STONE & WEBSTER ENGINEERING CORPORATION

CALCULATION TITLE PAGE

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▲5010.64 (FRONT)

CLIENT & PROJECT: Private Fuel Storage Limited Liability Corp. / Private Fuel Storage Facility

CALCULATION TITLE (Indicative of the Objective): Postulated Release of Removable Contamination from Canister Outer Surfaces - Dose Consequences

QA CATEGORY (✓): ☑ I - NUCLEAR SAFETY RELATED ☐ II ☐ III ☐ ____ OTHER

CALCULATION IDENTIFICATION NUMBER

J. O. OR W.O. NO.	DIVISION & GROUP	CURRENT CALC. NO.	OPTIONAL TASK CODE	OPTIONAL WORK PACKAGE NO.
05996.01	Rad Protection	UR-3	N.A.	N.A.

* APPROVALS - SIGNATURE & DATE

PREPARER(S)/DATE(S)	REVIEWER(S)/DATE(S)	INDEPENDENT REVIEWER(S)/DATE(S)	REV. NO. OR NEW CALC NO.	SUPERSEDES * CALC. NO. OR REV. NO.	CONFIRMATION *REQUIRED (✓) YES	NO
J.R. Johns [signature] 6/5/97	W.P. Hennessy [signature] 6/15/97	W.P. Hennessy [signature] 6/15/97	0	N.A.		✓
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PREPARER/DATE J.R. Johns 5/4/98	REVIEWER/CHECKER/DATE J.L. Coryn 5-5-98	INDEPENDENT REVIEWER	
SUBJECT/TITLE Postulated Release of Removable Contamination from Canister Outer Surfaces -Dose Consequences		QA CATEGORY/CODE CLASS I	

TABLE OF CONTENTS AND HISTORICAL DATA
(Revisions, Additions, Deletions, Etc.)

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CALCULATION OBJECTIVE

The objective of this calculation is to determine conservative doses at the Private Fuel Storage Facility (PFSF) Owner Controlled Area (OCA) boundary and at 150 meters from the postulated release of contamination from the outer surfaces of a canister. In addition, concentrations inside the Canister Transfer Building resulting from this postulated accident are calculated for comparison with 10 CFR 20 derived air concentration occupational values.

CALCULATION METHOD / ASSUMPTIONS

It is conservatively assumed that the entire outer surface of a canister is covered with removable contamination at a concentration of 22,200 dpm/100 cm^2, slightly above the maximum allowable limit of PFSF Proposed Technical Specification 3/4.1, "Canister External Surface Contamination", 22,000 dpm/100 cm^2. It is assumed that all of the surface contamination is Co-60, consistent with the approach used by Sierra Nuclear Corporation in their evaluation of this postulated accident in the TranStor SAR (Reference 1). This particular event is not analyzed in the HI-STORM SAR (Reference 2). It is conservatively assumed that 100% of this external surface contamination is released from the vendor's canister having the greatest external surface area. Internal inhalation doses and external submersion doses are calculated to individuals assumed to be 150 meters and 500 meters away, using the dispersion coefficients (χ/Qs) calculated for these distances in Reference 3. Dose conversion factors are taken from Reference 4 for inhalation and from Reference 5 for submersion. The fraction of particulates that is actually inhaled is based on Reference 6. Adding the committed effective dose equivalent (CEDE) from inhalation (an internal committed dose) to the external dose from submersion results in a calculated total effective dose equivalent (TEDE) at these two distances. It is also assumed that the 31.2 μCi of Co-60 postulated to be released from the outer surfaces of a canister into the high bay portion of the Canister Transfer Building remains in the building with uniform mixing. The concentration of Co-60 is calculated in the free volume of the high bay area and compared with 10 CFR 20 permissible derived air concentration values for occupational workers.

REFERENCES

1. Safety Analysis Report for the TranStor Storage Cask System, SNC-96-72SAR, Sierra Nuclear Corporation, Docket 72-1023, Revision B, March 1997.

2. Topical Safety Analysis Report for the Holtec International Storage and Transfer Operation Reinforced Module Cask System (HI-STORM 100 Cask System), Holtec Report HI-951312, Docket 72-1014, Revision 1, January 1997.

3. SWEC Calculation No. 0599601-UR-1, "Accident χ/Qs for the PFSF", prepared by J.R. Johns, dated June 4, 1997.

4. Federal Guidance Report No. 11, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, DE89-011065, U.S. Environmental Protection Agency, 1988.

5. Regulatory Guide 1.3, Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors, Revision 2, June 1974.

6. SAND80-2124, Transportation Accident Scenarios for Commercial Spent Fuel, Sandia National Laboratories, February 1981.

7. 10 CFR 20, Standards for Protection Against Radiation

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CONCLUSIONS

It was determined that the HI-STORM canister has the largest external surface area, of 312,000 cm^2. Assuming that the entire outer surface of a canister is covered with removable contamination at approximately the maximum allowable limit of PFSF Proposed Technical Specification 3/4.1 (22,000 dpm/100 cm^2) and that 100% of this activity is released from the outer surface of the canister and becomes airborne results in a source term of 31.2 µCi. Based on a review of the inhalation dose conversion factors in Reference 4 for Co-60, it is determined that the dose conversion factor for lung is higher than that for any other organ. Therefore, the lung is the maximally exposed organ. Committed Effective dose equivalents (CEDE) and committed dose equivalents (CDE) to the lung from inhalation were calculated at 150 m and 500 m distances, with the following results:

CEDE (150 m) = 1.58E-3 mrem
CDE (lung, 150 m) = 9.20 E-3 mrem

CEDE (500 m) = 2.18 E-4 mrem
CDE (lung, 500 m) = 1.28 E-3 mrem

In addition to these internal committed doses from inhalation, external doses were calculated for submersion in the radioactive plume using the equations from Regulatory Guide 1.3 (Reference 5), with the following results:

Submersion dose (150 m) = 2.73 E-4 mrem
Submersion dose (500 m) = 3.78 E-5 mrem

The total effective dose equivalent (TEDE) is the sum of the internal CEDE from inhalation and the external dose from submersion, as follows:

TEDE (150 m) = 1.58 E-3 mrem + 2.73 E-4 mrem = 1.85 E-3 mrem

TEDE (500 m) = 2.18 E-4 mrem + 3.78 E-5 mrem = 2.56 E-4 mrem

These calculated dose equivalents, based on a conservative postulated accident scenario, are well within the 5 Rem to the whole body or any organ limit specified in 10 CFR 72.106(b) for design basis accidents, which applies to an individual located at or beyond the OCA boundary.

Assuming that the 31.2 µCi of Co-60 were released into the high bay of the Canister Transfer Building from a canister transfer cell, and assuming the activity remains in the building with uniform mixing in the high bay free volume, the calculated airborne concentration of 1.05 E-9 µCi/cm^3 of Co-60 is within the 10 CFR 20 (Appendix B, Table 1) derived air concentration value for occupational workers.

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CALCULATION

Determine External Surface Area of a Canister

HI-Storm

Dimensions of Holtec International's (Holtec's) HI-STORM canister are given in the following drawings in Section 1 of the HI-STORM SAR (Reference 2) as follows:

O.D. = 68.5 inches, (68.5 inch)(2.540 cm/inch) = 174.0 cm = D

Based on Holtec Drawing No. 1395, sheet 1 of 5, "HI-STAR 100 MPC-24 Construction", Rev. 5 - gives the outer diameter of the canister as 68 3/8 inches ± 7/32 inch. This is identical to the outer diameter of the MPC-68 canister, shown on Holtec Drawing No. 1401, sheet 1 of 4, "HI-STAR 100 MPC-68 Construction", Rev. 5.

Height = 190.5 inches, (190.5 inch)(2.540 cm/inch) = 483.9 cm = H

Based on Holtec Drawing No. 1396, sheet 1 of 6, "HI-STAR 100 MPC-24 Construction", Rev. 5 - gives the outer height of the canister as 190 1/2 inches + 1/16 inch, - 1/8 inch. This is identical to the outer height dimension of the MPC-68 canister, shown on Holtec Drawing No. 1402, sheet 1 of 6, "HI-STAR 100 MPC-68 Construction", Rev. 5.

Surface Area = $\pi DH + 2(\pi D^2)/4$

Surface Area = $\pi(174.0\ \text{cm})(483.9\ \text{cm}) + 2(\pi)(174.0)^2/4 = 3.12\ \text{E5 cm}^2$

TranStor

Dimensions of Sierra Nuclear Corporation's (SNC) TranStor canister (PWR and BWR canister dimensions are identical) are given in SNC Drawing No TSP-001, sheet 1 of 3, "TranStor PWR Basket Assembly", Rev. 5, as follows:

O.D. = 66.0 inches, (66.0 inch)(2.540 cm/inch) = 167.6 cm = D

Height = 192.25 inches, (192.25 inch)(2.540 cm/inch) = 488.3 cm = H

Surface Area = $\pi DH + 2(\pi D^2)/4$

Surface Area = $\pi(167.6\ \text{cm})(488.3\ \text{cm}) + 2(\pi)(167.6)^2/4 = 3.01\ \text{E5 cm}^2$

Removable Contamination on Outer Surfaces of a Canister

Since the HI-STORM canister has the largest surface area (3.12 E5 cm^2), this surface area is used to determine the total quantity of removable surface contamination on the outer surface of a canister. It is conservatively assumed that the entire outer surface of a canister is covered with removable contamination at 1.0 E-4 $\mu Ci/cm^2$, equal to 22,200 dpm/100 cm^2, slightly above the maximum allowable limit of PFSF Proposed Technical Specification 3/4.1, "Canister External Surface Contamination", 22,000 dpm/100 cm^2.

By definition, 1 Ci = 3.7 E10 decays per second = 2.22 E12 decays per minute (dpm)

1 μCi = 1 E-6 Ci = 2.22 E6 dpm

$$\frac{(22{,}000 \text{ dpm})}{100 \text{ cm}^2} \; \frac{(1 \mu\text{Ci})}{2.22 \text{ E } 6 \text{ dpm}} = 9.91 \text{ E-5} \frac{\mu\text{Ci}}{\text{cm}^2}$$

Assume the canister is coated with removable contamination at a concentration of 1.0 E-4 $\mu Ci/cm^2$, equal to 22,200 dpm/100 cm^2 (0.9% above the Technical Specification limit):

($312{,}000 \text{ cm}^2$) ($1.0 \text{ E-4 } \mu Ci/cm^2$) = 31.2 μCi.

Thus, it is assumed that 31.2 μCi of Co-60 is released from the surfaces of the canister and becomes airborne.

Inhalation Dose Calculation

Based on Table XX of Reference 6, 95% of Co-60 particulates are greater than 10 microns aerodynamic diameter and are non-respirable. Reference 6 is SAND80-2124, Transportation Accident Scenarios for Commercial Spent Fuel, Sandia National Laboratories, dated February 1981. A section of this Sandia report entitled "From Environment to People", beginning on pg 38 of this report, states:

> "Once radioactive material has been released to the environment, a number of other factors become important in determining whether the radioactive material will reach people. Two important factors are the fraction of particles smaller than 10 microns aerodynamic diameter (particles less than this size are respirable) and the fraction of the material that becomes suspended in air. Table XX presents the values for these variables: volatiles, particulates and noble gases … Particles released via the burst-rupture mechanism have been characterized in Reference 25. Table 42 in this reference indicates that no more than 3 percent of the particles released are smaller than 10 microns. So a value of 5 percent was assigned."

While the fraction of particles with aerodynamic diameter smaller than 10 microns is based on release from the inside of a fuel rod by means of cladding rupture, this fraction is considered to be generally applicable to release from the outer surfaces of a canister, and likely conservative since cobalt is transported directly from the canister surfaces to air and is not released through a crack or pinhole in fuel rod cladding which would be expected to filter some of the larger diameter particles. Assuming 95% of the Co-60 particles are greater than 10 microns aerodynamic diameter, only 5% of the activity is inhaled into the lungs and taken into the body. That fraction that is taken into the body produces a long term internal committed dose, calculated in the following paragraphs.

Doses are calculated assuming that an offsite individual is located at the OCA boundary at its closest point of approach to the Canister Transfer Building, 500 meters east of the Canister Transfer Building. This represents the nearest distance to the OCA boundary from a point where a loaded canister would be staged, stored, or handled at the PFSF. Doses are also calculated to an onsite individual assumed to be located 150 meters from the release point, which is an arbitrarily selected distance inside the OCA boundary.

Doses are calculated in accordance with the following equation:

Dose = (activity released, μCi)(χ/Q, sec/m^3)(respirable fraction)(breathing rate, m^3/sec)(dose conversion factor, mrem/μCi)

where:

Activity released is 31.2 μCi, as calculated above.
Adult breathing rate is assumed to be 0.02 m^3/min (0.02 m^3/min X 1 min / 60 sec = 3.3 E-4 m^3/sec) in accordance with pg. 10 of Reference 4.
Respirable fraction is taken to be 5%, based on Reference 6 and the above discussion.
Dispersion factors of 1.40 E-2 sec/m^3 for 150 meters and 1.94 E-3 sec/m^3 for 500 meters were calculated in Reference 3, conservatively assuming an instantaneous release, a 1 meter/sec horizontal wind speed, and Pasquill Stability Class F meteorological conditions.
Dose conversion factors for Co-60 are stated in Reference 4 (Table 2.1) to be 5.91 E-8 Sv/Bq for Committed Effective Dose Equivalent, and 3.45 E-7 Sv/Bq for Committed Dose Equivalent to the lungs, which is the highest dose conversion factor for any organ. A factor of 3.7 E9 is used to convert from Sv/Bq to mrem/μCi, in accordance with Reference 4 (pg. 121), resulting in 218.7 mrem/μCi for CEDE and 1,277 mrem/μCi for CDE to the lungs.

CEDE (150 m) = (31.2 μCi)(1.40 E-2 sec/m^3)(0.05)(3.3 E-4 m^3/sec)(218.7 mrem/μCi)
= 1.58 E-3 mrem

CDE (lung, 150 m) = (31.2 μCi)(1.40 E-2 sec/m^3) (0.05)(3.3 E-4 m^3/sec)(1,277 mrem/μCi)
= 9.20 E-3 mrem

CEDE (500 m) = (31.2 μCi)(1.94 E-3 sec/m^3) (0.05)(3.3 E-4 m^3/sec)(218.7 mrem/μCi)
= 2.18 E-4 mrem

CDE (lung, 500 m) = (31.2 μCi)(1.94 E-3 sec/m^3) (0.05)(3.3 E-4 m^3/sec)(1,277 mrem/μCi)
= 1.28E-3 mrem

Submersion Dose Calculation

The submersion dose from this accident can be calculated by means of the equation for calculating the gamma dose rate in air from a semi-infinite cloud, given in NRC Regulatory Guide 1.3 (Reference 5), as follows:

$D\gamma = 0.25\ (E\gamma)\chi$

where:

$D\gamma$ is the gamma dose rate from a semi-infinite cloud in rad/sec.
$E\gamma$ is the average gamma energy per disintegration (MeV/dis).
χ is the concentration of gamma emitting isotope in the cloud (Ci/m^3).

The average gamma energy per disintegration of a Co-60 atom is 1.17 MeV+ 1.33 MeV = 2.50 MeV emitted per disintegration.

The time-integrated concentration of Co-60 in air is equal to the quantity of Co-60 assumed to be released times the χ/Qs calculated for this accident at the 150 meter and 500 meter distances. Using the same χ/Qs values used above for calculation of inhalation doses:

χ (150 m) = (31.2μCi) (1.40 E-2 s/m^3) = 4.37 E-1 μCi-s /m^3 = 4.37 E-7 Ci-s/m^3
This is a time-integrated concentration.

χ (500 m) = (31.2μCi) (1.94 E-3 s/m^3) = 6.05 E-2 μCi-s /m^3 = 6.05 E-8 Ci-s/m^3

$D\gamma$ (150 m) = 0.25 ($E\gamma$)χ, $D\gamma$ = 0.25 (2.50) (4.37 E-7) = 2.73 E-7 Rad
= 2.73 E-4 mrad

$D\gamma$ (500 m) = 0.25 ($E\gamma$)χ, $D\gamma$ = 0.25 (2.50) (6.05 E-8) = 3.78 E-8 Rad
= 3.78 E-5 mrad

Since the quality factor for gamma radiation is 1.0 (in converting from mrad to mrem), these equate to doses of 2.73 E-4 mrem at 150 meters and 3.78 E-5 mrem at 500 meters.

Total Effective Dose Equivalents

The total effective dose equivalent (TEDE) is the sum of the internal CEDE from inhalation and the external dose from submersion, calculated as follows:

TEDE (150 m) = 1.58 E-3 mrem + 2.73 E-4 mrem = 1.85 E-3 mrem

TEDE (500 m) = 2.18 E-4 mrem + 3.78 E-5 mrem = 2.56 E-4 mrem

These calculated dose equivalents, based on a conservative postulated accident scenario, are well within the 5 Rem to the whole body or any organ limit specified in 10 CFR 72.106(b) for design basis accidents, which applies to an individual located at or beyond the OCA boundary.

Activity Concentration in the Canister Transfer Building, Assuming Uniform Mixing of Co-60 in the Canister Transfer Building Atmosphere

It is assumed that the 31.2 µCi of Co-60 is released from the outer surfaces of a canister into the high bay portion of the Canister Transfer Building, and there is uniform mixing. The walls of a canister transfer cell are approximately 30 ft. high (based on discussions with Steve Smith - SWEC). The ceiling of the high bay area is approximately 75 ft above the building floor, at grade level, per SWEC Drawing No. 0599601-EA-9-B, "Canister Transfer Building Elevations -Sh1". Therefore, contamination released from a canister would not be trapped in the canister transfer cell in which the release occurred, but would tend to mix with air throughout the building. For conservatism, it is assumed the contamination mixes with only the air in the high bay portion of the Canister Transfer Building. The high bay area is approximately 63 ft wide by 260 ft long and includes canister transfer cells No. 1, 2, and 3, the transfer equipment laydown area, the LLW storage room (east of canister transfer cell No. 1), the crane aisle east of the transfer cells, the shipping cask load/unload bays No. 1 and 2, and the impact limiter laydown area (SWEC Drawing No. 0599601-EA-8-B, "Canister Transfer Building Floor Plan"). Based on these dimensions, the inside volume of the high bay area is:

Total Volume = (63 ft) (260 ft) (75 ft) = 1.23 E6 ft^3

Assume 15 % of this volume is occupied by equipment and walls, then the free volume inside the high bay area is approximately:

Free Volume = (0.85) (1.23 E6 ft^3) (2.832 E4 cm^3 / ft^3) = 2.96 E10 cm^3

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Assuming uniform mixing throughout the high bay free volume, the concentration of Co-60 would be:

$$\frac{31.2\ \mu Ci}{2.96\ E10\ cm^3} = 1.05\ E\text{-}9\ \mu Ci/cm^3$$

| 10 CFR 20 (Reference 7) Appendix B, Table 1, specifies derived air concentration values for occupational workers. For Co-60, the limits are 1 E-8 μCi/ml for cobalt oxides, hydroxides, halides, and nitrates and 7 E-8 μCi/ml for all other cobalt compounds. Since a cm^3 is the same volume as a ml, the calculated airborne concentration of 1.05 E-9 $\mu Ci/cm^3$ of Co-60 is less than the 10 CFR 20 derived air concentration values for occupational workers, and represents an acceptable concentration for occupational workers for this nuclide.