facility and Federal Facility, respectively, would facilitate assessing the proximity of the subject accident’s annual frequency relative to this threshold. Using 6.7E-09 per mile, at least 149 vehicle miles would need to be driven at a facility in a given year to reach the threshold.

Typical forklifts generally present less of a fire hazard than trucks (at least in terms of fire intensity and duration, key parameters in fire hazards analyses) due to having substantially smaller fuel tanks than trucks and lower combustibles in general than trucks (e.g. truck tires are a significant fuel source). Forklift speeds are typically much lower than trucks, thereby reducing the likelihood that the energetics of an accident will result in a fire or explosion.

The analysis assumes that a fire or explosion caused by a truck accident is the initiating event. As discussed above, the likelihood of a fire affecting multiple waste containers is quite low, even when several containers are engulfed in an external “pool” fire fueled by diesel. The consequence assessment of an explosion or fire involving a 55-gallon drum uses the same assumptions as those used in the container breach assessment, except different ARF and RF values are used, and, for the fire analysis, the continuous release equation for calculating χ/Q is used. For the CWF waste stream, the bounding ARF and RF values associated with “explosive stress” were used since the bounding ARF is two times larger for “explosive stress” than for “thermal stress” of “contaminated combustible materials heated/burned in packages.” Section 5.1 of DOE-HDBK-3010-94 gives a bounding ARF of 1.0E-03 and RF of 1.0 for “explosive stress” acting on contaminated, combustible solids. This ARF was applied to all radionuclides, except an ARF of 1.0 was conservatively assumed for I-129. Since this one analysis for the CWF is intended to bound an explosion or fire scenario, the larger χ/Q values associated with the modeling of a continuous release were used. The difference between the ARF x RF value for explosive stress and thermal stress for powders is much larger than a factor of two, and hence for the FWF two separate calculations are appropriate. The bounding ARF of 5.0E-03 and RF of 0.3

were used for blast effects on powder, while the bounding ARF of 6.0E-03 and RF of 1.0E-02 were used for thermal stress on powder. These values are provided in Section 4.4 of DOE-HDBK-3010-94. A puff release was assumed for the FWF explosion scenario.

A continuous release (of finite duration, such as for several minutes) is modeled for consequence assessment purposes for a fire accident scenario, as opposed to a puff (i.e., instantaneous) release which is more likely than an explosion-related accident. For ground level releases, the simplified equation for calculating χ/Q from a continuous release is as follows:

$$\chi/Q = 1/(\pi\sigma_y\sigma_z u)$$

where

σ_y	=	horizontal dispersion coefficient (meters)
σ_z	=	vertical dispersion coefficient (meters)
u	=	average wind speed (meters per second)

Various means for calculating σ_y and σ_z exist. These means are presented in various technical documents and textbooks. Formulas recommended by G. A. Briggs of the Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge, Tennessee for open country conditions are shown in Table 8.0-5-5. The variable, x, shown in Table 8.0-5-5 is the distance (in meters) downwind from the point of the release. The equations shown in Table 8.0-5-5 are used in various consequence assessment computer codes, including CAP88. The equations are presented in various literatures, including *CAP88-PC Version 2.1 Updated User's Guide*. Values for χ/Q using σ_y and σ_z values determined through the equations shown in Table 8.0-5-5 and the equation shown above compare favorably to those calculated by widely used radiological consequence assessment computer codes developed by national laboratories, such as HOTSPOT (developed by Lawrence Livermore National Laboratory) and Radiological Safety Analysis Code (RSAC) (developed by the Idaho National Engineering and Environmental Laboratory). Particularly comparable results are obtained when a 10 minute sampling time is used in the σ_y calculation in HOTSPOT, and when Hilsmeier-Gifford σ values are used in RSAC. Hilsmeier-Gifford σ values are used for releases "from a few minutes to 15 minutes in duration."

Table 8.0-5-5. Equations for Calculating Horizontal and Vertical Dispersion for Various Stability Classes

Pasquill-Gifford Stability Class	Horizontal Dispersion, σ_y	Vertical Dispersion, σ_z
A	$(0.22)(x)(1+0.0001x)^{-1/2}$	$(0.20)(x)$
B	$(0.16)(x)(1+0.0001x)^{-1/2}$	$(0.12)(x)$
C	$(0.11)(x)(1+0.0001x)^{-1/2}$	$(0.08)(x)(1+0.0002x)^{-1/2}$
D	$(0.08)(x)(1+0.0001x)^{-1/2}$	$(0.06)(x)(1+0.0015x)^{-1/2}$
E	$(0.06)(x)(1+0.0001x)^{-1/2}$	$(0.03)(x)(1+0.0003x)^{-1}$
F	$(0.04)(x)(1+0.0001x)^{-1/2}$	$(0.016)(x)(1+0.0003x)^{-1}$

Note: The downwind distance from the source is denoted as "x"

Consequence assessment calculations for workers assume a ground level release, a wind speed of 1.0 meter per second and stability class F meteorological conditions. These atmospheric conditions are widely used in the nuclear industry for providing conservative estimates. For offsite doses, the site-specific average wind speed of 3.1 meters per second and class D conditions were assumed. As discussed above, Class D conditions are the most frequent at the Site (63% of the time) and are the most conservative conditions that occur during daylight hours.

The distance to receptors of interest is addressed in the container breach accident scenario. (As previously discussed, to account for uncertainties in the location of person(s) associated with the nearest residence at any given time, the χ/Q associated with the nearest residence was conservatively calculated using a distance of 4000 meters.) Using the equations in Table 8.0-5-5 and the equation for χ/Q for a continuous release noted above, the χ/Qs associated with a worker, off-site individual, and nearest resident are 4.98 sec/m^3, 2.31E-03 sec/m^3, and 4.19E-06 sec/m^3, respectively.

As previously stated, the equation to determine the potential inhalation dose to receptors of interest is as follows:

$$\text{Inhalation Dose} = \text{MAR x ARF x RF x } \chi/Q \text{ x BR x DCF}$$

For the CWF energetic accident analysis, which is intended to bound the potential consequences from an explosion or fire driven release, and for the FWF fire scenario, it is assumed that the uncontrolled airborne release of radioactive material occurs for 10 minutes, and that a worker is exposed to the plume for 20 seconds. Therefore, for the estimated worker dose, the right side of the equation above is multiplied by 3.33E-02 (i.e., 20 seconds divided by 600 seconds) to account for the worker's duration of exposure to the plume. The assumption is considered reasonable since workers are trained to evacuate in the event of an accident and to don a respirator before returning to the scene. Off-site receptors, including those at the nearest residence, are assumed to be exposed for the full duration of the plume. For the off-site receptor evaluated at 100 meters, this assumption is considered to be very conservative since it is highly likely that a receptor at this location would be directed to relocate, or understand without external direction that relocation is appropriate.

For a highly energetic event such as an explosion or fire involving a 55-gallon drum at the Compact Facility, the committed effective dose equivalents to receptors at 10 meters, 100 meters, and 6,000 meters are 158 mrem, 2.20 mrem, and 3.99E-03 mrem, respectively. The dose to the on-site worker is below the annual occupational dose limit of 5 rem stipulated in 30 TAC §336.305. The dose to the off-site receptor is below the dose limit of 100 mrem for a member of the public, as stipulated in 30 TAC §336.313. The results indicate that a volume of waste equivalent to forty five 55-gallon drums could be involved in a highly energetic event with the dose to an off-site receptor still remaining below 100 mrem. If the median ARF of 8.0E-05 for "thermal stress" of "contaminated combustible materials heated/burned in packages" is used in the analysis instead of the bounding ARF of 1.0E-03 for "explosive stress," then a volume of waste equivalent to 560 55-gallon drums could be involved in a highly energetic event with the dose to an off-site receptor remaining below 100 mrem.

For a fire involving a 55-gallon drum at the Federal Facility, the committed effective dose equivalents to receptors at 10 meters, 100 meters, and 6000 meters are 179 mrem, 2.48 mrem, and 4.51E-03 mrem, respectively. The dose to the on-site worker is below the annual occupational dose limit of 5 rem stipulated in 30 TAC §336.305. The dose to the off-site receptor is below the dose limit of 100 mrem for a member of the public, as stipulated in 30 TAC §336.313. The results indicate that a volume of waste equivalent to forty 55-gallon drums could be involved in a fire with the dose to an off-site receptor remaining below 100 mrem. The FWF dose analysis is based on the conservative assumption that the waste form is combustible. However, the depleted uranium oxide is non-combustible so the dose estimates are conservatively high.

For an explosion involving a 55-gallon drum at the Federal Facility, the committed effective dose equivalents to receptors at 100 meters and 6000 meters are 6.17 mrem and 9.49E-04 mrem, respectively. The dose to the off-site receptor is below the dose limit of 100 mrem for a member of the public, as stipulated in 30 TAC §336.313. The dose to a worker at 10 meters from the explosion is not provided since the blast effects are likely of much greater impact and concern than potential radiological consequences. Additionally, other uncertainties in calculating a reasonable potential worker dose are involved in this scenario, such as the worker's breathing rate and location of the worker's face relative to the plume centerline if the worker is unconscious, and the location of the explosion relative to the location of the radiological material/waste and worker since an explosion would not likely originate within the radiological material/waste. Regardless, the worker's inhalation dose would be at most on the order of a few tens of rem, and hence not life threatening.

Because of the small ARF x RF value associated with the thermal stress of powder, the potential radiological consequences of a fire impacting the FWF waste stream presenting the second largest inhalation health hazard were considered. Waste streams from multiple waste generators tied for the second largest inhalation health hazard. The waste streams are all Class B "complex wide" DOE wastes, of which some fraction is assumed to be combustible. The dose to receptors of interest from a fire impacting a 55 gallon container of this Class B waste (assumed to be combustible for purposes of this analysis) is very comparable to the dose given above for the powdered depleted uranium oxide.

Lung doses were calculated for the above scenarios. Organ specific dose conversion factors were taken from Federal Guidance Report No. 11. For the CWF, the lung dose to the worker at 10 m is 580 mrem. For the FWF fire scenario, the lung dose to the worker at 10 m is 1490 mrem. The lung doses to an individual at the site boundary (100 m) were 8.05 mrem for the CWF, 20.6 mrem for the FWF fire scenario, and 51.3 mrem for the FWF explosion scenario. Doses to the whole body are generally not calculated under the dosimetry models of ICRP 26 and ICRP 30, upon which Federal Guidance Report No. 11 dose factors are based. The committed effective dose equivalent represents an organ weighted dose commitment to the entire body and is analogous to the whole body dose used in older, outdated dosimetry models.

8.0-5.4 Tornado or Severe Winds

The likelihood of a tornado or extreme straight winds of sufficient intensity to result in the breaching of container(s) and subsequent release of significant quantities of radioactive material is extremely small. The Compact Facility and Federal Facility are located on the Texas-New Mexico border. DOE's Waste Isolation Pilot Plant (WIPP) is located approximately 50 miles west of the subject facilities. DOE/WIPP-95-2065, *Waste Isolation Pilot Plant Contact Handled*

(CH) Waste Safety Analysis Report, Revision 7, states the following regarding tornadoes and strong winds:

> "For the period 1916-1958, 75 tornadoes were reported in New Mexico on 58 tornado days. Data for 1953 through 1976 indicate a state wide total of 205 tornadoes on 152 tornado days, or an average of 9 tornadoes a year on 6 tornado days. The greatest number of tornadoes in 1 year was 18 in 1972; the least was 0 in 1953. The average tornado density in New Mexico during this period was 0.7 per 1,000 mi^2. Thom has developed a procedure for estimating the probability of a tornado striking a given point. The method uses a mean tornado path length and width and a site specific frequency. Applying Thom's method to the WIPP facility yields a point probably of 0.00081 on an annual basis, or a recurrence interval of 1,235 years. An analysis by Fujita yields a point tornado recurrence interval of 2,832 years in the Pecos River Valley. According to Fujita, the WIPP design basis tornado with a million year return period has a maximum wind speed of 183 mi/hr, translational velocity of 41 mi/hr, and a maximum rotational velocity radius of 325 ft. The fastest 1-min wind ever recorded at Roswell was 75 mi/hr from the west in April 1953. Windstorms with speeds of 50 knots or more occurred ten times (during the period between 1955 and 1967), about one a year. The 100-year recurrence 30-foot level wind speed in southeastern New Mexico is 82 mi/hr. Based on a gust factor of 1.3, the highest instantaneous gust expected once in 100 years at 30 ft above grade is 107 mi/hr."

Relevant DOE design guidance states that no tornado design criteria would be specified for facilities such as the Compact Facility and Federal Facility. Based on DOE-STD-1021-93, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*, the maximum performance category (PC) that the subject facilities' structures, systems, and components would be placed in is PC-2 because there are no credible accidents that could produce a total effective dose equivalent approaching 25 rem for a member of the public, which is the criterion for PC-3 designation. (DOE-STD-1021-93 identifies five PCs, PC-0 through PC-4.) DOE-STD-1020-2002, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, does not specify tornado design criteria for PC-2 (and lower PC) structures, systems, and components.

Consequence assessment calculations performed for the explosion or fire accident scenario assume stability class F meteorological conditions with a wind speed of 1.0 meter per second. Stability class F corresponds to very stable atmospheric conditions. Stability class D corresponds to "windy days or the transition times of dawn and dusk." Class D is the most frequently occurring stability class. The dispersion factors (χ/Q) for stability class D and a 45 meter per second (100 mph) wind are 336, 324, and 280 times smaller at 10 meters, 100 meters, and 4,000 meters, respectively, than for stability class F and a 1.0 meter per second wind. It is therefore concluded that it is not credible that a tornado or severe winds could result in doses to receptors of interest that would exceed relevant regulations (e.g., 30 TAC §336.313). Using the same assumptions (including ARFs and RFs) used in the CWF fire/explosion analysis, a volume of Compact Facility waste equivalent to 659 55-gallon drums would need to be impacted to produce a 100 mrem committed effective dose equivalent to a receptor located 100 meters from the point of the release. Using the explosion accident scenario, the corresponding volume for Federal Facility waste is equivalent to 375 55-gallon drums.

8.0-5.5 Flooding

Flood control features at the facility are designed to prevent the flow of surface water into the disposal units. The disposal units are located near the high point of the local topography and above the 100-year flood plain to minimize the potential for run-on. Berms around the disposal units will divert all rainfall and floodwater on the ground surface away from the disposal units. Surface water that leaves the vicinity of the disposal units will not have come in contact with waste materials. Any potentially contaminated water will remain in the disposal units and be collected in sumps. This water will be used for dust suppression in the controlled areas or will be treated and released.

8.0-5.6 Crane Malfunction Suspends High Radiation Package

A crane malfunction or other equipment failure could result in a waste container remaining suspended for an extended period of time. Most waste containers are expected to have on-contact dose rates that exceed 100 mrem/hr. The consequence assessment assumes that the suspended waste container has a dose rate of one rem per hour at 30 centimeters. Waste with a dose rate greater than one rem per hour constitutes less than 10 percent of the waste available for disposal. In addition radiation safety and ALARA practices would require that waste packages with dose rates higher than 1 rem per hour be shielded. Modeling the waste container as a point source, the computer code MicroShield 5.05 yields a dose rate of one rem per hour at 30 centimeters for a source of 26.08E-02 curies of Cs-137. At a distance of one meter, 10 meters, 100 meters, and 4,000 meters (used to conservatively estimate the dose rate for a receptor associated with the nearest residence 6 km away), the dose rates are 90 mrem/hr, 0.89 mrem/hr, 7.54E-03 mrem/hr, and 1.23E-19 mrem/hr, respectively. An on-site worker would need to be located near the suspended waste container for many hours to exceed the annual occupational dose limit of 5 rem stipulated in 30 TAC §336.305. For an individual member of the public, 30 TAC §336.313 states that the dose rate in any unrestricted area from external sources shall not exceed two mrem per hour. The dose rate associated with this scenario is substantially less than two mrem per hour for an off-site individual. In addition, the waste handling operations will take place below ground in the disposal trenches. A direct line-of-sight exposure from a waste package to an off-site individual would be impossible.

8.0-5.7 Waste Possession Limits

The possession limits establish the amounts of radioactive material at the CWF and FWF that have been received at the Site, but have not been placed in the final disposal location. This includes material being received, inspected, unloaded, and temporarily staged. The possession limits ensure that the potential radiological consequences to human health will not exceed a specified criterion. This document presents the criterion that was used and the analyses that were performed to establish a possession limit at the CWF and FWF.

The criterion selected for determining the possession limit at the FWF and CWF is a 1-rem inhalation dose to an offsite individual from an accidental fire in the waste staging area. For purposes of this analysis, energetic accident conditions are represented by the airborne release phenomena associated with thermal stress/fire. For purposes of setting possession limits, the nearest off-site receptor is assumed to be located at the WCS property boundary, which is about 1,000 meters from the waste staging area.

The 1-rem criterion was selected because (1) it is consistent with other license application(s), in particular for an 11e(2) byproduct material facility, and (2) it is consistent with the Protective Action Guide (PAG) for initiating protective actions for the public (such as evacuation or sheltering) given in Environmental Protection Agency (EPA) 400-R-92-001, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*. EPA 400-R-92-001 states that “Although the PAG is expressed as a range of 1-5 rem, it is emphasized that, under normal conditions, evacuation of members of the general population should be initiated for most incidents at a projected dose of 1 rem.”

For each waste facility (CWF and FWF), the inventory was divided into low and high activity wastes. The low activity, contact handled, wastes pass through the staging buildings at the CWF or FWF. The high activity, remote handled, wastes do not pass through the staging buildings. After receipt and initial inspection, the high activity wastes go directly to the disposal units. An accident involving the high activity wastes would have little or no consequences because the wastes arrive in shielded containers and are generally non-combustible waste forms.

The worst case accident would involve a fire at one of the waste staging buildings. The CWF, FWF-CDU, and FWF-NCDU each have a staging building, so accidents were evaluated at all three. The postulated fire was assumed to involve all of the waste in the staging building.

The waste inventories were divided into four categories, as defined in Texas regulations found in 25 TAC 289.254(p)(1). The accidents doses were calculated for each category and the resulting possession limits are also given by category. Assumptions used in the accident analysis include the following:

- Product of Airborne Release Fraction (ARF) and Respirable Fraction (RF) is 5.0E-04
- Class F (most stable) atmospheric stability conditions
- Wind speed is 1 meter per second
- Distance from staging buildings to property boundary is 1,000 meters

The inhalation dose was calculated from the entire inventory expected at each waste staging building. The resulting dose was then scaled to equal 1 rem. The waste inventories at each staging building were scaled by the same amount to calculate the possession limits. The resulting limits are such that the maximum dose from an accident would be no more than 1 rem to an offsite individual.

Table 8.0-5-6 shows the proposed possession limits that correspond to a maximum accident dose of 1 rem to an offsite individual. The limits are given in terms of the number of curies in each of the four radionuclide categories. The spreadsheets calculations that form the basis for the possession limits are included on the attached CD at the end of this appendix.

Table 8.0-5-6. Proposed Possession Limits

CWF Staging Building	**Category 1**	**Category 2**	**Category 3**	**Category 4**	**Total Inventory**
Inventory (Ci)	5.83	0.843	1,430	9,020	10,500
Accident dose based on total inventory in each category (mrem)	67.1	0.0946	201	1.32	270
Possession Limits (Ci)	22	3	5,300	33,000	
FWF-CDU Staging Building	**Category 1**	**Category 2**	**Category 3**	**Category 4**	**Total Inventory**
Inventory (Ci)	12,900	4,790	24,500	906,000	948,000
Accident dose based on total inventory in each category (mrem)	3.37E+05	5.07E+04	2.48E+05	6.73E+00	6.36E+05
Possession Limits (Ci)	20	8	40	1,400	
FWF-NCDU Staging Building	**Category 1**	**Category 2**	**Category 3**	**Category 4**	**Total Inventory**
Inventory (Ci)	51.9	3,080	3,100	1,250	7,500
Accident dose based on total inventory in each category (mrem)	4,330	35,100	31,900	0.583	71,300
Possession Limits (Ci)	1	43	44	18	

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ATTACHMENT A: COMPACT DISK OF SUPPORTING DATA