OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
CALCULATION COVER SHEET

1. QA: QA
Page: 1 Of: 18

2. Calculation Title CANISTER TRANSFER SYSTEM EVENT SEQUENCE CALCULATION			
3. Document Identifier (including Revision Number) CAL-CTS-SE-000001 REV00			
4. Total Attachments 2	5. Attachment Numbers – Number of pages in each I-1, II-12		
	Print Name	Signature	Date
6. Originator	Richard Morissette	Richard P Morissette	8/15/01
7. Checker	Jo Ziegler	Jo Ziegler	8/15/01
8. Lead	Dealis Gwyn	Dennis Richardson	8/16/01

9. Remarks

The event sequencies and the frequencies developed in this calculation for the Canister Transfer System are based on the "Department of Energy Spent Nuclear Fuel Canister, Transportation, and Monitored Geologic Repository Systems, Structures, and Components Performance Allocation Study", TDR-CRW-SE-000004 REV 00.

Revision History

10. Revision No.	11. Description of Revision
00	Initial Issue

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1. PURPOSE

The *Department of Energy Spent Nuclear Fuel Canister, Transportation, and Monitored Geologic Repository Systems, Structures, and Components Performance Allocation Study* (CRWMS M&O 2000b) allocated performance to both the canisters received at the Monitored Geologic Repository (MGR) and the MGR Canister Transfer System (CTS). The purpose of this calculation is to evaluate an assumed range of canister and CTS performance allocation failure probabilities and determine the effect of these failure probabilities on the frequency of a radionuclide release.

Five canister types are addressed in this calculation; high-level radioactive waste (HLW) canisters containing vitrified borosilicate glass, HLW canisters containing immobilized plutonium surrounded by borosilicate glass (Pu/HLW canisters), Department of Energy (DOE) spent nuclear fuel (DSNF) standard canisters (4 sizes), DSNF multi-canister overpacks (MCOs) for N-reactor fuel and other selected DSNF, and naval spent nuclear fuel (SNF) canisters (2 sizes).

The quality assurance program applies to this calculation, and the work is performed in accordance with procedure AP-3.12Q, *Calculations*. The work done for this calculation was evaluated according to AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities* that determined this activity to be subject to the requirements of DOE/RW-0333P, *Quality Assurance Requirements and Description* (DOE 2000a). This work was performed in accordance with the *Technical Work Plan for: Department of Energy Nuclear Fuel Work Packages* (CRWMS M&O 2000c) for this activity.

2. METHOD

This calculation focuses on a particular initiating event; drop of a canister due to failure of the CTS bridge crane. This event has been determined to be the bounding event for the CTS in *Preliminary Selection of MGR Design Basis Events* (CRWMS M&O 1999e). Event sequences are established for drops of canisters that may occur during operations at the MGR surface facilities. The event sequences are developed using the anticipated operations at the MGR as denoted in Scenario 6 defined in Section 4.9 of CRWMS M&O (2000b).

Each event sequence has an outcome and a frequency associated with that outcome (e.g., result in a dose released to the offsite receptor). Once the event sequences are established, the frequency of each sequence is calculated using frequencies and probabilities associated with each event within the sequence. These are multiplied together to arrive at the sequence frequency. Each sequence has a specific outcome (i.e., a radionuclide release) as determined by the event and the waste type involved in the event. These outcomes have been categorized as no release (NR), release meets limits (ML), or release exceeds dose limits (EDL). The sequence frequencies with the same outcome for each canister type are summed to obtain the total event sequence frequency for the same potential initiating event. The event sequences in this calculation are only developed to the detail necessary to capture the specific outcome involved in the sequence. Additional events and resulting event sequences that do not change the outcome or the cumulative sequence frequencies were considered unnecessary for this parametric analysis and were not included to keep sequences as simple as possible. Specific cases where this approach is used are presented in Section 5. A detailed event sequence analysis of the MGR surface facility will be performed in support of license application.

In order to determine the allowable tolerance for the failure of the CTS or canisters to operate within their performance allocations, a parametric evaluation was performed over a range of failure probabilities selected to bound the evaluation within existing regulatory constraints. A sensitivity evaluation was also performed over a range of MCO annual throughputs.

Controls prescribed by AP-SV.1Q, *Control of the Electronic Management of Information*, are addressed by information management controls, such as access privileges through passwords, backup and storage of data, and compliance with procedure AP-17.1Q, *Record Source Responsibilities for Inclusionary Records.*

3. ASSUMPTIONS

The following assumptions were used to develop the event sequences and to calculate the frequencies for these sequences. These assumptions are used in the canister drop event development in Section 5.2 and in the canister drop event sequences in Attachment II. In addition, the results presented in Section 6 were produced using these assumptions.

3.1 ASSUMPTIONS GENERIC TO ALL FUEL TYPES

3.1.1 The CTS bridge crane failure rate is 1.4×10^{-5} drops per lift. This rate is based on technical information for heavy-lift cranes from Newport News Shipbuilding as reported in *Preliminary Preclosure Design Basis Event Calculations for the Monitored Geologic Repository* (CRWMS M&O 1998, p. 14 [3.3.3]) and is an average drop rate over a period of two years. This technical information represents the best available information on heavy-lift crane failure rate and, as such, is found suitable for this calculation and needs no further confirmation. *Usage:* The bridge crane failure rate is used in Section 5.1.2 and the event sequences contained in Attachment II.

3.1.2 The CTS bridge crane failure rate is the same for each canister lifted out of a shipping cask or out of the staging rack and lowered into a disposal container (DC) regardless of weight and size of the canister (these parameters must, however, be within the safe handling parameters of the crane). *Basis:* This is a fundamental assumption justified by the calculation of the crane drop frequency or failure rate (CRWMS M&O, 1998, Attachment X). This assumption does not assume a value for the frequency of crane failure, it merely assumes that the crane failure rate can be represented by a single value. *Usage*: This assumption is used in event sequences contained in Attachment II, and does not require confirmation because the calculation results are not sensitive to the cited information.

3.1.3 A canister dropped from a height above its certified height or a canister that is not certified will breach 100% of the time. *Basis:* This is a conservative assumption because canisters typically have a safety margin between the certified drop height and the height at which failure is expected to occur. *Usage*: This assumption is used in event sequences contained in Attachment II. This assumption does not require further confirmation because it is a bounding assumption.

3.1.4 A range of failure probabilities was selected to bound the evaluation within existing regulatory constraints. *Basis:* This assumption does not require further confirmation because it is part of a parametric evaluation to understand the sensitivity of these parameters and help establish design requirements. *Usage*: This assumption is used in event sequences contained in Attachment II.

3.1.5 A sensitivity evaluation was performed over a range of MCO annual throughputs. *Basis:* This assumption does not require further confirmation because it is part of a parametric evaluation to understand the sensitivity of this parameter. The actual MCO throughputs have not been established. *Usage*: This assumption is used in event sequences contained in Attachment II.

3.2 ASSUMPTIONS APPLICABLE TO COMMERCIAL SPENT NUCLEAR FUEL

The disposal of multi-purpose canisters (MPCs) containing commercial SNF is not considered in this calculation. *Basis*: There is no requirement for disposal of MPCs in CRWMS M&O (2000b, Section 1.1.1). *Usage*: This assumption is used in Section 5.1.3 and does not require further confirmation because calculation results are not sensitive to this assumption. *Design Basis Event Frequency and Dose Calculation for Site Recommendation* (CRWMS M&O 2000d, Table 9) has shown that a breach of shipping cask, loaded with the same amount of commercial SNF as an MPC, will not result in doses that exceed the site boundary dose limit for a Category 2 design basis event (DBE).

3.3 ASSUMPTIONS GENERIC TO SMALL DISPOSABLE CANISTERS

HLW and Pu/HLW canisters, DSNF standard canisters, and MCOs are less than 30 inches in diameter and assumed to be placed into a staging rack prior to loading into the DC. *Basis:* This is a conservative assumption as either the first or last canister is likely placed directly into a DC. Thus, the CTS crane must lift each canister twice, thereby increasing the lift frequency. The staging rack is designed to hold only small canisters as shown in CRWMS M&O (2000b, Figure 4-8). *Usage*: This assumption is used in the event sequences contained in Attachment II. This assumption does not require further confirmation because it is a bounding assumption for the design concept evaluated.

3.4 ASSUMPTIONS APPLICABLE TO NAVAL SPENT NUCLEAR FUEL

3.4.1 Naval SNF canisters are transferred directly to a DC (i.e., naval SNF canisters are not placed into the staging rack) and hence, are lifted only once by the CTS crane. *Basis:* Only one naval SNF canister is loaded into a DC and as such naval SNF canisters do not need to be placed in staging racks (CRWMS M&O 2000b, Section 2.3.2). *Usage*: This assumption is used in the naval SNF canister event sequences contained in Attachment II. This assumption does not require confirmation since the calculation results are not sensitive to the cited information. *DOE SNF DBE Offsite Dose Calculations* (CRWMS M&O 1999b) has shown that a breach of a canister loaded with naval SNF will not result in doses that exceed the site boundary dose limit.

3.4.2 Naval SNF canisters are assumed to breach if dropped. This assumption is bounding because a breach will not result in radionuclide release beyond the specified dose limits. *Basis:* These canisters are conservatively assumed not certified for the 23-foot flat-bottom drop or the 2-foot drop in any orientation. The design basis for the naval SNF canister is stated in Section 5.1.4.5. *Usage*: This assumption is used in the naval SNF canister event sequences contained in Attachment II. This assumption does not require further confirmation because it is bounding.

3.5 ASSUMPTIONS APPLICABLE TO DOE SPENT NUCLEAR FUEL

The fraction of DSNF standard canisters and MCOs that have the potential to result in an offsite total effective dose equivalent (TEDE) of greater than 5 rem or a maximum offsite organ dose of greater than 50 rem is conservatively assumed to be 1.0. This is equivalent to assuming all canisters have the potential to result in an offsite TEDE of greater than 5 rem or a maximum offsite organ dose of greater than 50 rem. *Basis:* This value is conservative. *DOE SNF Screening Dose Analysis* (CRWMS M&O 1999d, see Attachments) showed that nearly 80% of the canisters have releases below dose limits using conservative DSNF release parameters. *Usage*: This assumption is used in the DSNF canister event sequences contained in Attachment II. This assumption does not require further confirmation because it is bounding.

3.6 ASSUMPTIONS APPLICABLE TO CANISTER DESIGN BASES

The canister design bases for the DSNF standard canisters, HLW and Pu/HLW canisters, and MCOs will meet the performance allocation inputs listed in Section 5.1.1. The canister design basis for the naval SNF canister will meet the requirement specified in Section 5.1.4.5. *Basis*: CRWMS M&O (2000b) will set the design requirements for the canisters. *Usage*: This assumption is made to develop the event sequences in Attachment II.

3.7 ASSUMPTIONS APPLICABLE TO FACILITY AND OPERATIONAL CHARACTERISTICS

The heating, ventilation, and air conditioning system (including high-efficiency particulate air [HEPA] filters) in the CTS is assumed unavailable to filter particulate releases following a DBE. *Basis:* The system is only provided as defense-in-depth and taking credit for it in this parametric evaluation would result in overstating the allowable failure probability. *Usage*: This assumption provides the basis for not including HEPA filters in event sequences contained in Attachment II. This assumption does not require further confirmation because it is a bounding assumption.

4. USE OF COMPUTER SOFTWARE AND MODELS

Microsoft Excel 97, a commercial off-the-shelf software, was used for the calculations documented in this analysis. Microsoft Excel 97 was used in a Windows 95 operating system with a Pentium processor. Microsoft Excel 97 was appropriately used as a computational tool to perform calculations of canister drop event sequences. The formulas used in the calculation spreadsheets invoke a combination of built-in functions. The user-defined methods for the sequence calculations are described in Section 2. The checking process provides verification that the results documented in Attachments II are correct for the input data contained therein. The calculations shown in the attachments to this technical product can be reproduced and checked by hand. No routines, macros, or models are used in this calculation. Therefore, Section 2.1.6 of procedure AP-SI.1Q, *Software Management*, allows software used in this technical product to be exempted from the requirements of the procedure.

5. CALCULATIONS

5.1 INPUTS

5.1.1 Performance Allocations

CRWMS M&O (2000b) defines the performance allocations made to the CTS, transportation casks, DCs, and canisters. The following allocations are used in this calculation to define the event sequences (CRWMS M&O 2000b). Section 7.3 of CRWMS M&O (2000b) will drive the design requirements for the CTS.

5.1.1.1 Canister Transfer System

The maximum height lift (two-block height) of the DSNF standard canisters, HLW and Pu/HLW canisters, and MCOs by the CTS crane shall not raise the bottom of any canister more than 32 inches above the top lip of the transportation cask or DC at any time.

The maximum height lift (two-block height) of the naval SNF canister by the CTS crane shall not raise the bottom of this canister more than 24 inches above the top lip of the transportation cask or DC at any time. The CTS, in conjunction with the naval SNF canister, shall be designed to prevent any release of radioactive material to the atmosphere that would exceed the 5 rem TEDE or 50 rem organ dose limit at the site boundary (see 5.1.4.5).

The CTS shall prevent the impact of any canister dropped more than 24 inches onto the top lip of its transportation cask or DC from exceeding the impact energy equivalent to a 24-inch drop to an essentially unyielding surface.

The maximum height lift (two-block height) of the DSNF standard canisters, the HLW, and Pu/HLW canisters, the MCOs, and the naval SNF canisters by the CTS cranes shall not raise the bottom of any canister more than 24 inches above the top surface plane of the operating floor in the CTS shielded handling cell. The CTS, in conjunction with the naval SNF canister, shall be designed to prevent any release of radioactive material to the atmosphere that would exceed the 5 rem TEDE or 50 rem organ dose limit at the site boundary (see 5.1.4.5).

Canisters shall be prohibited from being lifted above other canisters in the transportation casks, DCs, and storage locations within the CTS lines without an intervening barrier.

The CTS lifting equipment shall be interlocked with the intervening barrier (transfer gates or hatch covers) so that the lifting equipment cannot move laterally from its selected position until the other canister positions in the transportation casks, DCs, and storage locations are covered by this barrier.

Dedicated lifting fixtures within the CTS shall be engineered so that only correctly specified canisters may be lifted with any particular fixture.

The CTS lifting equipment shall work in conjunction with the operating floor, dedicated lifting fixtures, crane instrumentation, and controls to restrict the normal lift heights of the canisters to 6 inches above the operating floor.

5.1.1.2 Canisters

The DSNF standard canisters, the HLW canisters, and the Pu/HLW canisters shall not exceed design limits during a flat-bottom drop into their respective transportation cask or DC from a height 32 inches above the top lip of their respective transportation cask or DC.

The DSNF standard canisters, the HLW canisters, the Pu/HLW canisters, and the MCOs shall not exceed design limits during a 24-inch drop in any orientation onto the operating floor.

The MCOs shall not exceed design limits during a flat-bottom drop into its transportation cask or DC from a height 32 inches above the top lip of the transportation cask or DC with the use of impact limiters placed in the bottom of the cask and DC.

5.1.2 Facility Characteristics

The CTS bridge crane failure rate is 1.4×10^{-5} drops per lift (Assumption 3.1.1).

5.1.3 Operational Characteristics

5.1.3.1 Cask Unload and Disposal Container Loading Operation

Table 1 lists the normal and maximum lift heights during cask unloading and DC loading as measured from the bottom of the canister to point of impact during a flat-bottom drop into the cask or DC.

Table 2 lists the normal and maximum lift heights of canisters (measured from the bottom of the canister to the floor of the CTS) as lifted by the CTS bridge crane. The values listed in these tables are based on the lift heights established in CRWMS M&O (2000b). The normal and maximum canister lift heights are used to determine the outcome in the event sequences in Attachment II.

Table 1. Normal and Maximum Canister Lift Heights for Flat-Bottom Drops

Description of Lift Height Parameter	Lift Height (inches)	
	Normal	Maximum
DSNF Short Standard Canister	156	174
DSNF Long Standard Canister	218	236
Pu/HLW & HLW Canister	156	174
DSNF MCO	203	221
Naval SNF Short Canister	217	235
Naval SNF Long Canister	242	260

Table 2. Normal and Maximum Canister Lift Heights for Drops in Any Orientation

Description of Lift Height Parameter	Lift Height (inches)	
	Normal	Maximum
DSNF Standard Canister (normal)	<6	24
Pu/HLW & HLW Canister (normal)	<6	24
DSNF MCO (normal)	<6	24
Naval SNF Canister (normal)	<6	24

5.1.3.2 Canister Throughputs into MGR

The maximum yearly MGR throughputs of canisters are listed in Table 3. The values listed in this table are based on the best available data established in the *Monitored Geologic Repository Project Description Document* (Curry 2001, Section 5.1.4.4). Throughput values are multiplied by the crane failure rate (Section 5.1.2) to determine the initiating event (canister drop) frequency for each event sequence in Attachment II. The throughputs do not include MPCs containing commercial SNF (Assumption 3.2).

Table 3. Maximum Canister Throughputs into MGR

Description of Throughput	Maximum Throughput (canisters/yr)	Reference
Total Number of Disposable Canisters	1065	Curry 2001 (Table 5-4)
DSNF Canisters (including MCOs)	150	Curry 2001 (Table 5-4)
Naval SNF Canisters	15	Curry 2001 (Table 5-4)
HLW Canisters	840	Curry 2001 (Table 5-4)
Pu/HLW Canisters	60	Curry 2001 (Table 5-4)

5.1.4 Assumed Certified Drop Heights for Canisters

Canister and CTS design bases are those defined in CRWMS M&O (2000b) and these are being imposed through waste acceptance requirements for canisters and through the CRWMS M&O system description documents for the CTS.

5.1.4.1 DSNF standard canisters shall be capable of sustaining a 23-foot drop in an upright vertical orientation and a 2-foot drop in any orientation onto a flat, essentially unyielding surface followed by a slapdown without breaching. *Basis:* Assumption 3.6. The DSNF canisters are expected to withstand the 23-foot and 2-foot drop height based on results of the DSNF canisters drop test from 30 feet onto an essentially unyielding flat surface in *FY1999 Drop Testing Report for the Standardized 18-Inch DOE SNF Canister* (Morton et al. 2000). *Usage*: The certified canister drop height is used to determine the outcome of event sequences in the event sequences contained in Attachment II.

5.1.4.2 HLW canisters shall be capable of sustaining a drop of 23 feet in an upright vertical orientation onto a flat, essentially unyielding surface without breaching. The capability to survive a 2-foot drop in any orientation has not been certified through drop testing. *Basis:* Assumption 3.6. The HLW canisters are expected to withstand the 23-foot flat-bottom drop based on results reported in the *DPWF Canister Procurement, Control, Drop Test, and Closure* (Marra et al. 1995, Section 8). The HLW canister is assumed to survive the 2-foot drop in any orientation (Assumption 3.6). *Usage*: The certified flat-bottom canister drop height and the expected certification for drops in any orientation are used to determine the outcome of event sequences contained in Attachment II.

5.1.4.3 Pu/HLW canisters shall be capable of sustaining a drop of 23 feet in an upright vertical orientation onto a flat, essentially unyielding surface and a 2-foot drop in any orientation onto any flat, essentially unyielding surface followed by a slapdown without breaching. *Basis:* Assumption 3.6. *Usage*: The canister drop height is used to determine the outcome of event sequences contained in Attachment II.

5.1.4.4 The MCO shall be capable of sustaining a flat-bottom drop into its transportation cask or DC from a height of 32 inches above the top lip of the transportation cask with the use of a 15-inch thick impact limiter placed in the bottom of the cask or DC and a 2-foot drop in any orientation onto any flat, essentially unyielding surface followed by a slapdown without breaching. *Basis:* Assumption 3.6. *Usage*: The canister drop height is used to determine the outcome of event sequences contained in Attachment II.

5.1.4.5 The naval SNF canister shall be designed to prevent any release of radioactive material to the atmosphere that would exceed the 5 rem TEDE or 50 rem organ dose limit at the site boundary. Previous analyses of naval SNF indicate that canister breaches would result in relatively small releases of radioactive material that would be well below regulatory limits at the site boundary. Because the canister will not be designed to prevent a breach when subject to DBEs, the naval SNF canister is assumed to fail during these events. *Basis:* Assumption 3.4.2. Although the letter from E.M. Naples to D.C. Haught (Naples 1999) has indicated that the naval SNF canister can survive a 22-foot flat-bottom drop and a 2-foot corner drop, no credit is taken in this calculation for this capability.

5.1.5 Waste Form Characteristics

This section covers several input features that are related to the different waste forms contained in the canisters at the MGR: HLW characteristics, Pu/HLW characteristics, naval SNF characteristics, general DSNF characteristics, and the characteristics of DSNF in MCOs. The waste form characteristics as they relate to radionuclide release during an event are needed to determine which of the three outcomes, as discussed in Section 2, will result from the event sequence. The releases were previously determined and compared to regulatory limits in the references noted below.

5.1.5.1 Table 4 lists characteristics specific to HLW. These values are used in the event sequences contained in Attachment II.

Table 4. Characteristics Specific to HLW

Description of HLW Characteristic	Characteristic Value	Characteristic Units	Reference
Fraction of single HLW canisters that exceed 5-rem TEDE or 50-rem Organ Dose	0.0	-	CRWMS M&O 1999a (based on results in Attachment VII which indicate 1 can breach = 0.64 rem TEDE and 10.6 rem organ dose)

5.1.5.2 Table 5 lists characteristics specific to naval SNF. Because the naval SNF canister will not be designed to prevent a breach when subjected to DBEs, it is assumed to fail during canister drop events (Assumption 3.4.2). These values are used in the event sequences contained in Attachment II.

Table 5. Characteristics Specific to Naval SNF

Description of Naval SNF Characteristics	Characteristic Input Value	Characteristic Units	Reference
Fraction of naval SNF canisters that exceed 5-rem TEDE or 50-rem Organ Dose	0.0	-	CRWMS M&O 1999b Attachment X indicates that dose is below limit

5.1.5.3 Table 6 lists characteristics specific to Pu/HLW that is co-disposed with HLW. These values are used in the event sequences in Attachment II.

Table 6. Characteristics Specific to Pu/HLW

Description of Pu-HLW Characteristic	Characteristic Value	Characteristic Units	Reference
Fraction of single Pu/HLW canisters that exceed 5-rem TEDE or 50-rem Organ Dose	1.0	-	CRWMS M&O 1999c (based on results in Table 6.1 which indicate that unmitigated offsite doses due to 1 breached plutonium canister exceed dose limits)

5.1.5.4 Table 7 contains characteristics specific to the DSNF stored in standard canisters and MCOs. This value is used in the event sequences in Attachment II.

Table 7. Characteristics Specific to DSNF

Description of DSNF in Standard Canisters and MCOs Characteristic	Characteristic Value	Characteristic Units	Reference
Fraction of DSNF in standard canisters that exceed 5-rem TEDE or 50-rem organ dose	1.0	-	Bounding condition, no reference required
Fraction of DSNF in MCOs that exceed 5-rem TEDE or 50-rem organ dose	1.0	-	CRWMS M&O 1999b (based on results in Attachment VIII which indicate that unmitigated offsite doses for N-Reactor fuels exceed applicable dose limits)

5.2 CANISTER DROP EVENT SEQUENCE TABLES

Event sequence tables were produced for potential canister drops by the CTS bridge crane based on the anticipated operations at the MGR as denoted in Scenario 6 of CRWMS M&O (2000b) where transportation casks and DCs are brought into the lower cell and positioned beneath the transfer ports. The casks and DCs are lifted into the transfer ports using an elevator on the transfer carts. Canisters are pulled out of the cask using the overhead crane and canister-specific yokes, moved horizontally and lowered into the DC. This operation is considered one lift for determining the drop frequency. If canisters are placed in lag storage prior to loading into the DC, the entire operation requires two lifts.

Several components are used to limit the drop height for a flat-bottom drop back into the transportation cask or DC. These include the transfer cart elevator, the canister specific yokes, and spacers or impact absorbers that may be present inside the casks or DCs. Flat-bottom drop heights during this operation are provided in Table 1.

After canisters are raised above the operating floor, sliding transfer gates are used to reduce the maximum drop to a drop onto the operating floor. The transfer operations are sequenced with the operation of the sliding transfer gates to prohibit lateral movement of the canisters without having the gates closed. Drops during this operation could occur in any orientation and the drop heights are provided in Table 2.

If canisters are placed in lag storage, the drop during movement of a canister in and out of a lag position is considered the same as the drop in the transportation cask or DC. The lag storage positions are covered when they are not being loaded or unloaded to prevent drops into those positions.

For this parametric analysis, the sequences are abbreviated to determine a drop frequency, in drops per year, based on the crane failure rate, the number of canisters transferred per year, and the number of lifts per transfer. The drop frequency is then multiplied by an assumed failure probability of the yoke, the transfer gate, or the canister. A failure of any one of these components is assumed to result in a canister breach. Therefore, a sequence is created for each failure probability including the probability of canister breach during its flat-bottom drop or its drop in any orientation. This results in each case having four parametric sequences for each canister type as shown in the Attachment II tables.

Attachment II includes each of the drop event sequences by canister type. For this parametric analysis, event sequences are developed only for canister drop events because the consequences of the drop events bound all other potential events that are not due to a crane failure as stated in Section 2 (CRWMS M&O 1999f). Other sequences with different initiating events do not impact the results of this calculation because they are not included in the total frequency for this crane drop event.

It is assumed in this calculation that a canister breach results in a release of radioactive materials. The outcome of these releases was previously established in Section 5.1. The outcome associated with each sequence is no radioactive release (NR), a radioactive release that meets the applicable DBE Category 2 dose limit at the site boundary (ML), or a radioactive release that exceeds the applicable Category 2 dose limit at the site boundary (EDL). Combining sequences with ML and EDL releases results in sequences with any release (AR) indicating a potential for a Category 1 DBE.

For Cases 1 through 8 shown in Attachment II, canisters and waste forms with similar outcomes if dropped were grouped together to limit the number of sequences. Where the event sequence combines Pu/HLW canisters and DSNF canisters, including MCOs, the sum of the individual throughputs are given in Attachment II tables. The outcome (ML or EDL) of specific breached canisters is determined from information presented in Tables 4 through 7 (by fuel type). The Pu/HLW canisters, DSNF standard canisters, and MCOs were combined into one set of event sequences because drops of these canisters all result in the same outcomes (i.e., EDL). Separate sequences were prepared for HLW and naval SNF because of different canister capabilities and consequences.

To evaluate the effect of different canister types having different failure probabilities, Cases 9 and 10 includes sequences for all canister types and examines the effect of different failure probabilities for each type. The canister-specific assumed failure probabilities are provided in Table 8. No breakdown is provided in CRWMS M&O (2000a) between DSNF standard canisters and MCOs throughputs. Throughput values assumed (Assumption 3.1.5) for Cases 9 through 11 are provided in Table 9. Case 11 looks at the sensitivity of MCO throughput using the higher failure probability assumed in Case 10.

Table 8. Cases 9 through11 Canister-Specific Failure Probabilities

Canister	Case 9 Assumed Failure Probability	Cases 10 & 11 Assumed Failure Probability
HLW	5.0E-5	1.0E-5
Pu/HLW	5.0E-5	1.0E-5
DSNF Standard	3.0E-6	3.0E-6
MCO	1.0E-4	1.0E-3
Naval	1.0	1.0

Table 9. Cases 9 through 11 DSNF Canister-Specific Throughputs

Canister Type	Assumed Maximum Throughput, Canisters/yr	
	Cases 9 and 10	Case 11
DSNF Standard	110	136
MCOs	40	14
Total DSNF	150	150

Based on the inputs provided in Section 5.1.5, Waste Form Characteristics, it was determined that drops of canisters onto other canisters did not change the outcome or the frequencies of these event sequences and these events were considered not critical to the parametric analysis.

Each of the canister drop sequences shown in Attachment II include the following:

1. **Crane Failure Rate:** The crane failure rate in drops per lift.

2. **Canisters per year:** The projected maximum annual throughput of canisters into the MGR.

3. **Drop Frequency**: The canister drop frequency is a product of canister throughput per year, number of crane lifts involved in the transfer of the canisters from the transportation cask to the DC, and the crane failure rate.

4. **Item Failure:** Items listed below that may fail in the sequence.

5. **Yoke**: The probability of using the wrong yoke on a canister resulting in a drop from heights greater than those in Table 1 and a canister breach is considered a variable in this calculation.

6. **Canister Breach due to Flat-Bottom Drop (FBD)**: The probability of a canister breach during a flat-bottom drop within the Table 1 heights is considered a variable in this calculation. In accordance with Assumption 3.4.2, the naval SNF canister is given a breach probability of 1.0.

7. **Gate**: The probability of the transfer gate not closing concurrent with a crane failure resulting in a drop from heights greater than those in Table 2 and a canister breach is considered a variable in this calculation.

8. **Canister Breach due to Any-Orientation Drop (AOD)**: The probability of a canister breaching during a drop in any orientation within the Table 2 heights is considered a variable in this calculation. In accordance with Assumption 3.4.2, the naval SNF canister is given a breach probability of 1.0.

9. **Failure Probability:** A variable in this calculation ranging from 1.0E-07 to 1.0E-04.

10. **Release Frequency/yr:** The calculated frequency for each sequence.

11. **Outcome:** The outcome of a release as determined by the regulatory limits at the site boundary.

Each case evaluated in Attachment II includes all sequences for each canister group or type. The sequences with the same outcome are summed to determine the total release frequency for each outcome.

6. RESULTS

This calculation has developed sequence tables shown in Attachment II for the canister drop event in the CTS as a result of a bridge crane failure. Ten cases presented in Attachment II were run to evaluate different probabilities of exceeding both the facility design bases and the design bases of DOE SNF, HLW, and Pu/HLW canisters. Case 11 in Attachment II evaluates the sensitivity of changing the MCO throughput. A determination of the total release frequencies, given these probabilities, was performed in Attachment II and results are summarized in Tables 8 and 9. The resultant frequencies are not an indication of the level of risk because consequences of breaching a canister are not quantified in this calculation.

Table 10 summarizes the release frequencies for all sequences that result in any release assuming different failure probabilities ranging from 1.0 for the naval SNF canister to 1.0E-07 for the yoke and gate. These results provide input for subsequent event sequence categorization. It can be seen from Table 10 that the results are dominated by the frequency of a SNF canister drop event sequence because the probability of a breach given a naval SNF canister drop has been conservatively assumed to be 1.0. However, the consequences of an unlikely naval SNF canister breach were previously determined in Table 5 to be below regulatory limits.

Table 11 summarizes the release frequencies for sequences that result in a dose to the offsite receptor greater than 5-rem TEDE and/or 50-rem to the maximum organ assuming different failure probabilities ranging from 1.0 for the naval SNF canister to 1.0E-07. Since releases from both HLW and naval SNF are less than 5 rem, their frequency of exceeding dose limits is zero. Also since both the DSNF and the Pu/HLW forms have potential releases above 5 rem, these were combined for Cases 1 through 8 to minimize the number of event sequences. It can be seen from Table 11 that the results are dominated by the frequency of the DSNF and the Pu/HLW canister drop event sequences. This is because the fraction of DSNF standard canisters and MCOs that have the potential to result in an offsite TEDE of greater than 5 rem or a maximum organ offsite dose of greater than 50 rem is conservatively assumed to be 1.0.

Table 10. Frequency Results for Canister Drop Sequences with Any Release

Assumed Failure Probability				Frequency Summation of Canister Drop Sequences Resulting in Any Release of Radioactive Material (/yr)			
Case	Yoke	Gate	Canister*	HLW	Pu/HLW DSNF	Naval SNF	Total
1	1.0E-4	1.0E-4	1.0E-4	9.41E-06	2.35E-06	4.20E-04	4.32E-04
2	1.0E-5	1.0E-5	1.0E-5	9.41E-07	2.35E-07	4.20E-04	4.21E-04
3	1.0E-6	1.0E-6	1.0E-6	9.41E-08	2.35E-08	4.20E-04	4.20E-04
4	1.0E-6	1.0E-6	1.0E-5	5.17E-07	1.29E-07	4.20E-04	4.21E-04
5	1.0E-6	1.0E-6	1.0E-4	4.75E-06	1.19E-06	4.20E-04	4.26E-04
6	1.0E-7	1.0E-7	1.0E-4	4.71E-06	1.18E-06	4.20E-04	4.26E-04
7	5.0E-5	5.0E-5	5.0E-5	4.70E-06	1.18E-06	4.20E-04	4.26E-04
8	0.0	5.0E-5	5.0E-5	3.53E-06	8.82E-07	4.20E-04	4.24E-04
9	5.0E-5	5.0E-5	(Table 8)	4.70E-06	(Attach. II)	4.20E-04	4.26E-04
10	1.0E-5	1.0E-5	(Table 8)	9.41E-07	(Attach. II)	4.20E-04	4.23E-04
11**	1.0E-5	1.0E-5	(Table 8)	9.41E-07	(Attach. II)	4.20E-04	4.22E-04

*The probability of breaching a naval SNF canister is assumed to be 1.0 in all cases.

** MCO throughput reduced from 40 to 14 canisters/year and DSNF standard canister throughput increased to 136/year

As discussed in Section 5.2, four separate probabilities are being varied in this calculation. Cases 1 through 3 assumed the same failure probability for each component. Cases 4 through 8 assume different failure probabilities were considered for different components. Case 8 assumes that the yoke design completely eliminates the yoke mismatch event as proposed in CRWMS M&O (2000b) making the probability of yoke failure zero. Cases 9 through 11, however, include sequences for each canister type to evaluate the sensitivity of different failure probabilities. Table 8 lists the failure probabilities for these cases. Case 11 evaluates the effect of changing the Case 10 throughput distribution between DSNF standard canisters and MCOs. Table 9 lists these throughputs.

Although several cases assume different failure probabilities for selected canisters or CTS components, these components will be designed to prevent failure. It is expected that the results of this calculation will provide an insight on the margins available for consideration of uncertainties in the CTS and canister design and structural analyses. For example, DOE (2000b) estimates the conditional probability for a DSNF standard canister to fail if dropped from within its design basis at 3.0E-06.

The results provided in the calculation are sensitive to the crane failure rate provided in Section 5.1.2. The results shown in Table 10 and 11 would increase or decrease linearly with increases or decreases in the crane failure rate. Decreases in crane failure rates would increase the design margins that insure no failure of canisters and CTS equipment.

It should be noted that this calculation has large conservatism in the selected inputs such as assuming that all breaches of DSNF will result in releases over the regulatory limit. Also the use of simplified sequence tables rather than detailed event trees does not consider many factors that could reduce the total frequencies.

Table 11. Frequency Results for Canister Drop Sequences that Exceed Dose Limits

Assumed Failure Probability				Frequency Summation of Canister Drop Sequences Resulting in Offsite Dose Exceeding 5-rem TEDE or 50 rem to the maximum organ (/yr)			
Case	Yoke	Gate	Canister*	HLW	Pu/HLW DSNF	Naval SNF	Total
1	1.0E-4	1.0E-4	1.0E-4	0.00E+00	2.35E-06	0.00E+00	2.35E-06
2	1.0E-5	1.0E-5	1.0E-5	0.00E+00	2.35E-07	0.00E+00	2.35E-07
3	1.0E-6	1.0E-6	1.0E-6	0.00E+00	2.35E-08	0.00E+00	2.35E-08
4	1.0E-6	1.0E-6	1.0E-5	0.00E+00	1.29E-07	0.00E+00	1.29E-07
5	1.0E-6	1.0E-6	1.0E-4	0.00E+00	1.19E-06	0.00E+00	1.19E-06
6	1.0E-7	1.0E-7	1.0E-4	0.00E+00	1.18E-06	0.00E+00	1.18E-06
7	5.0E-5	5.0E-5	5.0E-5	0.00E+00	1.18E-06	0.00E+00	1.18E-06
8	0.0	5.0E-5	5.0E-5	0.00E+00	8.82E-07	0.00E+00	8.82E-07
9	5.0E-5	5.0E-5	(Table 8)	0.00E+00	(Attach. II)	0.00E+00	9.98E-07
10	1.0E-5	1.0E-5	(Table 8)	0.00E+00	(Attach. II)	0.00E+00	2.41E-06
11**	1.0E-5	1.0E-5	(Table 8)	0.00E+00	(Attach. II)	0.00E+00	9.58E-07

*The probability of breaching a naval SNF canister is assumed to be 1.0 in all cases.

** MCO throughput reduced from 40 to 14 canisters/year and DSNF standard canister throughput increased to 136/year

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8. ATTACHMENTS

Attachment I	Acronyms
Attachment II	Canister Drop Event Sequences

ATTACHMENT I

Acronyms

AOD	Any-Orientation Drop
AR	Any Release
CTS	Canister Transfer System
DBE	Design Basis Event
DC	Disposal Container
DOE	U.S. Department of Energy
DSNF	U.S. Department of Energy Spent Nuclear Fuel
FBD	Flat-Bottom Drop
EDL	Exceeds Dose Limit
HEPA	High-Efficiency Particulate Air
HLW	High-Level Radioactive Waste
MCO	Multi-Canister Overpack
MGR	Monitored Geologic Repository
ML	Meets Limit
MPC	Multi-Purpose Canister
NR	No Release
Pu/HLW	Plutonium and High-Level Radioactive Waste
SNF	Spent Nuclear Fuel
TEDE	Total Effective Dose Equivalent

ATTACHMENT II

CANISTER DROP EVENT SEQUENCES

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CASE 1: 1.0E-04 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Frequency/yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-04	2.35E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-04	2.35E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-04	2.35E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-04	2.35E-06	ML
Total							9.41E-06	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	1.00E-04	5.88E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	1.00E-04	5.88E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	1.00E-04	5.88E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	1.00E-04	5.88E-07	EDL
Total							2.35E-06	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-04	2.10E-08	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-04	2.10E-08	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**2.35E-06**	EDL
TOTAL ML							**4.29E-04**	ML
TOTAL AR							**4.32E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

Canister Breach Parametric.xls

CASE 2: 1.0E-05 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Frequency/yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-05	2.35E-07	ML
Total							9.41E-07	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	1.00E-05	5.88E-08	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	1.00E-05	5.88E-08	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	1.00E-05	5.88E-08	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	1.00E-05	5.88E-08	EDL
Total							2.35E-07	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-05	2.10E-09	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-05	2.10E-09	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**2.35E-07**	EDL
TOTAL ML							**4.21E-04**	ML
TOTAL AR							**4.21E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

Canister Breach Parametric.xls

CASE 3: 1.0E-06 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Frequency/yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-06	2.35E-08	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-06	2.35E-08	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-06	2.35E-08	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-06	2.35E-08	ML
Total							9.41E-08	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	1.00E-06	5.88E-09	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	1.00E-06	5.88E-09	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	1.00E-06	5.88E-09	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	1.00E-06	5.88E-09	EDL
Total							2.35E-08	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-06	2.10E-10	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-06	2.10E-10	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**2.35E-08**	EDL
TOTAL ML							**4.20E-04**	ML
TOTAL AR							**4.20E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

Canister Breach Parametric.xls

CASE 4: Mix 1 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Frequency/yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-06	2.35E-08	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-06	2.35E-08	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-05	2.35E-07	ML
Total							5.17E-07	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	1.00E-06	5.88E-09	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	1.00E-06	5.88E-09	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	1.00E-05	5.88E-08	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	1.00E-05	5.88E-08	EDL
Total							1.29E-07	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-06	2.10E-10	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-06	2.10E-10	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**1.29E-07**	EDL
TOTAL ML							**4.21E-04**	ML
TOTAL AR							**4.21E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

Canister Breach Parametric.xls

CASE 5: Mix 2 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Frequency/yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-06	2.35E-08	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-06	2.35E-08	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-04	2.35E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-04	2.35E-06	ML
Total							4.75E-06	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	1.00E-06	5.88E-09	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	1.00E-06	5.88E-09	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	1.00E-04	5.88E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	1.00E-04	5.88E-07	EDL
Total							1.19E-06	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-06	2.10E-10	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-06	2.10E-10	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**1.19E-06**	EDL
TOTAL ML							**4.25E-04**	ML
TOTAL AR							**4.26E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

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CASE 6: Mix 3 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Frequency/yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-07	2.35E-09	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-07	2.35E-09	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-04	2.35E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-04	2.35E-06	ML
Total							4.71E-06	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	1.00E-07	5.88E-10	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	1.00E-07	5.88E-10	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	1.00E-04	5.88E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	1.00E-04	5.88E-07	EDL
Total							1.18E-06	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-07	2.10E-11	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-07	2.10E-11	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**1.18E-06**	EDL
TOTAL ML							**4.25E-04**	ML
TOTAL AR							**4.26E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

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CASE 7: 5.0E-05 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Frequency/yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	5.00E-05	1.18E-06	ML
Total							4.70E-06	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	5.00E-05	2.94E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	5.00E-05	2.94E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	5.00E-05	2.94E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	5.00E-05	2.94E-07	EDL
Total							1.18E-06	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	5.00E-05	1.05E-08	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	5.00E-05	1.05E-08	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**1.18E-06**	EDL
TOTAL ML							**4.25E-04**	ML
TOTAL AR							**4.26E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

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CASE 8: Mix 4 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Freq per yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	0.00E+00	0.00E+00	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	5.00E-05	1.18E-06	ML
Total							3.53E-06	ML
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Yoke	0.00E+00	0.00E+00	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Gate	5.00E-05	2.94E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister FBD	5.00E-05	2.94E-07	EDL
Pu/HLW & DSNF	1.40E-05	210	2	5.88E-03	Canister AOD	5.00E-05	2.94E-07	EDL
Total							8.82E-07	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	0.00E+00	0.00E+00	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	5.00E-05	1.05E-08	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**8.82E-07**	EDL
TOTAL ML							**4.24E-04**	ML
TOTAL AR							**4.24E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

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CASE 9: Mix 5 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Freq per yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	5.00E-05	1.18E-06	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	5.00E-05	1.18E-06	ML
Total							4.70E-06	ML
Pu/HLW	1.40E-05	60	2	1.68E-03	Yoke	5.00E-05	8.40E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Gate	5.00E-05	8.40E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Canister FBD	5.00E-05	8.40E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Canister AOD	5.00E-05	8.40E-08	EDL
Total							3.36E-07	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Yoke	5.00E-05	1.54E-07	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Gate	5.00E-05	1.54E-07	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Canister FBD	3.00E-06	9.24E-09	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Canister AOD	3.00E-06	9.24E-09	EDL
Total							3.26E-07	EDL
MCO	1.40E-05	40	2	1.12E-03	Yoke	5.00E-05	5.60E-08	EDL
MCO	1.40E-05	40	2	1.12E-03	Gate	5.00E-05	5.60E-08	EDL
MCO	1.40E-05	40	2	1.12E-03	Canister FBD	1.00E-04	1.12E-07	EDL
MCO	1.40E-05	40	2	1.12E-03	Canister AOD	1.00E-04	1.12E-07	EDL
Total							3.36E-07	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	5.00E-05	1.05E-08	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	5.00E-05	1.05E-08	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**9.98E-07**	EDL
TOTAL ML							**4.25E-04**	ML
TOTAL AR							**4.26E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

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CASE 10: Mix 6 Failure Probability for Canister, Yoke, and Gate								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Freq per yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-05	2.35E-07	ML
Total							9.41E-07	ML
Pu/HLW	1.40E-05	60	2	1.68E-03	Yoke	1.00E-05	1.68E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Gate	1.00E-05	1.68E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Canister FBD	1.00E-05	1.68E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Canister AOD	1.00E-05	1.68E-08	EDL
Total							6.72E-08	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Yoke	1.00E-05	3.08E-08	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Gate	1.00E-05	3.08E-08	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Canister FBD	3.00E-06	9.24E-09	EDL
DSNF standard	1.40E-05	110	2	3.08E-03	Canister AOD	3.00E-06	9.24E-09	EDL
Total							8.01E-08	EDL
MCO	1.40E-05	40	2	1.12E-03	Yoke	1.00E-05	1.12E-08	EDL
MCO	1.40E-05	40	2	1.12E-03	Gate	1.00E-05	1.12E-08	EDL
MCO	1.40E-05	40	2	1.12E-03	Canister FBD	1.00E-03	1.12E-06	EDL
MCO	1.40E-05	40	2	1.12E-03	Canister AOD	1.00E-03	1.12E-06	EDL
Total							2.26E-06	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-05	2.10E-09	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-05	2.10E-09	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**2.41E-06**	EDL
TOTAL ML							**4.21E-04**	ML
TOTAL AR							**4.23E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								
AR (any release) = ML + EDL								

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CASE 11: Mix 6 Failure Probability with reduced MCO throughput								
Canister Type	**Crane Failure Rate**	**Canisters per year**	**Number of Lifts/Transfer**	**Drop Frequency**	**Item Failure**	**Failure Probability**	**Release Freq per yr**	**Outcome**
HLW	1.40E-05	840	2	2.35E-02	Yoke	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Gate	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Canister FBD	1.00E-05	2.35E-07	ML
HLW	1.40E-05	840	2	2.35E-02	Canister AOD	1.00E-05	2.35E-07	ML
Total							9.41E-07	ML
Pu/HLW	1.40E-05	60	2	1.68E-03	Yoke	1.00E-05	1.68E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Gate	1.00E-05	1.68E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Canister FBD	1.00E-05	1.68E-08	EDL
Pu/HLW	1.40E-05	60	2	1.68E-03	Canister AOD	1.00E-05	1.68E-08	EDL
Total							6.72E-08	EDL
DSNF standard	1.40E-05	136	2	3.81E-03	Yoke	1.00E-05	3.81E-08	EDL
DSNF standard	1.40E-05	136	2	3.81E-03	Gate	1.00E-05	3.81E-08	EDL
DSNF standard	1.40E-05	136	2	3.81E-03	Canister FBD	3.00E-06	1.14E-08	EDL
DSNF standard	1.40E-05	136	2	3.81E-03	Canister AOD	3.00E-06	1.14E-08	EDL
Total							9.90E-08	EDL
MCO	1.40E-05	14	2	3.92E-04	Yoke	1.00E-05	3.92E-09	EDL
MCO	1.40E-05	14	2	3.92E-04	Gate	1.00E-05	3.92E-09	EDL
MCO	1.40E-05	14	2	3.92E-04	Canister FBD	1.00E-03	3.92E-07	EDL
MCO	1.40E-05	14	2	3.92E-04	Canister AOD	1.00E-03	3.92E-07	EDL
Total							7.92E-07	EDL
Naval	1.40E-05	15	1	2.10E-04	Yoke	1.00E-05	2.10E-09	ML
Naval	1.40E-05	15	1	2.10E-04	Gate	1.00E-05	2.10E-09	ML
Naval	1.40E-05	15	1	2.10E-04	Canister FBD	1.00E+00	2.10E-04	ML
Naval	1.40E-05	15	1	2.10E-04	Canister AOD	1.00E+00	2.10E-04	ML
Total							4.20E-04	ML
TOTAL EDL							**9.58E-07**	EDL
TOTAL ML							**4.21E-04**	ML
TOTAL AR							**4.22E-04**	AR
FBD (flat bottom drop) = The canister breach due to a flat bottom drop								
AOD (any orientation drop) = The canister breach due to a drop in any orientation								
ML (meets limits) = The sum of all senarios that meet DBE Category 2 release limits								
EDL (exceeds dose limits) = The sum of all scenarios that meet DBE Category 2 release limits								

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