Attachment 2
RBG-47505

Calculation G.13.18.2.7-116, Rev. 0
Load Drop Calculation for Spent Fuel Pool Gates (FNS-GATE1 and FNS-GATE2)

(208 pages)

ft☐ ANO-1	☐ ANO-2	☐ GGNS	☐ IP-2	☐ IP-3	☐ PLP
☐ JAF	☐PNPS	☒ RBS	☐ VY	☐ W3	
☐ NP-GGNS-3	☐ NP-RBS-3				

CALCULATION COVER PAGE	**EC # 52637**	

Design Basis Calc. ☐ YES ☒ NO	☒ CALCULATION	☐ EC Markup

Calculation No: G13.18.2.7-116	**Revision: 0**
Title: Load Drop Calculation for Spent Fuel Pool Gates (FNS-GATE1 and FNS-GATE2)	**Editorial:** ☐ YES ☒ NO

System(s): 055/ Refueling Platform Equipment	**Review Org (Department): BE3**

Safety Class:	**Component/Equipment/Structure Type/Number:**	
☒ **Safety / Quality Related** ☐ **Augmented Quality Program** ☐ **Non-Safety Related**	MHF-CRN1	FNS-GATE1
	MHF-CRN2	FNS-GATE2
Document Type: F43.02		
Keywords (Description/Topical Codes):		
Spent Fuel Pool, Pool Gates		
Heavy Loads, Load Drop		
Crane		

REVIEWS

Name/Signature/Date See AS	Name/Signature/Date See AS	Name/Signature/Date See AS
Responsible Engineer: **Jordan Carter** **Melissa Litherland**	☒ **Design Verifier:** **Eugene Desir** **Nasser Pazooki** ☐ **Reviewer** ☐ Comments Attached	**Supervisor/Approval:** **Isaac Wells** ☐ Comments Attached

CALCULATION REFERENCE SHEET	CALCULATION NO: **G13.18.2.7-116** REVISION: 0

I. EC Markups Incorporated (N/A to NP calculations)

None

II. Relationships:	Sht	Rev	Input Doc	Output Doc	Impact Y/N	Tracking No.
1. FB-1592	N/A	002	☑	☐	N	
2. ER-RB-1996-0082-000	N/A	000	☑	☐	N	
3. G13.18.2.7*031	N/A	000	☑	☐	N	
4. 4200.060-003-001A	N/A	A	☑	☐	N	
5. G13.18.9.5*059	N/A	001	☑	☐	N	
6. 8.2.102	N/A	000	☑	☐	N	
7. 4223.321-258-007A	N/A	300	☑	☐	N	
8. 0223.321-258-004	N/A	300	☑	☐	N	
9. G13.18.2.7*091	N/A	000	☑	☐	N	
10. 223.321	N/A	001	☑	☐	N	
11. EV-003A	N/A	011	☑	☐	N	
12. 0219.721-213-045	N/A	300	☑	☐	N	
13. EC-062H	N/A	006	☑	☐	N	
14. PN-311	N/A	002	☑	☐	N	
15. C62.500	N/A	003	☑	☐	N	
16. PID-34-02A	N/A	021	☑	☐	N	
17. LDT-SFC	N/A	000	☑	☐	N	
18. PCD-SFC-001-CD-A	N/A	007	☑	☐	N	
19. PCD-SFC-014-CD-A	N/A	007	☑	☐	N	
20. PCD-SFC-006-CD-A	N/A	006	☑	☐	N	
21. PCD-SFC-007-CD-A	N/A	010	☑	☐	N	
22. PCD-SFC-006-CD-C	N/A	005	☑	☐	N	
23. 228.000	N/A	004	☑	☐	N	

III. CROSS REFERENCES:

1. EC 42063 "Seismic Qualification of Fuel Building Bridge Crane MHF-CRN1 for Load of 2500 lbs and Revision of Fuel Pool Gate Rigging Plan for Resubmission of License Amendment Request LAR-2010-04"
2. EC 14186 "24 Month Cycles USAR Chapter 15 Safety Analysis"
3. NUREG/CR-6604, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation", Published April December 1998 1997,and Supplement 1 Dated 6/8/99, and Supplement 2 Dated 10/2002.
4. Regulatory Guide 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors", July 2000
5. Code of Federal Regulations, Title 10, Section 50.67, "Accident Source Term"

6. NUREG-0800, Standard Review Plan (July 1981), Section 6.4 (Rev. 2), "Control Room Habitability Systems"
7. American Institute of Steel Construction (AISC) Manual of Steel Construction, 13th Edition
8. General Electric Company, GESSAR II Nuclear Island Design, (22A7007)
9. Crane Technical Paper No. 410 "Flow of Fluids"
10. River Bend Technical Specifications Section 3.7.6, Fuel Pool Water Level
11. Web page *http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html* *(Copy provided as Attachment C)*
12. Perry's Chemical Engineer's Handbook, Sixth Edition, 1984
13. ASME III 1974, Section NA

IV. SOFTWARE USED:

Title: RADTRAD Version/Release: 3.02 Disk/CD No. N/A SDDF: 6244.400-912-001B Rev 300

V. DISK/CDS INCLUDED:

Title: N/A Version/Release______ Disk/CD No.______

VI. OTHER CHANGES:

None

Revision	Record of Revision
0	Initial issue.

5.0 PURPOSE

The purpose of this calculation is to perform a load drop analysis for the Spent Fuel Pool gates (FNS-GATE1 and FNS-GATE2) during the rigging and gate movement operations to perform gate seal replacement. This load drop analysis will conform to the recommended guidelines within NUREG-0612.

6.0 CONCLUSION

The drop of a Spent Fuel Pool Gate (FNS-GATE1 or FNS-GATE2) and the associated rigging from a maximum height of 6.00 feet above the top of spent fuel bundles will result in a maximum of 209 damaged fuel rods. To provide additional margin for changes in rigging or fuel design, a failure of 266 rods is postulated and analyzed for dose consequences.

The dose analysis for a load drop resulting in a failure of 266 fuel rods with a decay time of 14 days (336 hours) gives the following Total Effective Dose Equivalent (TEDE) at the Exclusion Area Boundary (EAB), Low Population Zone (LPZ) and Control Room (CR). As shown in the results table, the dose resulting from a drop of a Spent Fuel Pool Gate and the associated rigging is less than the RG 1.183 dose limits and is bounded by the dose analyzed for the design basis Fuel Handling Accident in the Fuel Building.

Calculation Results
TEDE (REM)

Dose Receptor	Acceptance Criteria	FHA in Fuel Building	Gate Drop in Fuel Building
EAB*	6.3	2.5725	1.2155
LPZ	6.3	0.33912	0.16017
CR	5	1.6790	0.87328

*Worst 2-hour period

Analysis of the penetration of the steel spent fuel pool liner as a result of the drop of the gate and associated rigging components has determined that the minimum required liner thickness required to prevent perforation resulting from object impact is less than the thickness of the stainless steel liner. Given the liner will not be penetrated due to impact of objects being moved for Spent Fuel Pool gate seal replacement, there will be no water leakage from the pool. Thus, no minimum water makeup capability to accommodate leakage from the load drop is required.

Analysis of a load drop on the spent fuel storage racks has determined that the impact force for each potential dropped object is bounded by the existing fuel storage rack load drop analysis. Thus, the required k_{eff} for stored spent fuel is maintained in the event that a load drop occurs during Spent Fuel Pool gate movement.

The assessment of the impact load drop on the Spent Fuel Pool Cooling piping located in the pool has determined that the Fuel Pool Cooling piping has adequate ductility to accommodate the impact of a fuel pool gate transitioning from an initial drop onto the spent fuel or racks and will not be perforated as a result of the impact. Based upon adequate ductility of the piping and the level of impact of the gate with the piping being below the minimum water level in the pool, it can be concluded that any damage to the piping will not affect the ability of the pool water to be transferred to or from the Spent Fuel Pool Cooling system. As a result, a load drop of the gates will not adversely affect the safe shutdown function to maintain spent fuel pool cooling.

The total weight of the objects utilized in this analysis is 2375 lbs. This is rounded to approximately 2500 lbs for inclusion in USAR Section 9.1.2.3.3. The use of "approximately 2500 lbs" in the USAR is appropriate given the conservatisms included in this calculation and the 20% margin included in the dose analysis to account for any minor changes in rigging or fuel design.

7.0 INPUT AND DESIGN CRITERIA

Definitions

AST	Alternate Source Term (same as RST)
CR	Control Room
EAB	Exclusion Area Boundary
FB	Fuel Building
FHA	Fuel Handling Accident
LPZ	Low Population Zone
RADTRAD	Radionuclide Transport and Removal and Dose Estimate
RG	Regulatory Guide
RPF	Radial Peaking Factor
RST	Revised Source Term (same as AST)
TEDE	Total Effective Dose Equivalent

Per References III.4 and III.5, the calculated Total Effective Dose Equivalent (TEDE) limits are as follows:

EAB:	6.3 REM TEDE* (2 hour duration)
LPZ:	6.3 REM TEDE (30 day duration)
Control Room:	5 REM TEDE (30 day duration)

*Worst 2-hour period

Equations

$E_{dif} = 1 - [M_1 / (M_1 + M_2)]$ (Ref. III.8, pg. 15.7-21; Ref. II.3, pg. 6-7)

Where:

E_{dif} = Fraction of kinetic energy absorbed during impact
M_1 = Mass of Gate
M_2 = Mass of Impacted Fuel Bundles
= (# of fuel bundles)(Buoyant bundle wt, lbs/bundle)

$E_{abs} = (PE)(E_{dif})$ (Ref. III.8, pg. 15.7-24; Ref. II.3, pg. 6-7)

Where:

E_{abs} = Energy absorbed during impact
PE = Potential Energy
E_{dif} = Fraction of kinetic energy absorbed during impact

$F_{comp} = [(E_{abs})(19/(19+5))] / 200$ ft-lb (Ref. III.8, pg. 15.7-24; Ref. II.5, pg. 15)

Where:

F_{comp} = number of fuel rod failures caused by compression
E_{abs} = Energy absorbed during impact

Ai = AC * FD * FRP *FG *(1/DF) (Ref. II.5_EC 14186 markup pg. 24)

Where:

Ai = total activity of isotope i released to the environment (Ci/MWt)
AC = total activity in the reactor core (Ci/MWt)
FD = fraction of core damaged (unitless)
= Number of rods damaged / (Rods per bundle * Bundles in core)
FRP = maximum radial peaking factor (unitless)
FG = fraction of isotope activity in damaged rods escaping as gap release (unitless).
DF = decontamination factor within pool water for isotope i (unitless)

$L = E_i / (U)(A_i)$ (Ref. II.7, pg. 4.2-240)

Where:

L = Length of Damage (in)
E_i = Total Impact Energy of Falling Object (in*lb)
U = Strain Energy for Unit Volume (in*lb/in^3)
A_i = Area of Impact Contact (in^2)

$A_i = (N)(l)(t)$ (Ref. II.7, pg. 4.2-240)

Where:

A_i = Area of Impact Contact (in^2)
N = Number of Plates in Impact Zone
l = Contact Length per Plate (in)
t = Plate Thickness (in)

$E = U + K$ (Ref. II.9, pg. 4)

Where:

E = Total Energy
U = Potential Energy
K = Kinetic Energy

$U = (M)(G)(H)$ (Ref. II.9, pg. 4)

Where:

U = Potential Energy
M = Mass
G = Acceleration of Gravity
H = Height of Drop

$K = \frac{1}{2}(M)(V^2)$ (Ref. II.9, pg. 4)

Where:

K = Kinetic Energy
M = Mass
V = Velocity

$T^{3/2} = 0.5\ M\ V_s^2\ /\ (17{,}400\ K^2\ D^{3/2})$ (Ref. II.4, pg. C-8)

Where:

T = steel thickness to just be perforated, in
M = mass of the missile, $lb\text{-}s^2/ft$
V_s = striking velocity of the missile normal to target surface, ft/s
K = constant depending on the grade of the steel, K is usually = 1
D = diameter or equivalent diameter of the missile, in

Thickness required to prevent steel perforation = T * 1.25 (Ref. II.4 pg. 2)

Where:

T = steel thickness to just be perforated, in

$V_0 = (2gh)^{1/2}$ (Ref. II.4, pg. E-4, 5-3)

Where:

V_0 = velocity of the missile at contact with the water surface, ft/s
g = gravitational acceleration = 32.17 ft/s^2
h = distance between the missile and the water surface, ft

$V_s = [Z(H)]^{1/2}$ (Ref. II.4, pg. 5-2)

Where:

V_s = velocity of the missile striking the steel surface, ft/s
Z(H) = function for determination of striking velocity (see formulas below)
H = feet of fluid between fluid surface and surface of steel target

The following equations are from Ref. II.4, pg. 5-2:

$Z_1(x) = (g/a) + (bA_0)[(1\text{-}2ax)/2a^2)] + e^{-2ax}[(V_0^2 - (g/a) - (bA_0 / 2a^2)]$

$Z_2(x) = V_2^2 + e^{-2ax}\{(bA_0 /2a^2)[e^{2aL}(1\text{-}2aL) - 1)] + V_0^2 + [(g/a)[(e^{2aL}(\gamma/\gamma_m) - 1)]\}$

Where:

$Z_1(x)$ = function for determining the striking velocity at depth H = x when $0 \le x \le L$

$Z_2(x)$ = function for determining the striking velocity at depth H = x when $x \ge L$

$a = (\gamma * A_0 * C_D) / (2 * W)$ (Ref. II.4, pg. 5-3)

$b = (\gamma * g) / W$ (Ref. II.4, pg. 5-3)

g = gravitational acceleration = 32.17 ft/s^2 (Ref. II.4, pg. 5-3)

W = weight of missile, lb (Ref. II.4, pg. 5-3)

γ = weight density of liquid, lb/ft^3 (Ref. II.4, pg. 5-3)

γ_m = weight density of missile, lb/ft^3 (Ref. II.4, pg. 5-3)

x = depth of missile center of gravity below the water surface, ft
(Ref. II.4, pg. 5-3, 5-5)

A_0 = horizontal cross-sectional area of the missile (constant over length L), ft^2
(Ref. II.4, pg. 5-3)

C_D = drag coefficient given in table 5-1 of the reference or other references on fluid mechanics which is a function of L/d, R and shape of the missile
(Ref. II.4, pg. 5-3, 5-4)

L = vertical length of the missile, ft (Ref. II.4, pg. 5-3)

d = characteristic dimension of the missile, for a rectangular surface d = width, ft
(Ref. II.4, pg. 5-3, 5-4)

R = Reynolds Number = $(V_0 * d) / \nu$ (Ref. II.4, pg. 5-3)

ν = kinematic viscosity of the liquid, ft^2/s (Ref. II.4, pg. 5-3)

V_0 = initial velocity of the missile at x = 0, ft/s (Ref. II.4, pg. 5-3, 5-5)

Vs = striking velocity of the missile at x = H, ft/s (Ref. II.4, pg. 5-2)

V_2 = terminal velocity, ft/s = $[(g/a) * (1 - \gamma/\gamma_m)]^{1/2}$ (Ref. II.4, pg. 5-3)

H = depth of the fluid, ft (Ref. II.4, pg. 5-3)

$a^2 + b^2 = c^2$ (Ref. III.12, pg. 2-27)

Where:

a = triangle side length
b = triangle side length
c = triangle hypotenuse length

$M_e = (D_x + 2d) * M_x$ Ref. II.4 pg. 3-6

Where:

M_e = Average effective mass of target during impact, lb
M_x = Mass per unit length of steel beam, lb/in
D_x = Maximum missile contact dimension in the x direction (longitudinal axis for beams), inches
d = depth of steel beam, inches

$E_s = (M_m^2 * V_s^2) / [2 * (M_m + M_e)]$ Ref. II.4 pg. 3-5

Where:

E_s = strain energy, in-lb
M_m = Mass of the missile, lb
M_e = Effective mass of target during impact, lb
V_s = Missile striking velocity, in/s

$R_m = (8*I*f_{dy}) / (L*d)$ Ref. II.4 pg. E-3

Where:

R_m = plastic resisting force, lb
I = moment of inertia, in^4
f_{dy} = allowable dynamic strength value = (DIF) * f_{stat}
DIF = dynamic increase factor = 1
F_{stat} = static strength (yield strength), psi
L = Length of beam, inches
d = depth of steel beam, inches

$x_e = R_m L^3 / 48EI$ Ref. II.4 pg. 4-5

Where:

x_e = yield displacement, in
R_m = plastic resisting force, lb
L = Length of beam, inches
E = modulus of elasticity, lb/in^2
I = moment of inertia, in^4

$\mu_r = [(E_s / (x_e * R_m)] + 0.5$ Ref. II.4 pg. 3-8

Where:

μ_r = required ductility ratio
E_s = strain energy, in-lb
R_m = plastic resisting force, lb
x_e = yield displacement, in

Data

L = Length of Spent Fuel Pool Gate = 24'-4 5/8" = 24.39 ft (Ref. II.1, pg. A11)

W = Width of Spent Fuel Pool Gate = 4'-9 ¼" = 4.771 ft (Ref. II.1, pg. A11)

T = Thickness of Spent Fuel Pool Gate = 4 ¾" = 0.3958 ft (Ref. II.1, pg. 17)

M_G = Weight of Spent Fuel Pool Gate = 1600 lbs (Ref. II.1, pg. 28)

M_1 = Estimated Total Weight of Spent Fuel Pool Gate and Rigging = 2000 lbs (Ref. III.1, pg. 4);

M_2 = Buoyant Weight of Fuel Bundle = 562 lbs (Ref. II.5, pg. 15)

Clad Yield Strength = 200 ft-lb (Ref. II.5, pg. 15)

Spacing between Fuel Bundles = 6.25" = 0.5208 ft (Ref. II.3, pg. 4)

L = Length of Intermediate Lifting Beam = 4'-9"= 4.75 ft (Ref. II.2, pg. 6)

W = Width of Intermediate Lifting Beam = 5" = 0.4167 ft (Ref. II.2, pg. 6)

D = Depth of Intermediate Lifting Beam = 5" = 0.4167 ft (Ref. II.2, pg. 6)

Nominal Weight of HSS6x5x½ = 31.71 lbs/ft (Ref. III.7, pg. 1-82)

W = Width of Alternate Lifting Beam = 4" = 0.333 ft (Ref. III.7, pg. 1-26)

D = Depth of Alternate Lifting Beam = 6" = 0.5 ft (Ref. III.7, pg. 1-26)

Nominal Weight of W6x12 Steel Beam = 12 lbs/ft (Ref. III.7, pg. 1-27)

U = Strain Energy for Unit Volume ($in*lb/in^3$) = 19740 $in\text{-}lb/in^3$ (Ref. II.7, pg. 4.2-240)

t = thickness of cell assembly = 0.075 inches (Ref. II.7, pg. 3.2-1)

Depth of poison material below top of rack = 16.22 inches (Ref. II.7, pg. 4.2-235)

Elevation of Top of Fuel Racks = 177" + 70'1-5/16" = 84.86' (Ref. II.8)

Elevation of bottom of Gate = 90' (Ref. II.2, pg. 8)

Elevation of bottom of Intermediate Lifting Beam = 115' (Ref. II.2, pg. 8)

Elevation of bottom of Alternate Lifting Beam = 123' (Ref. II.2, pg. 12)

Acceleration of Gravity = 32.174 ft/sec^2 (Ref. III.9, pg. B-10)

Impact Energy rating for Fuel Racks = 3800 ft-lb (Ref. II.10, pg. 1-18)

Spent Fuel and Cask Pool floor elevation = 70' 0" or 70.0' (Ref. II.11)

Spent Fuel Pool and Cask Pool floor steel liner thickness = 3/16" or 0.188" (Ref. II.12)

Elevation of Fuel and Cask Pool Curb = 113' 4" (Ref. II.13)

Approximate lift height above laydown floor elevation obstructions = 6" (Ref. III.1, pg. 16)

Minimum water level above the top of irradiated fuel = $\geq$ 23' (Ref. III.10, pg. 3.7-15)

Stored fuel bundle upper tie plate elevation = 84.6645' (Ref. II.3, pg. 4)

Maximum Spent Fuel Pool Water Temperature 155.6 deg. F (Ref. II.14, pg. 5)

Density of water @ 160 deg. F 60.994 lb/ft^3 (Ref. III.9, pg. A-6)

Kinematic viscosity of water @ 160 deg. F = 0.439 E-5 ft^2/s (Ref. III.11)

Allowable ductility ratio μ for steel elements, members proportioned to preclude lateral and local buckling;
Flexure, compression and shear $\mu \leq 20$ (Ref. II.4 pg. 4-7)

Fuel Pool Cooling Lines Penetrating Spent Fuel Pool (Ref. II.16)

SFC-012-001-3
SFC-012-014-3
SFC-012-006-3
SFC-012-007-3

Pipe Class (Spec. 228.000) of Spent Fuel Pool Cooling Piping = Class 153 (Ref. II.17)

Fuel Pool Cooling Piping Diameter and Schedule

SFC-012-001-3	12" diameter Schedule STD	(Ref. II.23 pg. 16, II.17)
SFC-012-014-3	12" diameter Schedule STD	(Ref. II.23 pg. 16, II.17)
SFC-012-006-3	12" diameter Schedule STD	(Ref. II.23 pg. 16, II.17)
SFC-012-007-3	12" diameter Schedule STD	(Ref. II.23 pg. 16, II.17)

Fuel Pool Cooling Piping Material

SFC-012-001-3 = SA312 Type 304 Stainless Steel	(Ref. II.23 pg. 167, II.18)
SFC-012-014-3 = SA312 Type 304 Stainless Steel	(Ref. II.23 pg. 167, II.19)
SFC-012-006-3 = SA312 Type 304 Stainless Steel	(Ref. II.23 pg. 167, II.20)
SFC-012-007-3 = SA312 Type 304 Stainless Steel	(Ref. II.23 pg. 167, II.21)

Piping Parameters, 12" Schedule Standard (Ref. III.9, pg. B-17)

Outer diameter = 12.75"
Wall thickness = 0.375"
Pipe weight per unit length = 49.56 lb / ft of length
Moment of inertia (I) = 279.3 in^4

Modulus of Elasticity, E, at 200 deg F for TP 304 SS = 27.7E6 lb_f / in^2 (Ref. III.12, pg. 6-92)

Material Properties, SA312 Type 304 Seamless Pipe (Ref. III.13, pg. 76, 77)

Minimum Yield Strength = 30 ksi
Minimum Ultimate Tensile Strength = 75 ksi

Distance Fuel Pool Cooling Piping Extends into Pool

SFC-012-001-3 = 1.302' (Ref. II.18)
SFC-012-014-3 = 1.302' (Ref. II.19)
SFC-012-006-3 = 1.5' (Ref. II.20)
SFC-012-007-3 = 1.33' (Ref. II.21)

Elevation of Fuel Pool Cooling Piping Connection to Liner Embed

SFC-012-001-3 = 110' 0" (Ref. II.18)
SFC-012-014-3 = 110' 0" (Ref. II.19)
SFC-012-006-3 = 110' 0" (Ref. II.20, II.22)
SFC-012-007-3 = 110' 0" (Ref. II.21)

Elevation of First Support below Liner Embed Connection

SFC-012-001-3 = 86' 0" (Ref. II.18)
SFC-012-014-3 = 86' 0" (Ref. II.19)
SFC-012-006-3 = 92' 0" (Ref. II.20, II.22)
SFC-012-007-3 = 92' 0" (Ref. II.21)

Meteorology Data (FB/RB X/Q Values)

EAB:	(0 - 2 hours):	8.58E-04 sec/m^3	(Ref. II.6)
LPZ:	(0 – 8 hours):	1.13E-04 sec/m^3	(Ref. II.6)
	(8 – 24 hours):	7.89E-05 sec/m^3	(Ref. II.6)
	(1 – 4 days):	3.65E-05 sec/m^3	(Ref. II.6)
	(4 – 30 days):	1.21E-05 sec/m^3	(Ref. II.6)
CR:	(0 – 20 min):	1.62E-03 sec/m^3	(Ref. II.5_EC 14186 markup pg. 9)
	(20 min – 8 hr):	4.05E-04 sec/m^3	(Ref. II.5_EC 14186 markup pg. 9)
	(8 – 24 hours):	3.00E-04 sec/m^3	(Ref. II.5_EC 14186 markup pg. 9)
	(1 – 4 days):	1.01E-04 sec/m^3	(Ref. II.5_EC 14186 markup pg. 9)
	(4 – 30 days):	1.62E-05 sec/m^3	(Ref. II.5_EC 14186 markup pg. 9)

Power Level: 3100 MWt (Ref. II.5_EC 14186 markup pg. 9)

Source Term: *(Ref. II.5_EC 14186 markup pg. 9)*

Isotope	24 Month Fuel Cycle Core Inventory (Ci/MW) at Time 0
I-131	2.70E+04
I-132	3.92E+04
I-133	5.52E+04
I-134	6.06E+04
I-135	5.17E+04
Kr-85	3.66E+02
Kr-85m	7.02E+03
Kr-87	1.35E+04
Kr-88	1.89E+04
Xe-133	5.26E+04
Xe-135	1.99E+04

Fuel Building Volume: 7.42E5 ft^3	(Ref. II.5_EC 14186 markup pg. 10)
CR Free Air Volume: 1.88E5 ft^3	(Ref. II.5_EC 14186 markup pg. 10)
CR Filtration Credited Iodine Efficiency: 0%	(Ref. II.5_EC 14186 markup pg. 10)
CR Filtered Air Modeled Intake Flow: 1700 cfm	(Ref. II.5_EC 14186 markup pg. 11)
CR Unfiltered Air Modeled Inleakage Flow: 300 cfm	(Ref. II.5_EC 14186 markup pg. 11)
CR Total Modeled Intake Flow: 2000 cfm	(Ref. II.5_EC 14186 markup pg. 11)
CR Total Modeled Discharge Flow: 2000 cfm	(Ref. II.5_EC 14186 markup pg. 11)
Number of Bundles in Core: 624	(Ref. II.5_EC 14186 markup pg. 17)
Core Radial Peaking Factor: 2.00	(Ref. II.5_EC 14186 markup pg. 17)
Peak Assembly Burnup: ≤ 62,000 MWd/t	(Ref. II.5_EC 14186 markup pg. 17)
Maximum Fuel Rod Pressurization: < 1200 psig	(Ref. II.5_EC 14186 markup pg. 17)
Minimum Spent Fuel Pool Water Depth: ≥ 23 feet	(Ref. II.5_EC 14186 markup pg. 17, Ref. III.10, pg. 3.7-15)
Number of Rods per Bundle for GE 9x9 Fuel: 74	(Ref. II.5_EC 14186 markup pg. 17)

8.0 ASSUMPTIONS

1. The kinetic energy acquired by a falling fuel assembly may be dissipated in one or more impacts. This assumption is consistent with GE methodology used in GESSAR II 22A7007 (Ref. III.8, Section 15.7.4.3.1).

2. The kinetic energy of a dropped assembly is assumed to be absorbed by only the cladding, non-fuel components of the assembly, and other pool structures (i.e., no energy is absorbed by the fuel). This assumption is consistent with GE methodology used in GESSAR II 22A7007 (Ref. III.8, Section 15.7.4.3.1).

3. The fraction of the energy absorbed by the non-fuel parts of the assembly is assumed to be the same as the fraction of the structural material. As a result, the cladding absorbs 19/(19+5) of the energy absorbed during impact. This assumption is consistent with GE methodology used in GESSAR II 22A7007 (Ref. III.8, Section 15.7.4.3.1).

4. For conservatism, dissipation of some of the mechanical energy of the falling Spent Fuel Pool Gate due to fluid drag is neglected. This assumption is consistent with GE methodology used in GESSAR II 22A7007 (Ref. III.8, Section 15.7.4.3.2).

5. For conservatism, the Spent Fuel Pool Storage racks are assumed to be 50% filled in Cases 2 and 4 (minimum impact fuel bundle cases) of the pool gate analysis. This condition would maximize the force of the gate on a fewer number of fuel bundles, failing a higher number of fuel rods.

6. In the design basis analysis, it is assumed that 50% of the energy is absorbed by the dropped fuel bundle and 50% by the struck assemblies. For conservatism, this analysis assumes that 100% of the energy is absorbed by the struck assemblies.

7. The decay time used in the radiological analysis is 14 days (336 hours). This decay time is based upon the gate seal replacement being done with the plant on-line or in non-refueling outage conditions. The minimum realistic refueling outage duration is 14 days, thus the minimum decay time for newly discharged fuel bundles in the spent fuel pool is 14 days. This is conservative based on the following:

   Gate seal replacement is typically scheduled late in the operating cycle. As a result, the actual fuel decay time will be greater than the assumed 14 days.

   The area of the gate and rigging members is significantly greater than the previously analyzed fuel bundle load drop, with a substantially larger number of fuel bundles impacted in the postulated gate and rigging drop scenario. A portion of these bundles will have been discharged prior to the most recent refueling outage with a minimum decay time exceeding 18 months. As a result, assuming all damaged bundles have a decay time of 14 days is conservative.

8. Regulatory Guide 1.183-based Assumptions

The following assumptions are documented in Ref. II.5 EC 14186 markup Section 5.1 pages 18 and 19 with detailed summary of specific compliance to RG 1.183 located in Attachment C of the markup. The Attachment C discussion is applicable to the information reproduced below with the exception of the time after shutdown of 24 hours in Attachment C paragraph 3.3.a. For this analysis, the conformance statement is as follows:

3.3 The applicable requirements of Subsection 3.3 of Regulatory Position 3 state:

a) For non-LOCA DBAs in which fuel damage is projected, the release from the fuel gap and the fuel pellet should be assumed to occur instantaneously with the onset of the projected damage. *Conformance:* In this analysis, all of the activity which is available for release from the fuel to the pool or reactor cavity is assumed to have been instantaneously released from the fuel gap to the water at the onset of the gate load drop analysis, 336 hours after shutdown. This assumption from RG 1.183 is met in its entirety.

8.1 The gap activity fractions of Table 3 in Regulatory Position 3 of RG 1.183 (Ref. III.1) are utilized, as follows:

I-131	0.08
All other halogens	0.05
Kr-85	0.10
All other noble gases	0.05

8.2 All gap activity in the damaged fuel rods is assumed to be instantaneously released.

8.3 Radionuclides considered include the xenons, kryptons, halogens, cesiums, and rubidiums. However, all particulate radionuclides species (some halogens, cesiums, and rubidiums) are assumed to be retained in the fuel pool (infinite decontamination factor) consistent with RG 1.183 Appendix B Section 3 (Ref. III.1). Also consistent with RG 1.183 Appendix B Section 3, all noble gases (xenons & kryptons) escape to the environment.

8.4 Of the radioiodine released from the damaged fuel rods, 99.85% of the released iodine is effectively assumed to be in the form of elemental iodine and 0.15% of the released iodine is assumed to be in the organic species (Ref. III.1, Appendix B, Section 2.0).

8.5 Consistent with RG 1.183 Appendix B Section 4.1 and 5.3 (Ref. III.1), all radionuclide releases from the pool to the environment are assumed to occur over a 2-hour period. This is accomplished via a 2-hour linear release from the pool to the building atmosphere with a simulated instantaneous release to the environment.

8.6 Consistent with RG 1.183 Appendix B Section 2 (Ref. III.1), the decontamination factor for organic iodine is assumed to be 1. The pool decontamination factor for elemental iodine is assumed such that the overall pool decontamination factor is 200 for all iodine species with a 23-foot water level above the postulated damaged fuel assembly.

8.7 The control room breathing rate is assumed to be 3.5E-04 m^3/sec. for the duration (Ref. III.1, Section 4.2.6).

8.8 The offsite breathing rates are as follows (Ref. III.1, Section 4.1.3):

0-8 hours:	3.5E-04 m^3/sec
8-24 hours:	1.8E-04 m^3/sec
1-30 days:	2.3E-04 m^3/sec

8.9 Control Room Operator Occupancy Factors are as follows (Ref. III.1, Section 4.2.6):

0-24 hours:	1.0
1-4 days:	0.6
4-10 days:	0.4

Note: The Occupancy Factors are already included in the X/Q's. They will not be defined in the Control Room input, since in doing so they will be taken into account twice. Instead the occupancy factors in the RADTRAD model will be set to 1.0.

8.10 Iodine Species Breakdown (Ref. III.1, Appendix B, Section 2):

Aerosol	0%
Elemental	57%
Organic	43%

9. The Intermediate Lifting Beam is TS5x5x½ per ER-RB-1996-082-000. This intermediate lifting beam is conservatively assumed to be HSS6x5x½ for the determination of the lifting beam mass only. The weight per foot of HSS6x5x½ bound the weight per foot of TS5x5x½. Therefore, the mass calculation of this beam using HSS6x5x½ weight per foot is conservative.

10. In the fuel impact damage cases, the length of the Intermediate Lifting Beam is assumed to be 5 ft. This length is conservative because the actual length of this beam is 4'-9" per ER-RB-1996-082-000 pg. 6 and assuming a greater length maximizes the potential energy change.

11. For the impact analysis on the pool liner and fuel storage racks, the density and viscosity water at 160 deg. F is used. This temperature exceeds the maximum pool temperature of the spent fuel pool water of 155.6 deg. F per Ref. II.14, pg. 5. Use of density and viscosity values for a slightly higher water temperature than the maximum pool water temperature is conservative as it results in a higher impact velocity.

12. For the impact analysis on the pool liner cases, the nominal top of active fuel is treated as the stored fuel bundle upper tie plate at elevation 84.6645' per Ref. II.3, pg. 4.

13. The purpose of this alternate lifting beam was to allow the option to have a rigging configuration that doesn't pull the crane hooks out of vertical. Per Ref. II.2, pg. 8, the Bridge Crane hook and Cask Crane hook are 9'-2" apart. For conservatism, the alternate lifting beam is assumed to be 12' in length.

14. For the impact analysis on the pool liner cases, the gate weight is assumed to be the weight of the gate and rigging to maximize the velocity and density of the object, thereby maximizing the penetration thickness of the pool liner.

15. For the impact analysis on the Fuel Pool Cooling piping, a strike area of 2 square inches is assumed. This is reasonable based upon the curvature of the nominal 12" piping and as all of the force is assumed to be delivered to the piping, when some force will be absorbed by the gates.

9.0 METHOD OF ANALYSIS

As in the design basis Fuel Handling Accident analysis, the potential energy associated with a free air drop will be calculated first. The drop height will be based on the distance from the approximate elevation of the bottom of the gate to the elevation of the Fuel Bundles. Two sets of fall geometries will be analyzed. The first fall geometry will have an air-drop impact with only one laydown impact. The second fall geometry will have an air-drop impact with two laydown impacts. Based on the irregularities in the Spent Fuel Pool Gate's geometry, there is the potential for the gate to fall on its edge (rather than on its face) before resting with this largest surface area against the spent fuel. These laydown impacts are calculated with 100% of the potential energy being transmitted into the impacted fuel rods.

These impact energies (multiplied by a cladding to other structural material fraction) are then divided by the cladding yield strength to determine the number of fuel rod failures caused by compression. The fuel rod failures are totaled for each impact.

Three dropped objects are analyzed: the Spent Fuel Pool gate, an intermediate lifting beam, and an alternate lifting beam. The dimensions of W6x12 that is 12 ft in length are used for analysis of the Alternate Lifting Beam. The dimensions of TS5x5x½ are used for analysis of the Intermediate Lifting Beam. The bounding cases of all these dropped objects are totaled to determine the potential maximum number of failed fuel rods in compression.

The radiological analysis is performed utilizing the methodology described in calculation G13.18.9.5*059, Evaluation of Exclusion Area Boundary, Low Population Zone, and Control Room TEDE due to a Design Basis Fuel Handling Accident with Regulatory Guide 1.183 AST-based Assumptions (Ref. II.5). Doses are evaluated at the Exclusion Area Boundary (EAB), Low Population Zone (LPZ), and the Control Room (CR) using the NRC-developed computer Code RADTRAD (Ref. III.3). These cases use the same methodology as the design basis Fuel Handling Accident (FHA) in the Fuel Building (FB) as described in USAR Section 15.7.4 with the following changes:

- The number of rods damaged in the load drop event represent the calculated number of rods damaged for a drop of the gate and rigging plus a nominal 20% margin to account for future fuel design or rigging configuration changes.
- An assumed decay time of 14 days (336 hours) rather than the 24 hour decay time assumed in the design basis FHA analysis.

A 2-hour linear release from the fuel pool to the building atmosphere is assumed with no credit taken for Fuel Building (FB) or Control Room (CR) filtration.

The design basis decay time of 24 hours for Fuel Handling Accident analysis represents the earliest time that a fuel bundle discharged from the reactor could be handled during the refueling evolution. The gate seal replacement will be performed on-line or during non-refueling shutdown conditions. As a result, the assumed decay time will be 14 days. This time period is based upon the minimum realistic refueling outage duration.

The second portion of the load drop analysis is to assess the effect of the dropped load on the spent fuel pool, cask pool, and gate opening area liner. The River Bend Fuel Building pools are equipped with a 3/16" thick stainless steel liner. The liner is designed to provide a leak-proof barrier for the pools. If it is determined that the dropped load will not completely penetrate the stainless steel liner, no water leakage will result from the dropped load and consequently no water makeup to the pools as a result of the load drop event will be required. The cask pool has been previously analyzed for a drop of a 250 ton fuel storage cask in Reference II.15 with no adverse impact to the structural integrity of the concrete pool structure. The cask drop analysis bounds the drop of all of the objects in the cask pool, gate area and spent fuel pool being analyzed in this calculation with respect to the concrete pool floor structure. As a result, this calculation will not analyze the concrete pool floor structure.

This portion of the calculation will also determine the impact velocities of the dropped objects on the fuel storage racks to be used in the effect on the fuel storage racks due to impact of the dropped objects.

The methodology used to determine the strike velocity on the submerged structures and the penetration in steel is from Reference II.4, BC-TOP-9A Revision 2, September 1984, "Topical Report, Design of Structures for Missile Impact" for a missile impacting steel when dropping through air and/or water. This methodology does consider buoyancy and drag forces during the object travel through the water and is the same general methodology used in Reference II.15 associated with the analysis of the concrete structure for the cask drop.

The third portion of the load drop analysis is to assess the effect on the spent fuel storage racks as a result of a drop of the gate, intermediate beam or alternate beam on the spent fuel storage racks to ensure that the required k_{eff} is maintained. This analysis compares the forces resulting from the subject dropped objects to the required force the racks must withstand per the rack design specification and analysis (References II.7 and II.10).

The final portion of the load drop analysis is to assess the effect on the Spent Fuel Pool Cooling piping that penetrates into the Spent Fuel Pool and has the potential to be struck by the gate in a secondary impact (i.e. transition to Position II or Position III as described in Section 10.1.1). Note that only a falling gate has adequate mass to result in any potential damage to the Spent Fuel Pool Cooling piping. The distance between the nearest potential drop point and the piping is determined for each of the lines. Then the elevation where the top of the gate impacts the line is then determined to assess if any potential damage is below the minimum pool water level. If any potential damage is below the minimum water level, no loss of cooling function will occur as water will still flow into/out of the damaged piping. The velocity of the impact of the gate on the piping is determined using the Reference II.4, BC-TOP-9A

Revision 2, September 1984, "Topical Report, Design of Structures for Missile Impact" for a missile impacting steel when dropping through air and/or water. Note that this methodology is primarily for a missile impacting perpendicular to the target. In this case, the impact will not be directly perpendicular and thus, the velocity value will be conservative. The structural effect on the piping will be assessed using the methodology from Reference II.4, treating the piping as a simply supported steel beam.

10.0 Calculations

10.1 Damage to Fuel Bundles

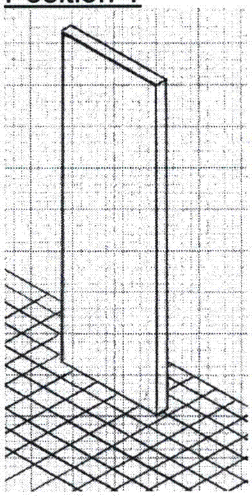
The damage to the spent fuel bundles will be analyzed first. Three dropped objects are analyzed: the Spent Fuel Pool gate, an intermediate lifting beam, and an alternate lifting beam.

10.1.1 Spent Fuel Pool Gate

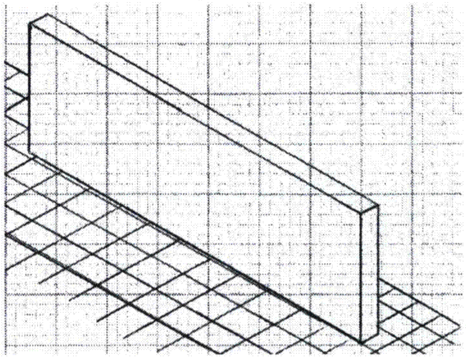
Fall Geometries

The following geometric orientations of Spent Fuel Pool Gate (FNS-GATE1 or FNS-GATE2) will be analyzed for a potential maximum and minimum number of fuel bundle impacts. All analyzed cases will begin with an impact in Position 1 and a final impact in Position 3. Two analyzed cases will incorporate a possible impact in Position 2 after Position 1 and before Position 3. There will be a total of 4 load drop cases analyzed.

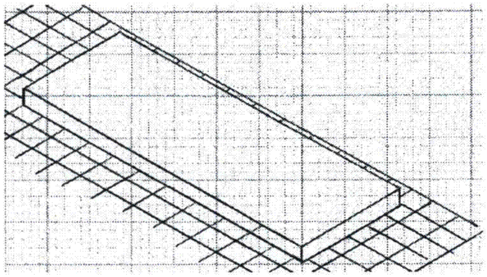
Position 1



Position 2



Position 3



CALCULATION DETAILS	CALCULATION NO:	G13.18.2.7-116
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In the table below, the specifics of each load case are detailed.

	Position 1 Impact	Position 2 Impact	Position 3 Impact	Max or Min Impacted Fuel Bundles
Case 1	x		x	Max
Case 2	x		x	Min
Case 3	x	x	x	Max
Case 4	x	x	x	Min

<u>Maximum Impacted Fuel Bundles</u>

Position 1:

In order to estimate the maximum number of impacted fuel bundles for this geometry, the width and thickness must be divided by spacing between bundles.

(Width of Gate) / (Spacing between bundles)

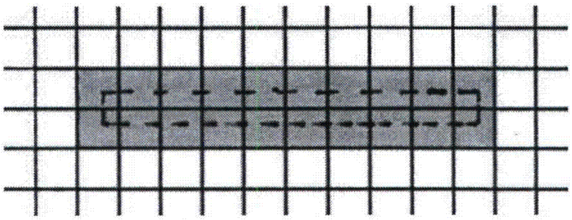
(4.771 ft) / (0.5208 ft) = 9.161 or 10 bundles

(Thickness of Gate) / (Spacing between bundles)

(0.3958 ft) / (0.5208 ft) = 0.7599 or 1 bundle

Because the thickness of the gate is over half the spacing of fuel bundles, it has the maximum potential to hit two rows of fuel bundles.

Total Bundles = (10 bundles)(2 bundles) = 20 impacted fuel bundles



Position 2:

In order to estimate the maximum number of impacted fuel bundles for this geometry, the length and thickness must be divided by spacing between bundles.

(Length of Gate) / (Spacing between bundles)

(24.39 ft) / (0.5208 ft) = 46.83 or 47 bundles

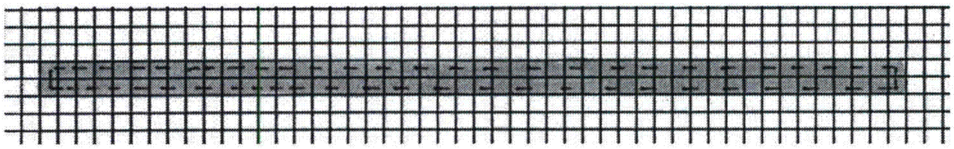
Because the fractional unit of length of the gate is over half the spacing of fuel bundles, it has the maximum potential to hit 48 rows of fuel bundles.

(Thickness of Gate) / (Spacing between bundles)

(0.3958 ft) / (0.5208 ft) = 0.7599 or 1 bundle

Because the thickness of the gate is over half the spacing of fuel bundles, it has the maximum potential to hit two rows of fuel bundles.

Total Bundles = (48 bundles)(2 bundles) = 96 impacted fuel bundles



Position 3:

In order to estimate the maximum number of impacted fuel bundles for this geometry, the length and width must be divided by spacing between bundles.

(Length of Gate) / (Spacing between bundles)

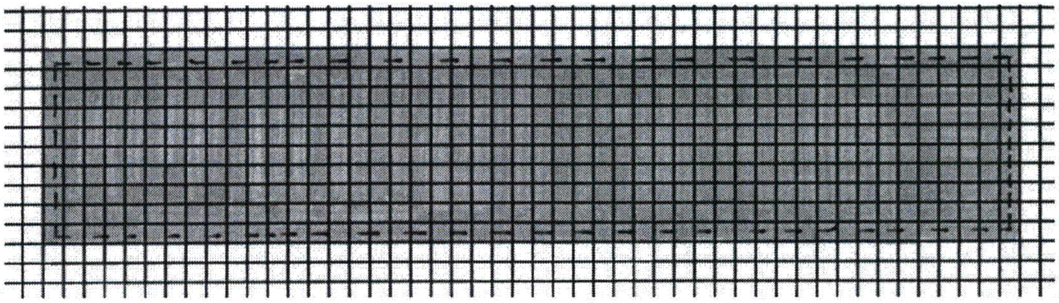
(24.39 ft) / (0.5208 ft) = 46.83 or 47 bundles

For the maximized case this object has the potential to hit 48 rows of fuel bundles (impact across the full width of 46 bundles and partial width of one bundle on each end)

(Width of Gate) / (Spacing between bundles)

(4.771 ft) / (0.5208 ft) = 9.161 or 10 bundles

Total Bundles = (48 bundles)(10 bundles) = 480 impacted fuel bundles



Minimum Impacted Fuel Bundles

The minimum number of impacted fuel bundles for each position is obtained by conservatively assuming that 50% of the Spent Fuel Pool racks are filled

Position 1:

In order to estimate the minimum number of impacted fuel bundles for this geometry, the width and thickness must be divided by spacing between bundles.

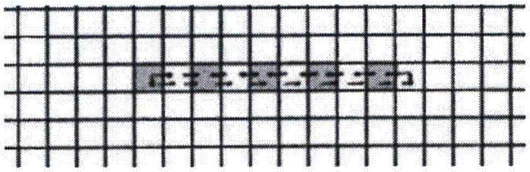
(Width of Gate) / (Spacing between bundles)

(4.771 ft) / (0.5208 ft) = 9.161 or 10 bundles

(Thickness of Gate) / (Spacing between bundles)

(0.3958 ft) / (0.5208 ft) = 0.7599 or 1 bundle

Total Bundles = (0.50)(10 bundles)(1 bundle) = 5 impacted fuel bundles



Position 2:

In order to estimate the minimum number of impacted fuel bundles for this geometry, the length and thickness must be divided by spacing between bundles.

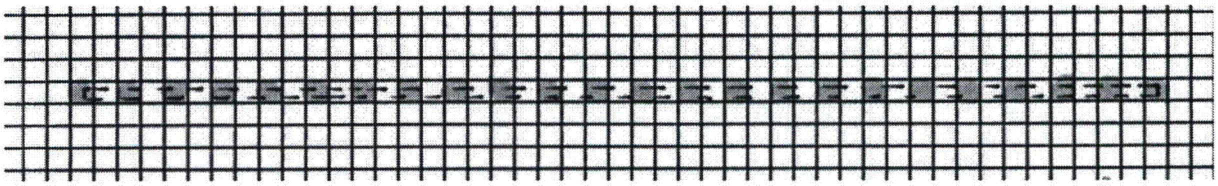
(Length of Gate) / (Spacing between bundles)

(24.39 ft) / (0.5208 ft) = 46.83 or 47 bundles

(Thickness of Gate) / (Spacing between bundles)

(0.3958 ft) / (0.5208 ft) = 0.7599 or 1 bundle

Total Bundles = (0.50)(47 bundles)(1 bundle)= 23 impacted fuel bundles



Position 3:

In order to estimate the minimum number of impacted fuel bundles for this geometry, the length and width must be divided by spacing between bundles.

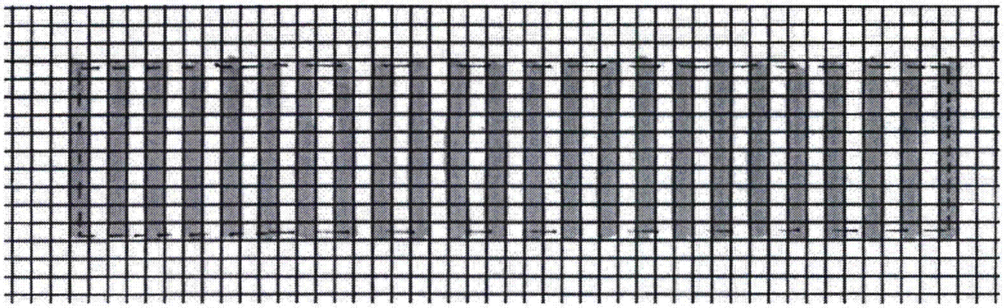
(Length of Gate) / (Spacing between bundles)

(24.39 ft) / (0.5208 ft) = 46.83 or 47 bundles

(Width of Gate) / (Spacing between bundles)

(4.771 ft) / (0.5208 ft) = 9.161 or 10 bundles

Total Bundles = (0.50)(47 bundles)(10 bundles) = 235 impacted fuel bundles



	Max Impacted Fuel Bundles	Min Impacted Fuel Bundles
Position 1 Impact	20	5
Position 2 Impact	96	23
Position 3 Impact	480	235

Initial Potential Energy

$PE = M_1 * H_d$

M_1 = Mass of Gate and Rigging Equipment = 2000 lbs

H_d = (Elev. bottom of Pool Gate – Elev. top of Fuel Racks) = (90' – 84.27') = 5.73 ft **use 6 ft**

PE = (2000 lb)(6.00 ft)

PE = 12000 ft-lb

Energy Difference

The energy absorbed during the impact is determined based upon the relationship as given in the design basis Fuel Handling Accident analysis. For conservatism, M_1 (weight of the Spend Fuel Pool Gate and associate rigging equipment) has been maximized and M_2 (buoyant weight of the fuel bundles) has minimized.

$E_{dif} = 1 - [M_1 / (M_1 + M_2)]$

M_1 = Mass of Gate and Rigging Equipment = 2000 lbs

M_2 = Mass of Impacted Fuel Bundles = (# of fuel bundles)(562 lbs/bundle)

Case 1

This case analyzes the free air drop resulting in a position 1 impact, and one laydown impact in position 3 with maximized fuel bundle impacts.

For the first impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (20 bundles)(562 lb)]

E_{dif} = 1 – [0.1511]

E_{dif} = 0.8489

For the second impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (480 bundles)(562 lb)]

E_{dif} = 1 – [0.0074]

$E_{dif} = 0.9926$

Essentially all of the second impact energy would be absorbed. As a result, third or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 84.89% of the initial energy or,

E_{abs} = (PE)(0.8489)

E_{abs} = (12000 ft-lb)(0.8489)

E_{abs} = 10187 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(10187 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 40.32 or 41 rods

The second impact involves a rebound consisting of 15.11% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

Potential Energy Change

CG_1 = Center of Gravity (Position One) = (L / 2) = (24.39 ft) / 2 = 12.20 ft

CG_3 = Center of Gravity (Position Three) = (T / 2) = (0.3958 ft) / 2 = 0.1979 ft

CG_Δ = Change in Center of Gravity = $CG_1 - CG_3$ = 12.20 ft – 0.1979 ft = 12.00 ft

Change in Potential Energy = (CG_Δ)(M_1) = 24000 ft-lb

The second impact:

E_{2nd} = (0.1511)(PE) + 24000 ft-lb

E_{2nd} = (0.1511)(12000 ft-lb) + 24000 ft-lb

E_{2nd} = 25813 ft-lb

F_{comp} = [(E_{2nd})(19/(19+5))] / 200 ft-lb

F_{comp} = [(25813 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 102.2 or 103 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1st Impact) + (2nd Impact) =

Total Fuel Rod Failures = (41) + (103) = 144 rods

Case 2

This case analyzes the free air drop resulting in a position 1 impact, and one laydown impact in position 3 with minimized fuel bundle impacts.

For the first impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (5 bundles)(562 lb)]

E_{dif} = 1 – [0.4158]

E_{dif} = 0.5842

For the second impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (235 bundles)(562 lb)]

E_{dif} = 1 – [0.0149]

E_{dif} = 0.9851

Essentially all of the second impact energy would be absorbed. As a result, third or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 58.42% of the initial energy or,

E_{abs} = (PE)(0.5842)

E_{abs} = (12000 ft-lb)(0.5842)

E_{abs} = 7010 ft-lb

$F_{comp} = [(E_{abs})(19/(19+5))] / 200$ ft-lb

$F_{comp} = [(7010$ ft-lb$)(19/(19+5))] / 200$ ft-lb

$F_{comp} = 27.75$ or 28 rods

The second impact involves a rebound consisting of 41.58% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

Potential Energy Change

CG_1 = Center of Gravity (Position One) = (L / 2) = (24.39 ft) / 2 = 12.20 ft

CG_3 = Center of Gravity (Position Three) = (T / 2) = (0.3958 ft) / 2 = 0.1979 ft

CG_Δ = Change in Center of Gravity = $CG_1 - CG_3$ = 12.20 ft – 0.1979 ft = 12.00 ft

Change in Potential Energy = $(CG_\Delta)(M_1)$ = 24000 ft-lb

The second impact:

$E_{2nd} = (0.4158)(PE) + 24000$ ft-lb

$E_{2nd} = (0.4158)(12000$ ft-lb$) + 24000$ ft-lb

$E_{2nd} = 28990$ ft-lb

$F_{comp} = [(E_{2nd})(19/(19+5))] / 200$ ft-lb

$F_{comp} = [(28990$ ft-lb$)(19/(19+5))] / 200$ ft-lb

$F_{comp} = 114.8$ or 115 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1^{st} Impact) + (2^{nd} Impact) =

Total Fuel Rod Failures = (28) + (115) = 143 rods

Case 3

This case analyzes the free air drop resulting in a position 1 impact, and two laydown impacts in position 2 and 3 with maximized fuel bundle impacts.

For the first impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (20 bundles)(562 lb)]

E_{dif} = 1 – [0.1511]

E_{dif} = 0.8489

For the second impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (96 bundles)(562 lb)]

E_{dif} = 1 – [0.0357]

E_{dif} = 0.9643

For the third impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (480 bundles)(562 lb)]

E_{dif} = 1 – [0.0074]

E_{dif} = 0.9926

Essentially all of the third impact energy would be absorbed. As a result, fourth or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 84.89% of the initial energy or,

E_{abs} = (PE)(0.8489)

E_{abs} = (12000 ft-lb)(0.8489)

E_{abs} = 10187 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(10187 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 40.32 or 41 rods

The second impact involves a rebound consisting of 15.11% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

<u>Potential Energy Change</u>

CG_1 = Center of Gravity (Position One) = (L / 2) = (24.39 ft) / 2 = 12.20 ft

CG_2 = Center of Gravity (Position Two) = (W / 2) = (4.771 ft) / 2 = 2.386 ft

CG_Δ = Change in Center of Gravity = CG_1 - CG_2 = 12.20 ft – 2.386 ft = 9.814 ft

Change in Potential Energy = (CG_Δ)(M_1) = 19628 ft-lb

The second impact:

E_{2nd} = (0.1511)(PE) + 19628 ft-lb

E_{2nd} = (0.1511)(12000 ft-lb) + 19628 ft-lb

E_{2nd} = 21441 ft-lb

F_{comp} = [(E_{2nd})(19/(19+5))] / 200 ft-lb

F_{comp} = [(21441 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 84.87 or 85 rods

The third impact involves a rebound consisting of 3.57% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

<u>Potential Energy Change</u>

CG_2 = Center of Gravity (Position Two) = (W / 2) = (4.771 ft) / 2 = 2.386 ft

CG_3 = Center of Gravity (Position Three) = (T / 2) = (0.3958 ft) / 2 = 0.1979 ft

CG_Δ = Change in Center of Gravity = CG_2 – CG_3 = 2.386 ft – 0.1979 ft = 2.188 ft

Change in Potential Energy = $(CG_{\Delta})(M_1)$ = 4376 ft-lb

The third impact:

E_{3rd} = (0.0357)(PE) + 4376 ft-lb

E_{3rd} = (0.0357)(12000 ft-lb) + 4376 ft-lb

E_{3rd} = 4804 ft-lb

F_{comp} = [(E_{3rd})(19/(19+5))] / 200 ft-lb

F_{comp} = [(4804 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 19.02 or 20 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1^{st} Impact) + (2^{nd} Impact) + (3^{rd} Impact) =

Total Fuel Rod Failures = (41) + (85) + (20) = 146 rods

Case 4

This case analyzes the free air drop resulting in a position 1 impact, and two laydown impacts in position 2 and 3 with maximized fuel bundle impacts.

For the first impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (5 bundles)(562 lb)]

E_{dif} = 1 – [0.4160]

E_{dif} = 0.5840

For the second impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (23 bundles)(562 lb)]

E_{dif} = 1 – [0.1340]

E_{dif} = 0.8660

For the third impact:

E_{dif} = 1 – [2000 lb / (2000 lb + (235 bundles)(562 lb)]

E_{dif} = 1 – [0.0149]

E_{dif} = 0.9851

Essentially all of the third impact energy would be absorbed. As a result, fourth or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 58.40% of the initial energy or,

E_{abs} = (PE)(0.5840)

E_{abs} = (12000 ft-lb)(0.5840)

E_{abs} = 7008 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(7008 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 27.74 or 28 rods

The second impact involves a rebound consisting of 41.60% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

Potential Energy Change

CG_1 = Center of Gravity (Position One) = (L / 2) = (24.39 ft) / 2 = 12.20 ft

CG_2 = Center of Gravity (Position Two) = (W / 2) = (4.771 ft) / 2 = 2.386 ft

CG_Δ = Change in Center of Gravity = CG_1 - CG_2 = 12.20 ft – 2.386 ft = 9.814 ft

Change in Potential Energy = (CG_Δ)(M_1) = 19628 ft-lb

The second impact:

E_{2nd} = (0.4160)(PE) + 19628 ft-lb

E_{2nd} = (0.4160)(12000 ft-lb) + 19628 ft-lb

E_{2nd} = 24620 ft-lb

F_{comp} = [(E_{2nd})(19/(19+5))] / 200 ft-lb

F_{comp} = [(24620 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 97.45 or 98 rods

The third impact involves a rebound consisting of 8.66% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

Potential Energy Change

CG_2 = Center of Gravity (Position Two) = (W / 2) = (4.771 ft) / 2 = 2.386 ft

CG_3 = Center of Gravity (Position Three) = (T / 2) = (0.3958 ft) / 2 = 0.1979 ft

CG_Δ = Change in Center of Gravity = $CG_2 - CG_3$ = 2.386 ft – 0.1979 ft = 2.188 ft

Change in Potential Energy = (CG_Δ)(M_1) = 4376 ft-lb

The third impact:

E_{3rd} = (0.0866)(PE) + 4376 ft-lb

E_{3rd} = (0.0866)(12000 ft-lb) + 4376 ft-lb

E_{3rd} = 5415 ft-lb

F_{comp} = [(E_{3rd})(19/(19+5))] / 200 ft-lb

F_{comp} = [(5415 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 21.43 or 22 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1^{st} Impact) + (2^{nd} Impact) + (3^{rd} Impact) =

Total Fuel Rod Failures = (28) + (98) + (22) = 149 rods

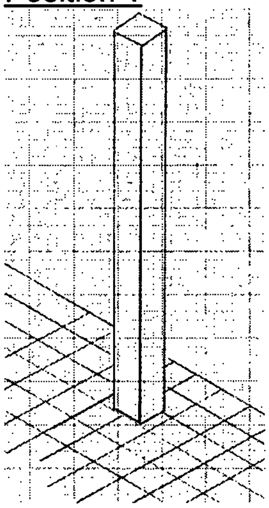
	Damaged Fuel Rods
Case 1	144
Case 2	143
Case 3	146
Case 4	148

10.1.2 Alternate Lifting Beam

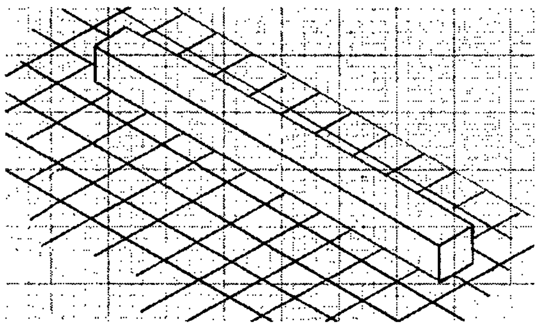
Fall Geometries

Lifting beams are long, slender members. For this reason, only two positions will be analyzed. Since the width and depth of both beams has the same potential for impacting rods, there is no need to analyze a position 3.

Position 1



Position 2



Position 1: Impact of beam on its end (width * depth).

Position 2: Impact of beam on its side (length * width).

	Position 1 Impact	Position 2 Impact	Max or Min Impacted Fuel Bundles
Case 1	x	x	Max
Case 2	x		Max
Case 3	x	x	Min
Case 4	x		Min

Initial Potential Energy

$PE = M_1 * H_d$

A W6x12 beam (12 ft long) is used for calculation of the Alternate Lifting Beam.

M_1 = Mass of Beam and Rigging Equipment = (12 ft)(12 lbs/ft) = 144 lbs **use 200 lbs**

H_d = (Elev. bottom of Beam – Elev. top of Fuel Racks) = (123' – 84.27') = 38.73 ft **use 39 ft**

PE = (200 lbs)(39 ft)

PE = 7800 ft-lb

Energy Difference

The energy absorbed during the impact is determined using the same relationship as given in the design basis Fuel Handing Accident analysis. For conservatism, M_1 (weight of the Spend Fuel Pool Gate and associate rigging equipment) has been maximized and M_2 (buoyant weight of the fuel bundles) has minimized.

$E_{dif} = 1 - [M_1 / (M_1 + M_2)]$

M_1 = Mass of Gate and Rigging Equipment = 200 lbs

M_2 = Mass of Impacted Fuel Bundles = (# of fuel bundles)(562 lbs/bundle)

Geometry

Position 1:

In order to estimate the maximum/minimum number of impacted fuel bundles for this geometry, the width and thickness must be divided by spacing between bundles.

(Width of Beam) / (Spacing between bundles)

(0.333 ft) / (0.5208 ft) = 0.6394 or 1 bundle

Because the width of the beam is over half the spacing of fuel bundles, it has the maximum potential to hit two rows of fuel bundles.

(Depth of Beam) / (Spacing between bundles)

(0.5 ft) / (0.5208 ft) = 0.9601 or 1 bundle

Because the depth of the beam is over half the spacing of fuel bundles, it has the maximum potential to hit two rows of fuel bundles.

Maxiumum Impacted Bundles = (2 bundles)(2 bundles) = 4 impacted fuel bundles

Minimum Impacted Bundles = (1 bundle)(1 bundle) = 1 bundle

Position 2:

In order to estimate the maximum/minimum number of impacted fuel bundles for this geometry, the length and width/depth must be divided by spacing between bundles. Because the width and depth of the beam have the same potential to impact fuel bundles, no position 3 will be analyzed.

(Width of Beam) / (Spacing between bundles)

(0.333 ft) / (0.5208 ft) = 0.6394 or 1 bundle

Because the width of the beam is over half the spacing of fuel bundles, it has the maximum potential to hit two rows of fuel bundles.

(Length of Beam) / (Spacing between bundles)

(12 ft) / (0.5208 ft) = 23.04 or 24 bundles

Maxiumum Impacted Bundles = (2 bundles)(24 bundles) = 48 impacted fuel bundles

Minimum Impacted Bundles = (1 bundle)(24 bundle) = 24 bundle

<u>Case 1</u>

This case analyzes the free air drop impact and one laydown impact with maximized fuel bundle impacts.

For the first impact:

E_{dif} = 1 – [200 lb / (200 lb + (4 bundles)(562 lb)]

E_{dif} = 1 – [0.0817]

E_{dif} = 0.9183

For the second impact:

E_{dif} = 1 – [200 lb / (200 lb + (48 bundles)(562 lb)]

E_{dif} = 1 – [0.0074]

E_{dif} = 0.9926

Essentially all of the second impact energy would be absorbed. As a result, third or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 91.83% of the initial energy or,

E_{abs} = (PE)(0.9183)

E_{abs} = (7800 ft-lb)(0.9183)

E_{abs} = 7163 ft-lb

F_{comp} ≈ [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} ≈ [(7163 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} ≈ 28.35 or 29 rods

The second impact involves a rebound consisting of 8.17% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

Potential Energy Change

CG_1 = Center of Gravity (Position One) = (L / 2) = (12 ft) / 2 = 6 ft

CG_3 = Center of Gravity (Position Three) = (T / 2) = (0.3333 ft) / 2 = 0.1667 ft

CG_Δ = Change in Center of Gravity = CG_1 – CG_3 = 6 ft – 0.1667 ft = 5.833 ft

Change in Potential Energy = (CG_Δ)(M_1) = 1167 ft-lb

The second impact:

E_{2nd} = (0.0817)(PE) + 1167 ft-lb

E_{2nd} = (0.0817)(7800 ft-lb) + 1167 ft-lb

E_{2nd} = 1804 ft-lb

F_{comp} ≈ [(E_{2nd})(19/(19+5))] / 200 ft-lb

F_{comp} ≈ [(1804 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} ≈ 7.14 or 8 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1st Impact) + (2nd Impact) =

Total Fuel Rod Failures = (29) + (8) = 37 rods

Case 2

This case analyzes the free air drop impact with the maximum potential for impacted fuel rods.

For the first impact:

E_{dif} = 1 – [200 lb / (200 lb + (48 bundles)(562 lb)]

E_{dif} = 1 – [0.0074]

E_{dif} = 0.9926

Essentially all of the first impact energy would be absorbed. As a result, second or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 99.26% of the initial energy or,

E_{abs} = (PE)(0.9926)

E_{abs} = (7800 ft-lb)(0.9926)

E_{abs} = 7742 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(7742 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 30.65 or 31 rods

Case 3

This case analyzes the free air drop impact and one laydown impact with minimized fuel bundle impacts.

For the first impact:

E_{dif} = 1 – [200 lb / (200 lb + (1 bundles)(562 lb)]

E_{dif} = 1 – [0.2625]

$E_{dif} = 0.7375$

For the second impact:

$E_{dif} = 1 - [200 \text{ lb} / (200 \text{ lb} + (24 \text{ bundles})(562 \text{ lb})]$

$E_{dif} = 1 - [0.0146]$

$E_{dif} = 0.9854$

Essentially all of the second impact energy would be absorbed. As a result, third or subsequent impacts need not be considered.

<u>Energy Absorbed</u>

The first impact absorbs 73.75% of the initial energy or,

$E_{abs} = (PE)(0.7375)$

$E_{abs} = (7800 \text{ ft-lb})(0.7375)$

$E_{abs} = 5753 \text{ ft-lb}$

$F_{comp} = [(E_{abs})(19/(19+5))] / 200 \text{ ft-lb}$

$F_{comp} = [(5753 \text{ ft-lb})(19/(19+5))] / 200 \text{ ft-lb}$

$F_{comp} = 22.77$ or 23 rods

The second impact involves a rebound consisting of 26.25% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

<u>Potential Energy Change</u>

CG_1 = Center of Gravity (Position One) = $(L / 2) = (12 \text{ ft}) / 2 = 6 \text{ ft}$

CG_3 = Center of Gravity (Position Three) = $(T / 2) = (0.3333 \text{ ft}) / 2 = 0.1667 \text{ ft}$

CG_Δ = Change in Center of Gravity = $CG_1 - CG_3 = 6 \text{ ft} - 0.1667 \text{ ft} = 5.833 \text{ ft}$

Change in Potential Energy = $(CG_\Delta)(M_1) = 1167 \text{ ft-lb}$

The second impact:

E_{2nd} = (0.2625)(PE) + 1167 ft-lb

E_{2nd} = (0.2625)(7800 ft-lb) + 1167 ft-lb

E_{2nd} = 3215 ft-lb

F_{comp} = [(E_{2nd})(19/(19+5))] / 200 ft-lb

F_{comp} = [(3215 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 12.73 or 13 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1^{st} Impact) + (2^{nd} Impact) =

Total Fuel Rod Failures = (23) + (13) = 36 rods

Case 4

This case analyzes the free air drop impact with the minimum potential for impacted fuel rods.

For the first impact:

E_{dif} = 1 – [200 lb / (200 lb + (24 bundles)(562 lb)]

E_{dif} = 1 – [0.0146]

E_{dif} = 0.9854

Essentially all of the first impact energy would be absorbed. As a result, second or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 98.54% of the initial energy or,

E_{abs} = (PE)(0.9854)

E_{abs} = (7800 ft-lb)(0.9854)

E_{abs} = 7686 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(7686 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 30.42 or 31 rods

	Damaged Fuel Rods
Case 1	37
Case 2	31
Case 3	36
Case 4	31

10.1.3 Intermediate Lifting Beam

Fall Geometries

Lifting beams are long, slender members. For this reason, only two positions will be analyzed. Since the width and depth of both beams has the same potential for impacting rods, there is no need to analyze a position 3.

Position 1: Impact of beam on its end (width * depth).

Position 2: Impact of beam on its side (length * width).

	Position 1 Impact	Position 2 Impact	Max or Min Impacted Fuel Bundles
Case 1	x	x	Max
Case 2	x		Max
Case 3	x	x	Min
Case 4	x		Min

Initial Potential Energy

$PE = M_1 * H_d$

A HSS6x5x½ beam (5 ft long) is used for calculation of the Intermediate Lifting Beam.

M_1 = Mass of Beam and Rigging Equipment = (5 ft)(31.71 lbs/ft) = 158.55 lbs **use 175 lbs**

H_d = (Elev. bottom of Beam – Elev. top of Fuel Racks) = (115' – 84.27') = 30.73 ft **use 31 ft**

PE = (175 lb)(31 ft)

PE = 5425 ft-lb

Energy Difference

The energy absorbed during the impact is assumed to be the same relationship as given in the original calculation. For conservatism, M_1 (weight of the Spend Fuel Pool Gate and associate rigging equipment) has been maximized and M_2 (buoyant weight of the fuel bundles) has minimized.

$E_{dif} = 1 - [M_1 / (M_1 + M_2)]$

M_1 = Mass of Beam and Rigging Equipment = (5 ft)(31.71 lbs/ft) = 158 lbs (175 lbs is

conservatively used for all further calculation)

M_2 = Mass of Impacted Fuel Bundles = (# of fuel bundles)(562 lbs/bundle)

Geometry

Position 1:

In order to estimate the maximum/minimum number of impacted fuel bundles for this geometry, the width and thickness must be divided by spacing between bundles.

(Width of Beam) / (Spacing between bundles)

(0.4167ft) / (0.5208 ft) = 0.8001 or 1 bundle

For the maximized case this object has the potential to hit two rows of fuel bundles (impact across the partial width of two bundles)

(Depth of Beam) / (Spacing between bundles)

(0.4167 ft) / (0.5208 ft) = 0.8001 or 1 bundle

For the maximized case this object has the potential to hit two rows of fuel bundles (impact across the partial width of two bundles)

Maxiumum Impacted Bundles = (2 bundles)(2 bundles) = 4 impacted fuel bundles

Minimum Impacted Bundles = (1 bundle)(1 bundle) = 1 bundle

Position 2:

In order to estimate the maximum/minimum number of impacted fuel bundles for this geometry, the length and width/depth must be divided by spacing between bundles. Because the width and depth of the beam have the same potential to impact fuel bundles, no position 3 will be analyzed.

(Width of Beam) / (Spacing between bundles)

(0.4167ft) / (0.5208 ft) = 0.8001 or 1 bundle

For the maximized case this object has the potential to hit two rows of fuel bundles (impact across the partial width of two bundles)

(Length of Beam) / (Spacing between bundles)

(5 ft) / (0.5208 ft) = 9.601 or 10 bundles

For the maximized case this object has the potential to hit eleven rows of fuel bundles (Impact across the full width of 9 bundles and partial width of one bundle on each end.)

Maxiumum Impacted Bundles = (2 bundles)(11 bundles) = 22 impacted fuel bundles

Minimum Impacted Bundles = (1 bundle)(10 bundle) = 10 bundles

Case 1

This case analyzes the free air drop impact and one laydown impact with maximized fuel bundle impacts.

For the first impact:

$E_{dif} = 1 - [175 \text{ lb} / (175 \text{ lb} + (4 \text{ bundles})(562 \text{ lb})]$

$E_{dif} = 1 - [0.0722]$

$E_{dif} = 0.9278$

For the second impact:

$E_{dif} = 1 - [175 \text{ lb} / (175 \text{ lb} + (22 \text{ bundles})(562 \text{ lb})]$

$E_{dif} = 1 - [0.0140]$

$E_{dif} = 0.986$

Essentially all of the second impact energy would be absorbed. As a result, third or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 92.78% of the initial energy or,

$E_{abs} = (PE)(0.9278)$

$E_{abs} = (5425 \text{ ft-lb})(0.9278)$

$E_{abs} = 5033 \text{ ft-lb}$

$F_{comp} = [(E_{abs})(19/(19+5))] / 200 \text{ ft-lb}$

$F_{comp} = [(5033 \text{ ft-lb})(19/(19+5))] / 200 \text{ ft-lb}$

$F_{comp} = 19.92$ or 20 rods

The second impact involves a rebound consisting of 7.22% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

Potential Energy Change

CG_1 = Center of Gravity (Position One) = (L / 2) = (5 ft) / 2 = 2.5 ft

CG_3 = Center of Gravity (Position Three) = (T / 2) = (0.4167 ft) / 2 = 0.2084 ft

CG_Δ = Change in Center of Gravity = $CG_1 - CG_3$ = 2.5 ft – 0.2084 ft = 2.292 ft

Change in Potential Energy = $(CG_\Delta)(M_1)$ = 401 ft-lb

The second impact:

$E_{2nd} = (0.0722)(PE) + 401 \text{ ft-lb}$

$E_{2nd} = (0.0722)(5425 \text{ ft-lb}) + 401 \text{ ft-lb}$

$E_{2nd} = 792.7 \text{ ft-lb}$

$F_{comp} = [(E_{2nd})(19/(19+5))] / 200 \text{ ft-lb}$

F_{comp} = [(792.7 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 3.14 or 4 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1st Impact) + (2nd Impact) =

Total Fuel Rod Failures = (20) + (4) = 24 rods

<u>Case 2</u>

This case analyzes the free air drop impact with the maximum potential to impact fuel bundles.

For the first impact:

E_{dif} = 1 – [175 lb / (175 lb + (22 bundles)(562 lb)]

E_{dif} = 1 – [0.0140]

E_{dif} = 0.986

Essentially all of the first impact energy would be absorbed. As a result, second or subsequent impacts need not be considered.

<u>Energy Absorbed</u>

The first impact absorbs 98.60% of the initial energy or,

E_{abs} = (PE)(0.9860)

E_{abs} = (5425 ft-lb)(0.9860)

E_{abs} = 5349 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(5349 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 21.17 or 22 rods

Case 3

This case analyzes the free air drop impact and one laydown impact with minimized fuel bundle impacts.

For the first impact:

E_{dif} = 1 – [175 lb / (175 lb + (1 bundles)(562 lb))]

E_{dif} = 1 – [0.2374]

E_{dif} = 0.7626

For the second impact:

E_{dif} = 1 – [175 lb / (175 lb + (10 bundles)(562 lb))]

E_{dif} = 1 – [0.0302]

E_{dif} = 0.9698

Essentially all of the second impact energy would be absorbed. As a result, third or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 76.26% of the initial energy or,

E_{abs} = (PE)(0.7626)

E_{abs} = (5425 ft-lb)(0.7626)

E_{abs} = 4137 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(4137 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 16.38 or 17 rods

The second impact involves a rebound consisting of 23.74% of the initial drop energy and the laydown drop energy. The laydown drop provides additional energy due to the potential energy change resulting from the change of the Spent Fuel Pool Gate center of gravity of approximately ½ of the Spent Fuel Pool Gate length.

Potential Energy Change

CG_1 = Center of Gravity (Position One) = (L / 2) = (5 ft) / 2 = 2.5 ft

CG_3 = Center of Gravity (Position Three) = (T / 2) = (0.4167 ft) / 2 = 0.2084 ft

CG_Δ = Change in Center of Gravity = $CG_1 - CG_3$ = 2.5 ft – 0.2084 ft = 2.292 ft

Change in Potential Energy = $(CG_\Delta)(M_1)$ = 401 ft-lb

The second impact:

E_{2nd} = (0.2374)(PE) + 401 ft-lb

E_{2nd} = (0.2374)(5425 ft-lb) + 401 ft-lb

E_{2nd} = 1689 ft-lb

F_{comp} = [(E_{2nd})(19/(19+5))] / 200 ft-lb

F_{comp} = [(1689 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 6.69 or 7 rods

The total fuel rod failures during this scenario are:

Total Fuel Rod Failures = (1^{st} Impact) + (2^{nd} Impact) =

Total Fuel Rod Failures = (17) + (7) = 24 rods

Case 4

This case analyzes the free air drop impact with the minimum potential to impact fuel bundles.

For the first impact:

E_{dif} = 1 – [175 lb / (175 lb + (10 bundles)(562 lb)]

E_{dif} = 1 – [0.0302]

E_{dif} = 0.9698

Essentially all of the first impact energy would be absorbed. As a result, second or subsequent impacts need not be considered.

Energy Absorbed

The first impact absorbs 96.98% of the initial energy or,

E_{abs} = (PE)(0.9698)

E_{abs} = (5425 ft-lb)(0.9698)

E_{abs} = 5261 ft-lb

F_{comp} = [(E_{abs})(19/(19+5))] / 200 ft-lb

F_{comp} = [(5261 ft-lb)(19/(19+5))] / 200 ft-lb

F_{comp} = 20.82 or 21 rods

	Damaged Fuel Rods
Case 1	24
Case 2	22
Case 3	24
Case 4	21

By totaling the bounding cases of each dropped object (pool gate, intermediate lifting beam, and alternate lifting beam), a maximum total number of 209 fuel rods will fail in compression.

Dose Analysis

Based upon the load drop analysis, the maximum number of damaged rods is 209. This number of rods is increased 20% to account for potential future fuel design changes or changes in rigging. This provides the following number of damaged rods to use in the dose analysis:

209 damaged rods * 1.20 = 265.2 **use 266 damaged rods**

The activity of each isotope released to the environment is determined using the following relationship:

Ai = AC * FD * FRP *FG *(1/DF)

where:

Ai = total activity of isotope i released to the environment (Ci/MWt)

AC = total activity in the reactor core (Ci/MWt)

FD = fraction of core damaged (unitless)

= Number of rods damaged / (Rods per bundle * Bundles in core)

FRP = maximum radial peaking factor (unitless)

FG = fraction of isotope activity in damaged rods escaping as gap release (unitless).

DF = decontamination factor within pool water for isotope i (unitless)

AC for each isotope is shown in the following table:

Source Term: (Ref. II.5_EC 14186 markup pg. 9)

Isotope	24 Month Fuel Cycle Core Inventory (Ci/MW) at Time 0
I-131	2.70E+04
I-132	3.92E+04
I-133	5.52E+04
I-134	6.06E+04
I-135	5.17E+04
Kr-85	3.66E+02
Kr-85m	7.02E+03
Kr-87	1.35E+04
Kr-88	1.89E+04
Xe-133	5.26E+04
Xe-135	1.99E+04

FD = fraction of core damaged (unitless)

= Number of rods damaged / (Rods per bundle * Bundles in core)

Number of rods damaged = 266
Number of Rods per Bundle for GE 9x9 Fuel: 74 (Ref. II.5_EC 14186 markup pg. 17)
Number of Bundles in Core: 624 (Ref. II.5_EC 14186 markup pg. 17)

FD = 266 rods damaged / (74 rods per bundle * 624 Bundles in core)

FD = 0.005761 or **5.761E-3**

FRP = maximum radial peaking factor (unitless)

Core Radial Peaking Factor: 2.00 (Ref. II.5_EC 14186 markup pg. 17)

FRP = **2.0**

FG = fraction of isotope activity in damaged rods escaping as gap release (unitless).

From Assumption 8.8.1, the gap activity fractions of Table 3 in Regulatory Position 3 of RG 1.183 (Ref. III.1) are utilized, as follows:

I-131	0.08
All other halogens	0.05
Kr-85	0.10
All other noble gases	0.05

$FG_{I\text{-}131}$ = **0.08**
$FG_{\text{Other halogens}}$ = **0.05**
$FG_{Kr\text{-}85}$ = **0.10**
$FG_{\text{Other noble gases}}$ = **0.05**

DF = decontamination factor within pool water for isotope i (unitless)

DF Noble Gases = 1

Per Assumption 8.8.6:

DF Iodines = 200

Ai for each isotope is calculated using an Excel spread sheet shown on the following page. A copy of the formula view of the spread sheet is also included on the subsequent page.

CALCULATION DETAILS	CALCULATION NO:	G13.18.2.7-116
	REVISION:	0
	PAGE:	61

Gate Drop Case 266 failed rods

	AC	FD	FRP	FG	DF	Ai	Ai * 3100 MWt
Isotope	24 Mo Core Inventory (Ci/MW) at time = 0	FHA Damaged Fuel - Fraction of Core	FHA Damaged Fuel - Radial Peaking Factor	AST FHA Gap Fraction Released	Effective Pool DF	Activity Released (Ci/MWt)	Activity Released (Ci)
I-131	2.70E+04	5.761E-03	2.00	0.08	200	1.244E-01	3.857E+02
I-132	3.92E+04	5.761E-03	2.00	0.05	200	1.129E-01	3.500E+02
I-133	5.52E+04	5.761E-03	2.00	0.05	200	1.590E-01	4.929E+02
I-134	6.06E+04	5.761E-03	2.00	0.05	200	1.745E-01	5.411E+02
I-135	5.17E+04	5.761E-03	2.00	0.05	200	1.489E-01	4.616E+02
I-136	N/A	N/A	N/A	N/A		N/A	N/A
KR-83m	N/A	N/A	N/A	N/A		N/A	N/A
Kr-85	3.66E+02	5.761E-03	2.00	0.1	1	4.217E-01	1.307E+03
KR-85m	7.02E+03	5.761E-03	2.00	0.05	1	4.044E+00	1.254E+04
Kr-87	1.35E+04	5.761E-03	2.00	0.05	1	7.777E+00	2.411E+04
KR-88	1.89E+04	5.761E-03	2.00	0.05	1	1.089E+01	3.375E+04
KR-89	N/A	N/A	N/A	N/A		N/A	N/A
Xe-131m	N/A	N/A	N/A	N/A		N/A	N/A
Xe-133m	N/A	N/A	N/A	N/A		N/A	N/A
Xe-133	5.26E+04	5.761E-03	2.00	0.05	1	3.030E+01	9.393E+04
Xe-135m	N/A	N/A	N/A	N/A		N/A	N/A
Xe-135	1.99E+04	5.761E-03	2.00	0.05	1	1.146E+01	3.554E+04
Xe-137	N/A	N/A	N/A	N/A		N/A	N/A
Xe-138	N/A	N/A	N/A	N/A		N/A	N/A

Formula view of Excel Spread Sheet

	A	B	C	D	E	F	G	H
189								
190	Isotope	24 Mo Core Inventory (Ci/MW) at time = 0	FHA Damaged Fuel - Fraction of Core	FHA Damaged Fuel - Radial Peaking Factor	AST FHA Gap Fraction Released	Effective Pool DF	Activity Released (Ci/MWt)	Activity Released (Ci)
191	I-131	27000	=266/(74*624)	2	0.08	200	=(B191*C191*D191*E191)/F191	=G191*3100
192	I-132	39200	=266/(74*624)	2	0.05	200	=(B192*C192*D192*E192)/F192	=G192*3100
193	I-133	55200	=266/(74*624)	2	0.05	200	=(B193*C193*D193*E193)/F193	=G193*3100
194	I-134	60600	=266/(74*624)	2	0.05	200	=(B194*C194*D194*E194)/F194	=G194*3100
195	I-135	51700	=266/(74*624)	2	0.05	200	=(B195*C195*D195*E195)/F195	=G195*3100
196	I-136	N/A	N/A	N/A	N/A		N/A	N/A
197								
198	KR-83m	N/A	N/A	N/A	N/A		N/A	N/A
199	Kr-85	366	=266/(74*624)	2	0.1	1	=(B199*C199*D199*E199)/F199	=G199*3100
200	KR-85m	7020	=266/(74*624)	2	0.05	1	=(B200*C200*D200*E200)/F200	=G200*3100
201	Kr-87	13500	=266/(74*624)	2	0.05	1	=(B201*C201*D201*E201)/F201	=G201*3100
202	KR-88	18900	=266/(74*624)	2	0.05	1	=(B202*C202*D202*E202)/F202	=G202*3100
203	KR-89	N/A	N/A	N/A	N/A		N/A	N/A
204								
205	Xe-131m	N/A	N/A	N/A	N/A		N/A	N/A
206	Xe-133m	N/A	N/A	N/A	N/A		N/A	N/A
207	Xe-133	52600	=266/(74*624)	2	0.05	1	=(B207*C207*D207*E207)/F207	=G207*3100
208	Xe-135m	N/A	N/A	N/A	N/A		N/A	N/A
209	Xe-135	19900	=266/(74*624)	2	0.05	1	=(B209*C209*D209*E209)/F209	=G209*3100
210	Xe-137	N/A	N/A	N/A	N/A		N/A	N/A
211	Xe-138	N/A	N/A	N/A	N/A		N/A	N/A

RADTRAD Model – Load Drop over Spent Fuel Pool – 336 Hours Decay with no Credit Taken for FB, Containment Integrity or CR Filtration

A RADTRAD CR model based on ventilation system parameters as described in Sections 7, 8 and 9 is developed as discussed below. Note that this model is identical to the model developed for Case 1 in calculation G13.18.9.5*059 (Ref. II.5) with the exception of the source term and the assumed decay time. RADTRAD model information from G13.18.9.5*059 is provided in this section. References for the various inputs are provided in the inputs section of this calculation, thus the references are not duplicated in this section.

The activity released to the environment previously calculated is modeled to be released at ground level from the Fuel Building in a time period not to exceed 2 hours. This is accomplished by purging the actual FB free volume at a very high rate while releasing the available activity in the Fuel Pool over a 2 hour period. All leakage is immediately released to the environment from the FB without holdup, plateout, or dilution.

RADTRAD Volume 1 represents the FB
• RBS FB volume is modeled as 7.42E+05 ft^3
• 100% of the AST FHA source term exiting the pool is released to the Environment
• No additional inputs

RADTRAD Volume 2 represents the Environment
• No inputs

RADTRAD Volume 3 represents the Control Room
• Control Room habitability volume equals 188,000 ft^3
• No additional inputs

RADTRAD Pathway 1 represents the FB leakage term (total release in 24 hours)
• FB air exhaust rate modeled as 7.42E+09 cfm (to allow for a 2 hour release)
• 0% efficient filters for elemental & organic species
• No additional inputs.

RADTRAD Source Term:
• User Inventory file RBS_FHARev1a266.nif. This file is developed by using the calculated release for the individual isotopes (Ai) previously determined based upon a failure of 266 fuel rods.
• Modeled RBS AEP power level as 3100 MWth
Model isotopic decay and daughter in-growth
• Use the user defined RADTRAD release fraction file, rbs_fharev1.rft. This file defines a .001 - hour release duration with a 100% release fraction in that period after allowing a 336-hour decay period.
• The specified iodine species fractions are 0.57 elemental and 0.43 organic
• Use the default RADTRAD FGR 11 & 12 dose conversion factors for the MACCS 60 isotope inventory, FGR11&12.inp

• No additional inputs

RADTRAD Analysis Results

Calculation Results
TEDE (REM)

Dose Receptor	Acceptance Criteria	Gate Drop in Fuel Building
EAB*	6.3	1.2155
LPZ	6.3	0.16017
CR	5	0.87328

*Worst 2-hour period

10.2 Damage to Pool Liner

In assessing the damage to the pool liner the following cases are analyzed based upon the load path.

Drop from Maximum Lift Height

The maximum lift height occurs when transferring the gate from the cask pool to the laydown area on the Fuel Building 113' elevation. Objects analyzed for this drop are the gate, intermediate lifting beam and alternate lifting beam. Potential points of impact for this drop are:

1) Cask pool floor at 70' elevation;
2) Cask pool shelf at 93' elevation;
3) Gate opening at 88' elevation.

Load Drop with Gate in Pool

This scenario is during the movement of the gate from its installed location in the spent fuel pool to the gate opening between the spent fuel pool and cask pool, through the gate opening, then into the cask pool. Objects analyzed for this drop are the gate, intermediate lifting beam and alternate lifting beam. Potential points of impact for this drop are:

1) Spent fuel pool or cask pool floor at 70' elevation;
2) Gate opening floor at 88' elevation.

Load Drop onto Fuel Storage Racks

This scenario postulates a load drop during movement of the load in the spent fuel pool area that impacts the fuel storage racks. Objects analyzed for this drop are the gate, intermediate lifting beam and alternate lifting beam. ***This scenario only determines the impact velocity of the objects as an input to the evaluation in Section 10.3***.

10.2.1 Drop from Maximum Lift Height

The maximum lift height occurs when transferring the gate from the cask pool to the laydown area on the Fuel Building 113' elevation. Objects analyzed for this drop are the gate, intermediate lifting beam and alternate lifting beam. Potential points of impact for this drop are:

1) Cask pool floor at 70' elevation;
2) Cask pool shelf at 93' elevation;
3) Gate opening at 88' elevation.

Determine Pool Minimum Water Level Elevation

TS Minimum water level above the top of irradiated fuel = $\geq$ 23' (Ref. III.10, pg. 3.7-15)

Stored fuel bundle upper tie plate elevation = 84.6645'
(Ref. II.3, pg. 4 and Assumption 8.12)

Pool Min Level Elevation = Top of Irradiated Fuel Elevation + Min TS Water Coverage

Pool Min Level Elevation = 84.6645' + 23' = 107.6645' **use 107.7'**

Determine Maximum Object Lift Elevation

For the initial movement the objects being evaluated had the following elevations:

Elevation of bottom of Gate = 90'	(Ref. II.2, pg. 8)
Elevation of bottom of Intermediate Lifting Beam = 115'	(Ref. II.2, pg. 8)
Elevation of bottom of Alternate Lifting Beam = 123'	(Ref. II.2, pg. 12)

Maximum Lift Elevation of the Gate Bottom

Elevation of Fuel and Cask Pool Curb = 113' 4" (Ref. II.13)

Approximate lift height above laydown floor elevation obstructions = 6" (Ref. III.1, pg. 16)

Max Gate Bottom Lift Elevation = Curb elevation + lift height above obstructions

Max Gate Bottom Lift Elevation = 113' 4" + 6" = 113' 10' use **115' 0" or 115.0'**

Using the elevations of the bottom of the gate, intermediate lifting beam and alternate lifting beam from the initial movement, determine the Maximum Lift Elevation for the Intermediate Beam and Alternate Beam.

Max Lift Elevation of Intermediate Beam
= Max Gate Bottom Lift El. + (Initial Lift Int. Beam Bottom El. – Initial Lift Gate Bottom El.)

Max Lift Elevation of Intermediate Beam = 115.0' + (115'-90') = **140'**

Max Lift Elevation of Alternate Beam
= Max Gate Bottom Lift El. + (Initial Lift Alt. Beam Bottom El. – Initial Lift Gate Bottom El.)

Max Lift Elevation of Alternate Beam = 115' + (123'-90') = **148'**

Determine Object Air Drop Distance

Air Drop Distance = Max Lift Elevation – Pool Min Level Elevation

Gate Air Drop Distance = Max Lift Elevation – Pool Min Level Elevation
Gate Air Drop Distance = 115' – 107.7' = **7.3'**

Intermediate Beam Air Drop Distance = Max Lift Elevation – Pool Min Level Elevation
Intermediate Beam Air Drop Distance = 140' – 107.7' = **32.3'**

Alternate Beam Air Drop Distance = Max Lift Elevation – Pool Min Level Elevation
Alternate Beam Air Drop Distance = 148' – 107.7' = **40.3'**

Determine Water Drop Distance

Water Drop Distance = Pool Min Level Elevation – Elevation of Impact Point

Cask Pool Floor Water Drop Distance = 107.7 – 70' = **37.7'**

Cask Pool Shelf Water Drop Distance = 107.7' – 93' = **14.7'**

Gate Opening Water Drop Distance = 107.7' – 88' = **19.7'**

The equation to determine strike velocity is selected based upon the relationship of object length (L) to water depth (H) as follows:

$Z_1(x)$ = function for determining the striking velocity at depth H = x when $0 \le x \le L$

$Z_2(x)$ = function for determining the striking velocity at depth H = x when $x \ge L$

The following table provides a summary of the air drop distance, water drop distance H, the length of the dropped object, and the selected strike velocity function based upon the criteria above for each Maximum Lift Load Drop case.

Case Description	Air Drop Distance, h ft	Water Drop Distance, H ft	L ft	Strike Velocity Function
Gate Drop to Cask Pool Floor	7.3'	37.7'	24.39'	$Z_2(x)$
Gate Drop to Cask Pool Shelf	7.3'	14.7'	24.39'	$Z_1(x)$
Gate Drop to Gate Opening	7.3'	19.7'	24.39'	$Z_1(x)$
Intermediate Beam Drop to Cask Pool Floor	32.3'	37.7'	4.75'	$Z_2(x)$
Intermediate Beam Drop to Cask Pool Shelf	32.3'	14.7'	4.75'	$Z_2(x)$
Intermediate Beam Drop to Gate Opening	32.3'	19.7'	4.75'	$Z_2(x)$
Alternate Beam Drop to Cask Pool Floor	40.3'	37.7'	12'	$Z_2(x)$
Alternate Beam Drop to Cask Pool Shelf	40.3'	14.7'	12'	$Z_2(x)$
Alternate Beam Drop to Gate Opening	40.3'	19.7'	12'	$Z_2(x)$

For the Object Drop cases to assess liner damage, the following equations will be used:

$V_0 = (2gh)^{1/2}$ (Ref. II.4, pg. E-4, 5-3)

Where:

V_0 = velocity of the missile at contact with the water surface, ft/s
g = gravitational acceleration = 32.17 ft/s^2
h = distance between the missile and the water surface, ft

$V_s = [Z(H)]^{1/2}$ (Ref. II.4, pg. 5-2)

Where:

V_s = velocity of the missile striking the steel surface, ft/s
$Z(H)$ = function for determination of striking velocity (see formulas below)
H = feet of fluid between fluid surface and surface of steel target

The following equations are from Ref. II.4, pg. 5-2:

$Z_1(x) = (g/a) + (bA_0)[(1\text{-}2ax)/2a^2)] + e^{-2ax}[(V_0^2 - (g/a) - (bA_0 / 2a^2)]$

$Z_2(x) = V_2^2 + e^{-2ax}\{(bA_0 /2a^2)[e^{2aL}(1\text{-}2aL) - 1)] + V_0^2 + [(g/a)[(e^{2aL}(\gamma/\gamma_m) - 1)]\}$

Where:

$Z_1(x)$ = function for determining the striking velocity at depth H = x when $0 \leq x \leq L$

$Z_2(x)$ = function for determining the striking velocity at depth H = x when $x \geq L$

$a = (\gamma * A_0 * C_D) / (2 * W)$ (Ref. II.4, pg. 5-3)

$b = (\gamma * g) / W$ (Ref. II.4, pg. 5-3)

g = gravitational acceleration = 32.17 ft/s^2 (Ref. II.4, pg. 5-3)

W = weight of missile, lb (Ref. II.4, pg. 5-3)

γ = weight density of liquid, lb/ft^3 (Ref. II.4, pg. 5-3)

γ_m = weight density of missile, lb/ft^3 (Ref. II.4, pg. 5-3)

x = H = depth of missile center of gravity below the water surface, ft
(Ref. II.4, pg. 5-3, 5-5)

A_0 = horizontal cross-sectional area of the missile (constant over length L), ft^2
(Ref. II.4, pg. 5-3)

C_D = drag coefficient given in table 5-1 of the reference or other references on fluid mechanics which is a function of L/d, R and shape of the missile
(Ref. II.4, pg. 5-3, 5-4)

L = vertical length of the missile, ft (Ref. II.4, pg. 5-3)

d = characteristic dimension of the missile, for a rectangular surface d = width, ft
(Ref. II.4, pg. 5-3, 5-4)

R = Reynolds Number = $(V_0 * d) / \nu$ (Ref. II.4, pg. 5-3)

ν = kinematic viscosity of the liquid, ft^2/s (Ref. II.4, pg. 5-3)

V_0 = initial velocity of the missile at x = 0, ft/s (Ref. II.4, pg. 5-3, 5-5)

Vs = striking velocity of the missile at x = H, ft/s (Ref. II.4, pg. 5-3)

V_2 = terminal velocity, ft/s = $[(g/a) * (1 - \gamma/\gamma_m)]^{1/2}$ (Ref. II.4, pg. 5-3)

H = depth of the fluid, ft (Ref. II.4, pg. 5-1)

$T^{3/2} = 0.5\ M\ V_s^2 / (17{,}400\ K^2\ D^{3/2})$ (Ref. II.4, pg. C-8)

Where:

T = steel thickness to just be perforated, in
M = mass of the missile, $lb\text{-}s^2/ft$
V_s = striking velocity of the missile normal to target surface, ft/s
K = constant depending on the grade of the steel, K is usually = 1
D = diameter or equivalent diameter of the missile, in

The inputs for the maximum lift load drop cases are as follows:

All cases:

g = Acceleration of Gravity = 32.174 ft/sec^2 (Ref. III.9, pg. B-10)

γ = Density of water @ 160 deg. F = 60.994 lb/ft^3 (Ref. III.9, pg. A-6)

ν = Kinematic viscosity of water @ 160 deg. F = 0.439 E-5 ft^2/s (Ref. III.11)

K = constant related to grade of steel = 1

The inputs for the maximum lift gate load drop cases are as follows:

L = Length of Spent Fuel Pool Gate = 24.39 ft (Ref. II.1, pg. A11)

d = Width of Spent Fuel Pool Gate = 4.771 ft (Ref. II.1, pg. A11)

t = Thickness of Spent Fuel Pool Gate = 0.3958 ft (Ref. II.1, pg. 17)

W = Weight of Spent Fuel Pool Gate and Rigging = 2000 lbs (Ref. III.1, pg. 4);

Case Description	Air Drop Distance, h ft	Water Drop Distance, H ft	L ft	Strike Velocity Function
Gate Drop to Cask Pool Floor	7.3'	37.7'	24.39'	$Z_2(x)$
Gate Drop to Cask Pool Shelf	7.3'	14.7'	24.39'	$Z_1(x)$
Gate Drop to Gate Opening	7.3'	19.7'	24.39'	$Z_1(x)$

γ_m = weight density of missile, lb/ft^3 = weight, lb / (L, ft * d, ft * t, ft)

γ_m = weight density of gate, lb/ft^3 = 2000 lb / (24.39 ft * 4.771 ft * 0.3958 ft) = 43.424 lb/ft^3

For Gate Drop to Cask Pool Floor

Determine V_0

$V_0 = (2gh)^{1/2}$

Where:
V_0 = velocity of the missile at contact with the water surface, ft/s
g = gravitational acceleration = 32.17 ft/s^2
h = distance between the missile and the water surface, ft

V_0 = (2 * 32.17 ft/s^{2}* 7.3 ft) $^{1/2}$ = 21.672 ft/s

Determine R

Note that d in the Reynolds number represents the width of the gate.

R = (V_0 * d) / ν = (21.672 ft/s * 4.771 ft) / 0.439 E-5 ft^2/s = 2.355E7

Determine C_D

In determining C_D for rectangular bodies L = length of the body, d = width

Gate length (height) = 24.39'   Gate width = 4.771'

L/d = 24.39' /4.771' = 5.112

Using Ref. II.4, pg. 5-4 Table 5-1 C_D = 1.20

Determine A_0

A_0 = horizontal cross-sectional area of the missile (constant over length L), ft^2
(Ref. II.4, pg. 5-3)

A_0 = gate width * gate thickness = 4.771* 0.3958 = 1.888 ft^2

Determine Coefficient a

$a = (\gamma * A_0 * C_D) / (2 * W) = (60.994\ lb/ft^3 * 1.888\ ft^2 * 1.20) / (2*2000\ lb) = 0.035$

Determine Coefficient b

$b = (\gamma * g) / W = (60.994\ lb/ft^3 * 32.17\ ft/s^2) / 2000\ lb = 0.981$

Determine Terminal Velocity V_2

$V_2 = [(g/a) * (1 - \gamma/\gamma_m)]^{1/2} = [(32.17\ ft/s^2 / 0.035) * (1 - (60.994\ lb/ft^3 / 43.424\ lb/ft^3))]^{1/2}$

$V_2 = [919.143 * (1-1.405)]^{1/2}$

$V_2 = [-372.253]^{1/2}$

As the square root of a negative number is indeterminate, this indicates that the gate will float as the density of the gate is less than the density of water. Although the value determined for the overall gate density is correct, it is unlikely that the gate will float. Therefore the thickness of the gate will be adjusted to achieve a gate density greater than water. The smaller gate thickness will be used throughout this case. This will ultimately reduce the impact area experienced by the liner which increases the penetration thickness and is thus conservative. ***Note that this dimension adjustment is only used for this case.***

The adjusted gate thickness is 0.275' or 3.3"

The adjusted density of the gate is as follows:

$\gamma_m = 2000\ lb / (24.39\ ft * 4.771\ ft * 0.275\ ft) = 62.499\ lb/ft^3$

Determine Revised A_0

A_0 = horizontal cross-sectional area of the missile (constant over length L), ft^2 (Ref. II.4, pg. 5-3)

A_0 = gate width * gate thickness = 4.771* 0.275 = 1.312 ft^2

Determine Revised Coefficient a

$a = (\gamma * A_0 * C_D) / (2 * W) = (60.994\ lb/ft^3 * 1.312\ ft^2 * 1.20) / (2*2000\ lb) = 0.024$

Determine Revised Terminal Velocity V_2

$V_2 = [(g/a) * (1 - \gamma/\gamma_m)]^{1/2} = [(32.17\ ft/s^2 / 0.024) * (1 - (60.994\ lb/ft^3 / 62.499\ lb/ft^3))]^{1/2}$

$V_2 = [1340.417 * (1-0.976)]^{1/2} = 5.681\ ft/s$

Determine $Z_2(x)$

Note that x=H such that the result of $Z_2(x)$ can be directly used to determine strike velocity.

$Z_2(x) = V_2^2 + e^{-2ax}\{(bA_0/2a^2)[e^{2aL}(1-2aL) - 1)] + V_0^2 + [(g/a)[(e^{2aL}(\gamma/\gamma_m) - 1)]\}$

For simplicity the various intermediate relations in the formula are determined individually. Only results values are listed without units.

$V_2^2 = (5.681\ ft/s)^2 = 32.274$

$e^{-2ax} = e^{(-2 * 0.024 * 37.7)} = 0.164$

$(bA_0/2a^2) = (0.981 * 1.312) / (2 * (0.024)^2) = 1117.250$

$2aL = 2*0.024*24.39 = 1.171$

$e^{2aL} = e^{(1.171)} = 3.225$

$[e^{2aL}(1-2aL) - 1)] = [((3.225 (1 - 1.171)) - 1] = -1.551$

$V_0^2 = (21.672\ ft/s)^2 = 469.676$

$g/a = 32.17 / 0.024 = 1340.417$

$\gamma/\gamma_m = 60.994\ lb/ft^3 / 62.499\ lb/ft^3 = 0.976$

$Z_2(x) = V_2^2 + e^{-2ax}\{(bA_0/2a^2)[e^{2aL}(1-2aL) - 1)] + V_0^2 + [(g/a)[(e^{2aL}(\gamma/\gamma_m) - 1)]\}$

$Z_2(x) = 32.274 + 0.164\{(1117.250)[-1.551] + 469.676 + [(1340.417)[(3.225(0.976) - 1)]\}$

$Z_2(x) = 32.274 + 0.164\{-1732.855 + 469.676 + 2878.679\} = 297.216$

Determine V_s

$V_s = [Z(H)]^{1/2}$ (Ref. II.4, pg. 5-2)

Where:

V_s = velocity of the missile striking the steel surface, ft/s
Z(H) = function for determination of striking velocity
H = feet of fluid between fluid surface and surface of steel target

$V_s = [297.216]^{1/2} = 17.239$ ft/s

Convert the impact area to equivalent diameter D

The impact area is equal to A_0 calculated previously.

$A_0 = 1.312\ ft^2$

$1.312\ ft^2 * 144\ in^2/ft^2 = 188.928\ in^2$

$188.928\ in^2 = \pi r^2$ r = 7.755 in

D = 2*r = 2 * 7.755 in = 15.509 in

Determine M

M = W / g

$M = 2000\ lb / 32.17\ ft/s^2 = 62.170\ lb\text{-}s^2/ft$

Determine Steel Penetration Thickness

$T^{3/2} = 0.5\ M\ V_s^2 / (17{,}400\ K^2\ D^{3/2})$ (Ref. II.4, pg. C-8)

Where:

T = steel thickness to just be perforated, in
M = mass of the missile, $lb\text{-}s^2/ft$
V_s = striking velocity of the missile normal to target surface, ft/s
K = constant depending on the grade of the steel, K is usually = 1
D = diameter or equivalent diameter of the missile, in

$T^{3/2} = 0.5 * 62.170 * (17.239)^2 / (17{,}400 *(1)^2 (15.509^{3/2})) = 0.008693$

$T = 0.042$ in

The analysis methodology to calculate $Z_2(x)$ and T has been input into an Excel spread sheet. The results of the spread sheet for the previously calculated case is on the following page. Note that there are differences in some values due to variations the significant figures stored in Excel verses those displayed in the manual calculation. Due to the Excel limitations with respect to formatting, some of the variables are indicated by description rather than symbol. The spread sheet method will be used in all of the subsequent cases.

Gate Drop from Max Lift Height to Pool Floor 70'	Value	Units
Gate Length L	24.390	ft
Gate Width, d	4.771	ft
Gate thickness (reduced to obtain density greater than water)	0.275	ft
Gate weight, W	2000.000	lb
Gate density	62.499	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/s
water density/gate density	0.976	
drop distance in air	7.300	ft
drop distance in water	37.700	ft
Vo where h is drop distance in air, V = (2gh)^2	21.672	ft/s
Reynolds no =(Vo * d)/viscosity	2.355E+07	
Check L/d using gate length and width	5.112	
Check L/D using gate width and thickness	17.349	
Drag Coefficient CD	1.200	
Ao = width * thickness	1.312	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.024	
b = (water density * g)/W	0.981	
Terminal Velocity, V2 = SQRT((g*(1-density water/density gate)/a)	5.681	ft/s
exp(-2*a*x) where x = drop distance in water	0.164	
bAo	1.287	
exp(2aL)	3.226	
2aL	1.171	
V2^2	32.276	
Vo^2	469.682	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-1732.907	
g*(exp(2aL) * wtr dens/gate dens -1)/a	2878.065	
Z2x	296.504	
Vs = (Zx)^0.5	17.219	ft/s
Convert impact area to equivalent diameter	15.509	in
mass ≈ weight/g	62.170	lb-s2/ft
thickness T	**0.042**	in

For Gate Drop to Cask Pool Shelf

$Z_1(x) = (g/a) + (bA_0)[(1\text{-}2ax)/2a^2)] + e^{-2ax}[(V_0^2 - (g/a) - (bA_0 / 2a^2)]$

Determine V_0

$V_0 = (2gh)^{1/2}$

Where:
V_0 = velocity of the missile at contact with the water surface, ft/s
g = gravitational acceleration = 32.17 ft/s^2
h = distance between the missile and the water surface, ft

$V_0 = (2 * 32.17 \text{ ft/s}^2 * 7.3 \text{ ft})^{½} = 21.672$ ft/s

Determine R

Note that d in the Reynolds number represents the width of the gate.

$R = (V_0 * d) / \nu = (21.672 \text{ ft/s} * 4.771 \text{ ft}) / 0.439\text{E-5 ft}^2\text{/s} = 2.355\text{E}7$

Determine C_D

In determining C_D for rectangular bodies L = length of the body, d = width

Gate length (height) = 24.39'   Gate width = 4.771'

L/d = 24.39' /4.771' = 5.112

Using Ref. II.4, pg. 5-4 Table 5-1 $C_D = 1.20$

Determine A_0

A_0 = horizontal cross-sectional area of the missile (constant over length L), ft^2
(Ref. II.4, pg. 5-3)

A_0 = gate width * gate thickness = 4.771* 0.3958 = 1.888 ft^2

Determine Coefficient a

$a = (\gamma * A_0 * C_D) / (2 * W) = (60.994 \text{ lb/ft}^3 * 1.888 \text{ ft}^2 * 1.20) / (2*2000 \text{ lb}) = 0.0345$

Determine Coefficient b

$b = (\gamma * g) / W = (60.994\ lb/ft^3 * 32.17\ ft/s^2) / 2000\ lb = 0.981$

Determine $Z_1(x)$

Note that x=H such that the result of $Z_2(x)$ can be directly used to determine strike velocity.

$Z_1(x) = (g/a) + (bA_0)[(1-2ax)/2a^2)] + e^{-2ax}[(V_0^2 - (g/a) - (bA_0 / 2a^2)]$

For simplicity the various intermediate relations in the formula are determined individually. Only results values are listed without units.

$e^{-2ax} = e^{(-2 * 0.0345 * 14.7)} = 0.3627$

$bA_0 = (0.981 * 1.888) = 1.852$

$2ax = 2 * 0.0345 * 14.700 = 1.014$

$V_0^2 = (21.672\ ft/s)^2 = 469.676$

$g/a = 32.17 / 0.0345 = 932.464$

$(bA_0)[(1-2ax)/2a^2)] = (1.852)[(1-1.014)/2*(0.0345)^2] = -10.892$

$e^{-2ax}[(V_0^2 - (g/a) - (bA_0 / 2a^2)] = (0.3627)[(469.676)-(932.464)-(1.852/2*0.0345^2)] = -450.029$

$Z_1(x) = (g/a) + (bA_0)[(1-2ax)/2a] + e^{-2ax}[(V_0^2 - (g/a) - (bA_0 / 2a^2)]$

$Z_1(x) = 932.464 + (-10.892) + (-450.029) = 471.543$

Determine V_s

$V_s = [Z(H)]^{1/2}$ (Ref. II.4, pg. 5-2)

Where:

V_s = velocity of the missile striking the steel surface, ft/s
Z(H) = function for determination of striking velocity
H = feet of fluid between fluid surface and surface of steel target

$V_s = [471.543]^{1/2} = 21.712$ ft/s

Convert the impact area to equivalent diameter D

The impact area is equal to A_0 calculated previously.

$A_0 = 1.888\ ft^2$

$1.888\ ft^2 * 144\ in^2/ft^2 = 271.872\ in^2$

$271.872\ in^2 = \pi\ r^2$ $\quad\quad r = 9.302$ in

D = 2*r = 2 * 9.302 in = 18.605 in

Determine M

M = W / g

$M = 2000\ lb / 32.17\ ft/s^2 = 62.170\ lb\text{-}s^2/ft$

Determine Steel Penetration Thickness

$T^{3/2} = 0.5\ M\ V_s^2 / (17{,}400\ K^2\ D^{3/2})$ (Ref. II.4, pg. C-8)

Where:

T = steel thickness to just be perforated, in
M = mass of the missile, $lb\text{-}s^2/ft$
V_s = striking velocity of the missile normal to target surface, ft/s
K = constant depending on the grade of the steel, K is usually = 1
D = diameter or equivalent diameter of the missile, in

$T^{3/2} = 0.5 * 62.170 * (21.712)^2 / (17{,}400 *(1)^2 (18.605^{3/2}) = 0.010494$

T = 0.048 in

The analysis methodology to calculate $Z_1(x)$ and T has been input into an Excel spread sheet. The results of the spread sheet for the previously calculated case is shown on the following page. Note that there are differences in some values due to variations the significant figures stored in Excel verses those displayed in the manual calculation. Due to the Excel limitations with respect to formatting, some of the variables are indicated by description rather than symbol. The spread sheet method will be used in all of the subsequent cases.

Gate Drop from Max Lift Height to Cask Shelf	Value	Units
Gate Length L	24.390	ft
Gate Width, d	4.771	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.424	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/s
water density/gate density	1.405	
drop distance in air	7.300	ft
drop distance in water	14.700	ft
Vo where h is drop distance in air, V = (2gh)^2	21.672	ft/s
Reynolds no =(Vo * d)/viscosity	2.355E+07	
Check L/d using gate length and width	5.112	
Check L/D using gate width and thickness	12.054	
Drag Coefficient CD	1.200	
Ao = width * thickness	1.888	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.362	
bAo	1.853	
2ax	1.016	
Vo^2	469.682	
g/a	931.017	
bAo*[(1-2ax)]/2a^2	-12.318	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-447.965	
Z1x	470.734	
Vs = (Zx)^0.5	21.696	ft/s
Convert impact area to equivalent diameter	18.606	in
mass = weight/g	62.170	lb-s2/ft
thickness	**0.048**	in

For Gate Drop to Gate Opening

Gate Drop from Max Lift Height to Gate Opening	Value	Units
Gate Length L	24.390	ft
Gate Width, d	4.771	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.424	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/s
water density/gate density	1.405	
drop distance in air	7.300	ft
drop distance in water	19.700	ft
Vo where h is drop distance in air, V = (2gh)^2	21.672	ft/s
Reynolds no =(Vo * d)/viscosity	2.355E+07	
Check L/d using gate length and width	5.112	
Check L/D using gate width and thickness	12.054	
Drag Coefficient CD	1.200	
Ao = width * thickness	1.888	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.256	
bAo	1.853	
2ax	1.361	
Vo^2	469.682	
g/a	931.017	
bAo*[(1-2ax)]/2a^2	-280.401	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-317.088	
Z1x	333.528	
Vs = (Zx)^0.5	18.263	ft/s
Convert impact area to equivalent diameter	18.606	in
mass = weight/g	62.170	lb-s2/ft
thickness	**0.038**	in

Intermediate Beam Cases

The inputs for the maximum lift intermediate beam load drop cases are as follows:

L = Length of Intermediate Lifting Beam = 4.75 ft (Ref. II.2, pg. 6)

d = Width of Intermediate Lifting Beam = 0.4167 ft (Ref. II.2, pg. 6)

t = Thickness of Intermediate Lifting Beam = 0.4167 ft (Ref. II.2, pg. 6)

W = Weight of Beam and Rigging = 175 lbs (Section 10.1.3)

Case Description	Air Drop Distance, h ft	Water Drop Distance, H ft	L ft	Strike Velocity Function
Intermediate Beam Drop to Cask Pool Floor	32.3'	37.7'	4.75'	$Z_2(x)$
Intermediate Beam Drop to Cask Pool Shelf	32.3'	14.7'	4.75'	$Z_2(x)$
Intermediate Beam Drop to Gate Opening	32.3'	19.7'	4.75'	$Z_2(x)$

γ_m = weight density of missile, lb/ft^3 = weight, lb / (L, ft * d, ft * t, ft)

γ_m = weight density of beam, lb/ft^3 = 175 lb / (4.75 ft * 0.4167 ft * 0.4167 ft) = 212.177 lb/ft^3

For Intermediate Beam Drop to Cask Pool Floor

Intermediate Beam Drop from Max Lift Height to Pool Floor 70'		
Beam Length L	4.750	ft
Beam Width, d	0.417	ft
Beam thickness	0.417	ft
Beam weight, W	175.000	lb
Beam density	212.177	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.287	
drop distance in air	32.300	ft
drop distance in water	37.700	ft
Vo where h is drop distance in air, V = (2gh)^2	45.587	ft/s
Reynolds no =(Vo * d)/viscosity	4.327E+06	
Check L/d using beam length and width	11.399	
Check L/D using beam width and thickness	1.000	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.174	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	11.212	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	25.554	ft/s
exp(-2*a*x) where x = drop distance in water	0.071	
bAo	1.947	
exp(2aL)	1.396	
2aL	0.333	
V2^2	653.027	
Vo^2	2078.182	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-55.030	
g*(exp(2aL) * wtr dens/beam dens -1)/a	-548.751	
Z2x	757.546	
Vs = (Zx)^0.5	27.524	ft/s
Convert impact area to equivalent diameter	5.642	in
mass = weight/g	5.440	lb-s2/ft
thickness	**0.043**	in

For Intermediate Beam Drop to Cask Pool Shelf

Intermediate Beam Drop from Max Lift Height to Cask Shelf 93' El		
Beam Length L	4.750	ft
Beam Width, d	0.417	ft
Beam thickness	0.417	ft
Beam weight, W	175.000	lb
Beam density	212.177	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/s
water density/gate density	0.287	
drop distance in air	32.300	ft
drop distance in water	14.700	ft
Vo where h is drop distance in air, V = (2gh)^2	45.587	ft/s
Reynolds no =(Vo * d)/viscosity	4.327E+06	
Check L/d using beam length and width	11.399	
Check L/D using beam width and thickness	1.000	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.174	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	11.212	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	25.554	ft/s
exp(-2*a*x) where x = drop distance in water	0.356	
bAo	1.947	
exp(2aL)	1.396	
2aL	0.333	
V2^2	653.027	
Vo^2	2078.182	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-55.030	
g*(exp(2aL) * wtr dens/beam dens -1)/a	-548.751	
Z2x	1178.357	
Vs = (Zx)^0.5	34.327	ft/s
Convert impact area to equivalent diameter	5.642	in
mass = weight/g	5.440	lb-s2/ft
thickness	**0.057**	in

For Intermediate Beam Drop to Gate Opening

Intermediate Beam Drop from Max Lift Height to Gate Opening 88'		
Beam Length L	4.750	ft
Beam Width, d	0.417	ft
Beam thickness	0.417	ft
Beam weight, W	175.000	lb
Beam density	212.177	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/s
water density/gate density	0.287	
drop distance in air	32.300	ft
drop distance in water	19.700	ft
Vo where h is drop distance in air, V = (2gh)^2	45.587	ft/s
Reynolds no =(Vo * d)/viscosity	4.327E+06	
Check L/d using beam length and width	11.399	
Check L/D using beam width and thickness	1.000	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.174	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	11.212	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	25.554	ft/s
exp(-2*a*x) where x = drop distance in water	0.251	
bAo	1.947	
exp(2aL)	1.396	
2aL	0.333	
V2^2	653.027	
Vo^2	2078.182	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-55.030	
g*(exp(2aL) * wtr dens/beam dens -1)/a	-548.751	
Z2x	1022.846	
Vs = (Zx)^0.5	31.982	ft/s
Convert impact area to equivalent diameter	5.642	in
mass = weight/g	5.440	lb-s2/ft
thickness	**0.052**	in

The inputs for the maximum lift alternate beam load drop cases are as follows:

L = Length of Alternate Lifting Beam = 12' (Assumption 8.13)

d = Width of Alternate Lifting Beam = 0.5 ft (Ref. III.7, pg. 1-26)

t = Thickness of Alternate Lifting Beam = 0.333 ft (Ref. III.7, pg. 1-26)

W = Weight of Beam and Rigging = 200 lbs (Section 10.1.2)

Case Description	Air Drop Distance, h ft	Water Drop Distance, H ft	L ft	Strike Velocity Function
Alternate Beam Drop to Cask Pool Floor	40.3'	37.7'	12'	$Z_2(x)$
Alternate Beam Drop to Cask Pool Shelf	40.3'	14.7'	12'	$Z_2(x)$
Alternate Beam Drop to Gate Opening	40.3'	19.7'	12'	$Z_2(x)$

γ_m = weight density of missile, lb/ft^3 = weight, lb / (L, ft * d, ft * t, ft)

γ_m = weight density of beam, lb/ft^3 = 200 lb / (12 ft * 0.333 ft * 0.5 ft) = 100.100 lb/ft^3

For Alternate Beam Drop to Cask Pool Floor

Alternate Beam Drop from Max Lift Height to Pool Floor 70'

Beam Length L	12.000	ft
Beam Width, d	0.500	ft
Beam thickness	0.333	ft
Beam weight, W	200.000	lb
Beam density	100.100	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.609	
drop distance in air	40.300	ft
drop distance in water	37.700	ft
Vo where h is drop distance in air, V = (2gh)^2	50.921	ft/s
Reynolds no =(Vo * d)/viscosity	5.800E+06	
Check L/d using beam length and width	24.000	
Check L/D using beam width and thickness	1.502	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.167	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	9.811	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	20.658	ft/s
exp(-2*a*x) where x = drop distance in water	0.109	
bAo	1.634	
exp(2aL)	2.028	
2aL	0.707	
V2^2	426.738	
Vo^2	2592.902	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-381.910	
g*(exp(2aL) * wtr dens/beam dens -1)/a	257.178	
Z2x	694.643	
Vs = (Zx)^0.5	26.356	ft/s
Convert impact area to equivalent diameter	5.525	in
mass = weight/g	6.217	lb-s2/ft
thickness	**0.045**	in

For Alternate Beam Drop to Cask Pool Shelf

Alternate Beam Drop from Max Lift Height to Cask Shelf 93' El

Beam Length L	12.000	ft
Beam Width, d	0.500	ft
Beam thickness	0.333	ft
Beam weight, W	200.000	lb
Beam density	100.100	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.609	
drop distance in air	40.300	ft
drop distance in water	14.700	ft
Vo where h is drop distance in air, V = (2gh)^2	50.921	ft/s
Reynolds no =(Vo * d)/viscosity	5.800E+06	
Check L/d using beam length and width	24.000	
Check L/D using beam width and thickness	1.502	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.167	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	9.811	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	20.658	ft/s
exp(-2*a*x) where x = drop distance in water	0.421	
bAo	1.634	
exp(2aL)	2.028	
2aL	0.707	
V2^2	426.738	
Vo^2	2592.902	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-381.910	
g*(exp(2aL) * wtr dens/beam dens -1)/a	257.178	
Z2x	1465.074	
Vs = (Zx)^0.5	38.276	ft/s
Convert impact area to equivalent diameter	5.525	in
mass = weight/g	6.217	lb-s2/ft
thickness	**0.074**	in

For Alternate Beam Drop to Gate Opening

Alternate Beam Drop from Max Lift Height to to Gate Opening 88'

Beam Length L	12.000	ft
Beam Width, d	0.500	ft
Beam thickness	0.333	ft
Beam weight, W	200.000	lb
Beam density	100.100	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.609	
drop distance in air	40.300	ft
drop distance in water	19.700	ft
Vo where h is drop distance in air, V = (2gh)^2	50.921	ft/s
Reynolds no =(Vo * d)/viscosity	5.800E+06	
Check L/d using beam length and width	24.000	
Check L/D using beam width and thickness	1.502	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.167	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	9.811	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	20.658	ft/s
exp(-2*a*x) where x = drop distance in water	0.313	
bAo	1.634	
exp(2aL)	2.028	
2aL	0.707	
V2^2	426.738	
Vo^2	2592.902	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-381.910	
g*(exp(2aL) * wtr dens/beam dens -1)/a	257.178	
Z2x	1200.191	
Vs = (Zx)^0.5	34.644	ft/s
Convert impact area to equivalent diameter	5.525	in
mass = weight/g	6.217	lb-s2/ft
thickness	**0.065**	in

10.2.2 Load Drop with Gate in Pool

This scenario is during the movement of the gate from its installed location in the spent fuel pool to the gate opening between the spent fuel pool and cask pool, through the gate opening, then into the cask pool. Objects analyzed for this drop are the gate, intermediate lifting beam and alternate lifting beam. Potential points of impact for this drop are:

1) Spent fuel pool or cask pool floor at 70' elevation;
2) Gate opening floor at 88' elevation.

Object Lift Elevation

For the initial movement the objects being evaluated had the following elevations:

Elevation of bottom of Gate = 90'	(Ref. II.2, pg. 8)
Elevation of bottom of Intermediate Lifting Beam = 115'	(Ref. II.2, pg. 8)
Elevation of bottom of Alternate Lifting Beam = 123'	(Ref. II.2, pg. 12)

Pool Min Level Elevation = 84.6645' + 23' = 107.6645' **use 107.7'**

Determine Object Air Drop Distance

Air Drop Distance = Lift Elevation – Pool Min Level Elevation

Gate Air Drop Distance = Lift Elevation – Pool Min Level Elevation

Gate Air Drop Distance = 90' – 107.7' = -17.7'

As the gate is mostly submerged, the air drop distance for the gate is 0'. Correspondingly, the value for V_0 and R will also be zero. As the Reynolds number is less than 1E3, the drag coefficient, C_D will be assumed to be 1.00.

Intermediate Beam Air Drop Distance = Lift Elevation – Pool Min Level Elevation

Intermediate Beam Air Drop Distance = 115' – 107.7' = 7.3'

Alternate Beam Air Drop Distance = Lift Elevation – Pool Min Level Elevation

Alternate Beam Air Drop Distance = 123' – 107.7' = 15.3'

Determine Water Drop Distance

Because the gate is partially submerged, the water drop distance formula is as follows:

Gate Water Drop Distance = Elevation of Gate Bottom – Elevation of Impact Point

For the Pool Floors

Gate Water Drop Distance = 90' – 70' = 20'

For the Gate Opening

Gate Water Drop Distance = 90' – 88' = 2'

As the beams have an initial elevation above the pool level, the beam water drop distance utilizes the same relationship as that utilized in Section 10.2.1.

Water Drop Distance = Pool Min Level Elevation – Elevation of Impact Point

Pool Floor Water Drop Distance = 107.7 – 70' = 37.7'

Gate Opening Water Drop Distance = 107.7' – 88' = 19.7'

The following table provides a summary of the air drop distance, water drop distance H, the length of the dropped object, and the selected strike velocity function based upon the criteria above for each Load Drop case.

Case Description	Air Drop Distance, h ft	Water Drop Distance, H ft	L ft	Strike Velocity Function
Gate Drop to Pool Floor	0'	20'	24.39'	$Z_1(x)$
Gate Drop to Gate Opening	0'	2'	24.39'	$Z_1(x)$
Intermediate Beam Drop to Pool Floor	7.3'	37.7'	4.75'	$Z_2(x)$
Intermediate Beam Drop to Gate Opening	7.3'	19.7'	4.75'	$Z_2(x)$
Alternate Beam Drop to Pool Floor	15.3'	37.7'	12'	$Z_2(x)$
Alternate Beam Drop to Gate Opening	15.3'	19.7'	12'	$Z_2(x)$

The inputs for the load drop cases are as follows:

All cases:

g = Acceleration of Gravity = 32.174 ft/sec^2 (Ref. III.9, pg. B-10)

γ = Density of water @ 160 deg. F = 60.994 lb/ft^3 (Ref. III.9, pg. A-6)

ν = Kinematic viscosity of water @ 160 deg. F = 0.439 E-5 ft^2/s (Ref. III.11)

K = constant related to grade of steel = 1

The inputs for the gate load drop cases are as follows:

L = Length of Spent Fuel Pool Gate = 24.39 ft (Ref. II.1, pg. A11)

d = Width of Spent Fuel Pool Gate = 4.771 ft (Ref. II.1, pg. A11)

t = Thickness of Spent Fuel Pool Gate = 0.3958 ft (Ref. II.1, pg. 17)

W = Weight of Spent Fuel Pool Gate and Rigging = 2000 lbs (Ref. III.1, pg. 4);

γ_m = weight density of gate, lb/ft^3 = 2000 lb / (24.39 ft * 4.771 ft * 0.3958 ft) = 43.424 lb/ft^3

The inputs for the intermediate beam load drop cases are as follows:

L = Length of Intermediate Lifting Beam = 4.75 ft (Ref. II.2, pg. 6)

d = Width of Intermediate Lifting Beam = 0.4167 ft (Ref. II.2, pg. 6)

t = Thickness of Intermediate Lifting Beam = 0.4167 ft (Ref. II.2, pg. 6)

W = Weight of Beam and Rigging = 175 lbs (Section 10.1.3)

γ_m = weight density of beam, lb/ft^3 = 175 lb / (4.75 ft * 0.4167 ft * 0.4167 ft) = 212.177 lb/ft^3

The inputs for the alternate beam load drop cases are as follows:

L = Length of Alternate Lifting Beam = 12' (Assumption 8.13)

d = Width of Alternate Lifting Beam = 0.5 ft (Ref. III.7, pg. 1-26)

t = Thickness of Alternate Lifting Beam = 0.333 ft (Ref. III.7, pg. 1-26)

W = Weight of Beam and Rigging = 200 lbs (Section 10.1.2)

γ_m = weight density of beam, lb/ft^3 = 200 lb / (12 ft * 0.333 ft * 0.5 ft) = 100.100 lb/ft^3

The inputs were entered into the Excel spread sheet with the results for each case shown in the following tables.

Gate Drop to Pool Floor		
Gate Length L	24.390	ft
Gate Width, d	4.771	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.424	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	1.405	
drop distance in air	0.000	ft
drop distance in water	20.000	ft
Vo where h is drop distance in air, V = (2gh)^2	0.000	ft/s
Reynolds no =(Vo * d)/viscosity	0.000E+00	
Check L/d using gate length and width	5.112	
Check L/D using gate width and thickness	12.054	
Drag Coefficient CD	1.000	
Ao = width * thickness	1.888	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.316	
bAo	1.853	
2ax	1.152	
Vo^2	0.000	
g/a	1117.220	
bAo*[(1-2ax)]/2a^2	-169.580	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-706.242	
Z1x	241.398	
Vs = (Zx)^0.5	15.537	ft/s
Convert impact area to equivalent diameter	18.606	in
mass = weight/g	62.170	lb-s2/ft
thickness	0.031	in

Gate Drop in Gate Opening		
Gate Length L	24.390	ft
Gate Width, d	4.771	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.424	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	1.405	
drop distance in air	0.000	ft
drop distance in water	2.000	ft
Vo where h is drop distance in air, V = (2gh)^2	0.000	ft/s
Reynolds no =(Vo * d)/viscosity	0.000	
Check L/d using gate length and width	5.112	
Check L/D using gate width and thickness	12.054	
Drag Coefficient CD	1.000	
Ao = width * thickness	1.888	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.891	
bAo	1.853	
2ax	0.115	
Vo^2	0.000	
g/a	1117.220	
bAo*[(1-2ax)]/2a^2	988.540	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-1991.348	
Z1x	114.412	
Vs = (Zx)^0.5	10.696	ft/s
Convert impact area to equivalent diameter	18.606	in
mass = weight/g	62.170	lb-s2/ft
thickness	0.019	in

Intermediate Beam Drop to Pool Floor

Beam Length L	4.750	ft
Beam Width, d	0.417	ft
Beam thickness	0.417	ft
Beam weight, W	175.000	lb
Beam density	212.177	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.287	
drop distance in air	7.300	ft
drop distance in water	37.700	ft
Vo where h is drop distance in air, V = (2gh)^2	21.672	ft/s
Reynolds no =(Vo * d)/viscosity	2.057E+06	
Check L/d using beam length and width	11.399	
Check L/D using beam width and thickness	1.000	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.174	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	11.212	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	25.554	
exp(-2*a*x) where x = drop distance in water	0.071	
bAo	1.947	
exp(2aL)	1.396	
2aL	0.333	
V2^2	653.027	
Vo^2	469.682	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-55.030	
g*(exp(2aL) * wtr dens/beam dens -1)/a	-548.751	
Z2x	643.521	
Vs = (Zx)^0.5	25.368	ft/s
Convert impact area to equivalent diameter	5.642	in
mass = weight/g	5.440	lb-s2/ft
thickness	**0.038**	in

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Intermediate Beam Drop to Gate Opening

Beam Length L	4.750	ft
Beam Width, d	0.417	ft
Beam thickness	0.417	ft
Beam weight, W	175.000	lb
Beam density	212.177	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.287	
drop distance in air	7.300	ft
drop distance in water	19.700	ft
Vo where h is drop distance in air, V = (2gh)^2	21.672	ft/s
Reynolds no =(Vo * d)/viscosity	2.057E+06	
Check L/d using beam length and width	11.399	
Check L/D using beam width and thickness	1.000	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.174	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	11.212	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	25.554	ft/s
exp(-2*a*x) where x = drop distance in water	0.251	
bAo	1.947	
exp(2aL)	1.396	
2aL	0.333	
V2^2	653.027	
Vo^2	469.682	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-55.030	
g*(exp(2aL) * wtr dens/beam dens -1)/a	-548.751	
Z2x	619.392	
Vs = (Zx)^0.5	24.888	ft/s
Convert impact area to equivalent diameter	5.642	in
mass = weight/g	5.440	lb-s2/ft
thickness	**0.037**	in

Alternate Beam Drop to Pool Floor

Beam Length L	12.000	ft
Beam Width, d	0.500	ft
Beam thickness	0.333	ft
Beam weight, W	200.000	lb
Beam density	100.100	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.609	
drop distance in air	15.300	ft
drop distance in water	37.700	ft
Vo where h is drop distance in air, V = (2gh)^2	31.375	ft/s
Reynolds no =(Vo * d)/viscosity	3.573E+06	
Check L/d using beam length and width	24.000	
Check L/D using beam width and thickness	1.502	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.167	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	9.811	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	20.658	ft/s
exp(-2*a*x) where x = drop distance in water	0.109	
bAo	1.634	
exp(2aL)	2.028	
2aL	0.707	
V2^2	426.738	
Vo^2	984.402	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-381.910	
g*(exp(2aL) * wtr dens/beam dens -1)/a	257.178	
Z2x	520.050	
Vs = (Zx)^0.5	22.805	ft/s
Convert impact area to equivalent diameter	5.525	in
mass = weight/g	6.217	lb-s2/ft
thickness	**0.037**	in

Alternate Beam Drop to Gate Opening

Beam Length L	12.000	ft
Beam Width, d	0.500	ft
Beam thickness	0.333	ft
Beam weight, W	200.000	lb
Beam density	100.100	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	0.609	
drop distance in air	15.300	ft
drop distance in water	19.700	ft
Vo where h is drop distance in air, V = (2gh)^2	31.375	ft/s
Reynolds no =(Vo * d)/viscosity	3.573E+06	
Check L/d using beam length and width	24.000	
Check L/D using beam width and thickness	1.502	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.167	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	9.811	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	20.658	ft/s
exp(-2*a*x) where x = drop distance in water	0.313	
bAo	1.634	
exp(2aL)	2.028	
2aL	0.707	
V2^2	426.738	
Vo^2	984.402	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-381.910	
g*(exp(2aL) * wtr dens/beam dens -1)/a	257.178	
Z2x	696.134	
Vs = (Zx)^0.5	26.384	ft/s
Convert impact area to equivalent diameter	5.525	in
mass = weight/g	6.217	lb-s2/ft
thickness	**0.045**	in

Using the calculated steel thickness to just experience perforation calculated in Sections 10.2.1 and 10.2.2, determine the minimum required liner thickness to prevent perforation based upon the following equation:

Thickness required to prevent steel perforation = T * 1.25 (Ref. II.4 pg. 2)

Where:

T = steel thickness to just be perforated, in

For the Max Gate Drop to Cask Pool Floor case T = 0.042 in

Thickness required to prevent steel perforation = T * 1.25

Thickness required to prevent steel perforation = 0.042 in * 1.25 = 0.053 in

This formula was placed in an Excel spread sheet to determine the thickness required to prevent steel perforation for the balance of the liner impact drop cases. The results are shown in the table below.

Case Description	Calculated Perforation Thickness, T, in	Thickness Required to Prevent Perforation, in	Actual Liner Thickness, in
Max Gate Drop to Cask Pool Floor	0.042	0.053	0.188
Max Gate Drop to Cask Pool Shelf	0.048	0.060	0.188
Max Gate Drop to Gate Opening	0.038	0.048	0.188
Max Intermediate Beam Drop to Cask Pool Floor	0.043	0.054	0.188
Max Intermediate Beam Drop to Cask Pool Shelf	0.057	0.071	0.188
Max Intermediate Beam Drop to Gate Opening	0.052	0.065	0.188
Max Alternate Beam Drop to Cask Pool Floor	0.045	0.056	0.188
Max Alternate Beam Drop to Cask Pool Shelf	0.074	0.093	0.188
Max Alternate Beam Drop to Gate Opening	0.065	0.081	0.188
Gate in Water Gate Drop to Pool Floor	0.031	0.039	0.188
Gate in Water Gate Drop to Gate Opening	0.019	0.024	0.188
Gate in Water Intermediate Beam Drop to Pool Floor	0.038	0.048	0.188
Gate in Water Intermediate Beam Drop to Gate Opening	0.037	0.046	0.188
Gate In Water Alternate Beam Drop to Pool Floor	0.037	0.046	0.188
Gate in Water Alternate Beam Drop to Gate Opening	0.045	0.056	0.188

In all analyzed cases, the actual pool liner thickness exceeds the thickness required to prevent steel perforation resulting from impact of the dropped load. As the steel liner will not be perforated as a result of the analyzed load drops, no liner leakage will occur as a result of the impact. Given that no leakage will occur due to impact of the dropped load, no water makeup to accommodate leakage is required.

10.2.3 Load Drop Spent Fuel Storage Rack Strike Velocity

This section is to determine the strike velocity of the objects during the movement of the gate from its installed location in the spent fuel pool to the gate opening when the potential exists for these objects to impact the fuel storage racks. Objects analyzed for this drop are the gate, intermediate lifting beam and alternate lifting beam. The point of impact for this scenario is the top of the racks.

Elevation of Top of Fuel Racks = 177" + 70'1-5/16" = 84.86' (Ref. II.8)

Object Lift Elevation

For the initial movement the objects being evaluated had the following elevations:

Elevation of bottom of Gate = 90' (Ref. II.2, pg. 8)

Elevation of bottom of Intermediate Lifting Beam = 115' (Ref. II.2, pg. 8)

Elevation of bottom of Alternate Lifting Beam = 123' (Ref. II.2, pg. 12)

Pool Min Level Elevation = 84.6645' + 23' = 107.6645' **use 107.7'**

Determine Object Air Drop Distance

As the initial drop elevations are identical to that in Section 10.2.2, the air drop distance is unchanged from that determined in Section 10.2.2.

Determine Water Drop Distance to Top of Racks

Because the gate is partially submerged, the water drop distance formula is as follows:

Gate Water Drop Distance = Elevation of Gate Bottom – Elevation of Impact Point

Gate Water Drop Distance = 90' – 84.86' = 5.14'

As the beams have an initial elevation above the pool level, the beam water drop distance utilizes the same relationship as that utilized in Section 10.2.1.

Water Drop Distance = Pool Min Level Elevation – Elevation of Impact Point

Rack Water Drop Distance = 107.7 – 84.86" = 22.84'

The following table provides a summary of the air drop distance, water drop distance H, the length of the dropped object, and the selected strike velocity function based upon the criteria above for each Load Drop case.

Case Description	Air Drop Distance, h ft	Water Drop Distance, H ft	L ft	Strike Velocity Function
Gate Drop to Racks	0'	5.14'	24.39'	$Z_1(x)$
Intermediate Beam Drop to Racks	7.3'	22.84'	4.75'	$Z_2(x)$
Alternate Beam Drop to Racks	15.3'	22.84'	12'	$Z_2(x)$

The other inputs for the load drop cases are the same as Section 10.2.2.

The inputs were entered into the Excel spread sheet with the results for each case shown in the following tables.

Gate Drop to Racks

Gate Length L	24.390	ft
Gate Width, d	4.771	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.424	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	1.405	
drop distance in air	0.000	ft
drop distance in water	5.140	ft
Vo where h is drop distance in air, V = (2gh)^2	0.000	ft/s
Reynolds no =(Vo * d)/viscosity	0.000	
Check L/d using gate length and width	5.112	
Check L/D using gate width and thickness	12.054	
Drag Coefficient CD	1.000	
Ao = width * thickness	1.888	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.744	
bAo	1.853	
2ax	0.296	
Vo^2	0.000	
g/a	1117.220	
bAo*[(1-2ax)]/2a^2	786.512	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-1661.933	
Z1x	241.800	
Vs = (Zx)^0.5	**15.550**	ft/s

Intermediate Beam Drop to Racks

Beam Length L	4.750	ft
Beam Width, d	0.417	ft
Beam thickness	0.417	ft
Beam weight, W	175.000	lb
Beam density	212.177	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/beam density	0.287	
drop distance in air	7.300	ft
drop distance in water	22.841	ft
Vo where h is drop distance in air, V = (2gh)^2	21.672	ft/s
Reynolds no =(Vo * d)/viscosity	2.057E+06	
Check L/d using beam length and width	11.399	
Check L/D using beam width and thickness	1.000	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.174	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.035	
b = (water density * g)/W	11.212	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	25.554	ft/s
exp(-2*a*x) where x = drop distance in water	0.201	
bAo	1.947	
exp(2aL)	1.396	
2aL	0.333	
V2^2	653.027	
Vo^2	469.682	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-55.030	
g*(exp(2aL) * wtr dens/beam dens -1)/a	-548.751	
Z2x	626.048	
Vs = (Zx)^0.5	**25.021**	ft/s

Alternate Beam Drop to Racks

Beam Length L	12.000	ft
Beam Width, d	0.500	ft
Beam thickness	0.333	ft
Beam weight, W	200.000	lb
Beam density	100.100	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/beam density	0.609	
drop distance in air	15.300	ft
drop distance in water	22.840	ft
Vo where h is drop distance in air, V = (2gh)^2	31.375	ft/s
Reynolds no =(Vo * d)/viscosity	3.573E+06	
Check L/d using beam length and width	24.000	
Check L/D using beam width and thickness	1.502	
Drag Coefficient CD	1.160	
Ao = width * thickness	0.167	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.029	
b = (water density * g)/W	9.811	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	20.658	ft/s
exp(-2*a*x) where x = drop distance in water	0.260	
bAo	1.634	
exp(2aL)	2.028	
2aL	0.707	
V2^2	426.738	
Vo^2	984.402	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	-381.910	
g*(exp(2aL) * wtr dens/beam dens -1)/a	257.178	
Z2x	650.645	
Vs = (Zx)^0.5	**25.508**	ft/s

Results summary

The strike velocity of each object on the spent fuel pool storage racks is as follows:

Gate	15.550 ft/s
Intermediate Beam	25.021 ft/s
Alternate Beam	25.508 ft/s

10.3 Damage to Fuel Rack Assembly

Damage to the Spent Fuel Pool Rack will be analyzed within two impact cases. Case 1 will analyze the damage to the fuel rack by objects (gate, intermediate lifting beam, alternate lifting beam) that impact the centerline of empty fuel cells. This bounding case would analyze the minimum amount of structural material resisting the energy of each object dropped, which would maximize the length of damage.

The fuel racks are rated for an impact energy of 3800 ft-lb. Case 2 will analyze the impact velocities of the dropped objects to determine if these impact energies are bounded. Each impact case will evaluate all previously analyzed objects (gate, intermediate lifting beam, alternate lifting beam).

Case 1

The poison material within the fuel pool racks is 16.22 inches below the top of the rack. It is necessary to demonstrate that the accidental drop of an object will not violate the criticality requirements. The following equation can be used to determine the length of damage.

$$L = E_i / (U)(A_i)$$

L = Length of Damage (in)
E_i = Total Impact Energy of Falling Object (in-lb)
U = Strain Energy for Unit Volume (in-lb/in^3)
A_i = Area of Impact Contact (in^2)

In order to solve for length of damage, the area of impact contact must first be calculated. The following equation can be used to determine the area of impact contact.

$$A_i = (N)(l)(t)$$

A_i = Area of Impact Contact (in^2)
N = Number of Plates in Impact Zone
l = Contact Length per Plate (in)
t = Plate Thickness (in)

Part A (Spent Fuel Pool Gate)

The number of plates within the impact zone is determined by dividing the width of the gate by the bundle spacing.

(4.771 ft) / (0.5208 ft) = 9.16 bundles are impacted

Therefore, the gate has the potential to impact a minimum of 9 plates. Using the minimum number of plates for calculation is conservative because this minimizes the area of support that resists the energy of the drop.

$A_i = (N)(l)(t)$

$A_i = (9)(4.75 \text{ in.})(0.075 \text{ in.})$

$A_i = 3.206 \text{ in}^2$

It is conservatively assumed that the entire potential energy of the drop is transferred into the rack in one impact.

$L = E_i / (U)(A_i)$

$E_i = PE = 12000 \text{ ft-lb} = 144000 \text{ in-lb}$ (Section 10.1.1, pg. 27)

$L = (144000 \text{ in-lb}) / (19740 \text{ in-lb/in}^3)(3.206 \text{ in}^2)$

$L = 2.275 \text{ in} < 16.22 \text{ in}$ to poison material

Part B (Alternate Lifting Beam)

The number of plates within the impact zone is determined by dividing the width and depth of the beam by the bundle spacing.

(0.333 ft) / (0.5208 ft) = 0.6394 bundles are impacted

(0.5 ft) / (0.5208 ft) = 0.9601 bundles are impacted

Therefore, the beam has the potential to impact a minimum of 1 plate. Using the minimum number of plates for calculation is conservative because this minimizes the area of support that resists the energy of the drop.

Note: A W6x12 beam will be used for the Alternate Lifting Beam. 4"x6"x½" plates will be welded to each end of the beam. These plates will increase the surface area of the ends of the beam, reducing the damage to the fuel rack, if dropped. Four inches is used for the length of impact because this will be the smallest dimension of the plate that is attached to the beam.

$A_i = (N)(l)(t)$

$A_i = (1)(4 \text{ in.})(0.075 \text{ in.})$

$A_i = 0.3 \text{ in}^2$

It is conservatively assumed that the entire potential energy of the drop is transferred into the rack in one impact.

$L = E_i / (U)(A_i)$

$E_i = PE = 7800 \text{ ft-lb} = 93600 \text{ in-lb}$ (Section 10.1.2, pg. 37)

$L = (93600 \text{ in-lb}) / (19740 \text{ in-lb/in}^3)(0.3 \text{ in}^2)$

$L = 15.81 \text{ in} < 16.22$ in to poison material

Part C (Intermediate Lifting Beam)

The number of plates within the impact zone is determined by dividing the width and depth of the beam by the bundle spacing.

(0.4167 ft) / (0.5208 ft) = 0.8001 bundles are impacted

(0.4167 ft) / (0.5208 ft) = 0.8001 bundles are impacted

Therefore, the beam has the potential to impact a minimum of 1 plate. Using the minimum number of plates for calculation is conservative because this minimizes the area of support that resists the energy of the drop.

Note: A TS5x5x½ beam will be used for the Intermediate Lifting Beam. Plates will be welded to each end of the beam, per Ref II-2, pg. 6. These plates will increase the surface area of the ends of the beam, reducing the damage to the fuel rack, if dropped. Five inches is used for the length of impact because this will be the smallest dimension of the plate that is attached to the beam.

$A_i = (N)(l)(t)$

$A_i = (1)(5 \text{ in.})(0.075 \text{ in.})$

$A_i = 0.375 \text{ in}^2$

It is conservatively assumed that the entire potential energy of the drop is transferred into the rack in one impact.

$L = E_i / (U)(A_i)$

$E_i = PE = 5425 \text{ ft-lb} = 65100 \text{ in-lb}$ (Section 10.1.3, pg. 45)

$L = (65100 \text{ in-lb}) / (19740 \text{ in-lb/in}^3)(0.375 \text{ in}^2)$

$L = 8.794 \text{ in} < 16.22$ in to poison material

Case 2

The fuel racks are rated for an impact energy of 3800 ft-lb. Case 2 will analyze the impact velocities of the dropped objects to determine if these impact energies are bounded per (Ref. II-10).

The rack strike velocity for each object determined in Section 10.2.3 are as follows:

Gate	15.550 ft/s
Intermediate Beam	25.021 ft/s
Alternate Beam	25.508 ft/s

Part A (Spent Fuel Pool Gate)

$K = \frac{1}{2}(M)(V^2)$ (Ref. II-9, pg. 4)

Where:

K = Kinetic Energy
M = Mass
V = Velocity

$K = \frac{1}{2}\ (2000\ lbs)(15.550\ ft/s)^2(1\ /\ 32.174\ ft/s^2)$

Note: The $(1\ /\ 32.174\ ft/s^2)$ term in the equation above is needed to convert to the correct units.

K = 7515.463 ft-lb

Since the Spent Fuel Pool Gate has the minimum potential to impact 5 fuel bundles (conservatively assuming that the fuel rack is 50% full), we must divide this impact energy by 5.

K = (7515.463) / (5) = 1503.093 ft-lb < 3800 ft-lb Therefore, OK.

Part B (Alternate Lifting Beam)

$K = \frac{1}{2}(M)(V^2)$ (Ref. II-9, pg. 4)

Where:

K = Kinetic Energy
M = Mass
V = Velocity

$K = \frac{1}{2}\ (200\ lbs)(25.508\ ft/s)^2(1\ /\ 32.174\ ft/s^2)$

Note: The $(1\ /\ 32.174\ ft/s^2)$ term in the equation above is needed to convert to the correct units.

K = 2022.31 ft-lb < 3800 ft-lb Therefore, OK.

Part C (Intermediate Lifting Beam)

$K = ½(M)(V^2)$ (Ref. II-9, pg. 4)

Where:

K = Kinetic Energy
M = Mass
V = Velocity

$K = ½ (175 \text{ lbs})(25.021 \text{ ft/s})^2(1 / 32.174 \text{ ft/s}^2)$

Note: The $(1 / 32.174 \text{ ft/s}^2)$ term in the equation above is needed to convert to the correct units.

K = 1702.599 ft-lb < 3800 ft-lb Therefore, OK.

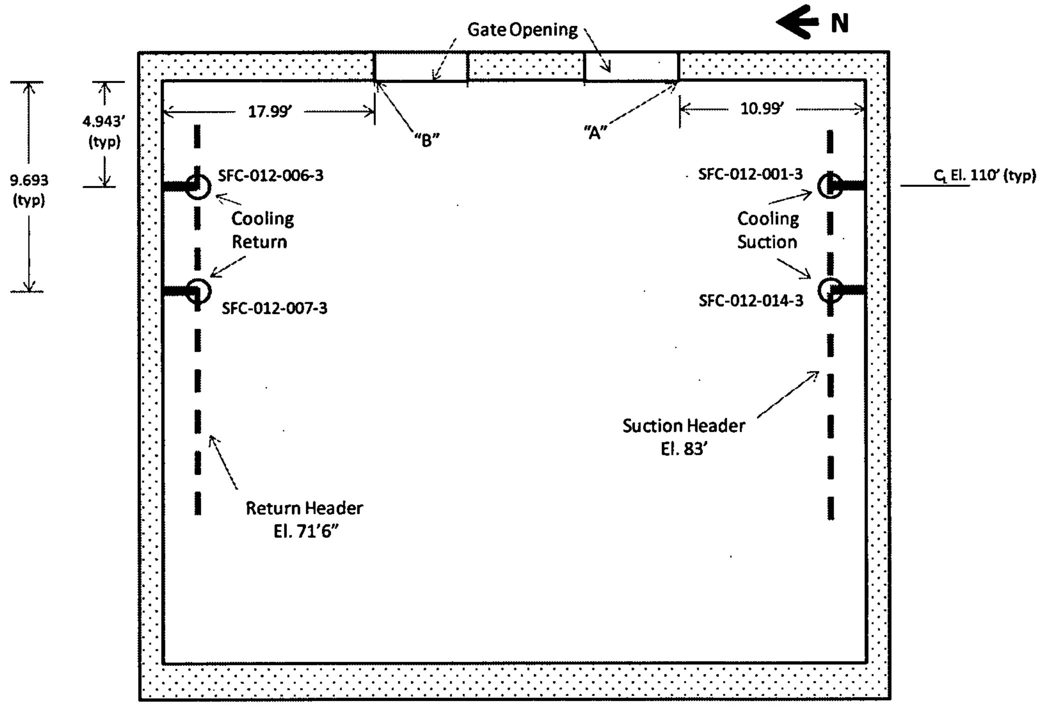
10.4 Impact of Gate Drop on Fuel Pool Cooling Piping

The only safe shutdown equipment with the potential to be affected by a Spent Fuel Pool Gate Movement load drop are the suction and return lines for the Spent Fuel Pool Cooling portion of the Fuel Pool Cooling and Cleanup System (SFC).

The Spent Fuel Cooling suction piping consists of two (2) 12" diameter lines located on the south wall of the Spent Fuel Pool. Each line penetrates horizontally into the pool at elevation 110' for approximately 16 inches then turns 90 degrees downward extending to nominal elevation 83' 6" where the lines transition into a nominal 6" diameter horizontal suction header located at elevation 83'. (Ref. II.16, 18, 19, 20, 21, 22)

The Spent Fuel Cooling discharge piping consists of two (2) 12" diameter lines located on the north wall of the Spent Fuel Pool. Each line penetrates horizontally into the pool at elevation 110' for approximately 16 inches then turns 90 degrees downward extending to nominal elevation 72'0" where the lines transition into a nominal 6" diameter horizontal distribution sparger located at elevation 71'6". (Ref. II.16, 18, 19, 20, 21, 22)

A general diagram of the piping layout is shown below. (Ref. II.11, 13, 16, 18, 19, 20, 21, 22)



Plan Elevation 113' Spent Fuel Pool Area

The pool gates have adequate length that they could potentially strike the cooling piping following an initial impact on the spent fuel storage racks, i.e. in the transition to Position 2 or 3 as described in Section 10.1.1. The piping could be struck as the top of the gate moves downward toward the storage racks. The highest potential location for the impact of each line is determined by:

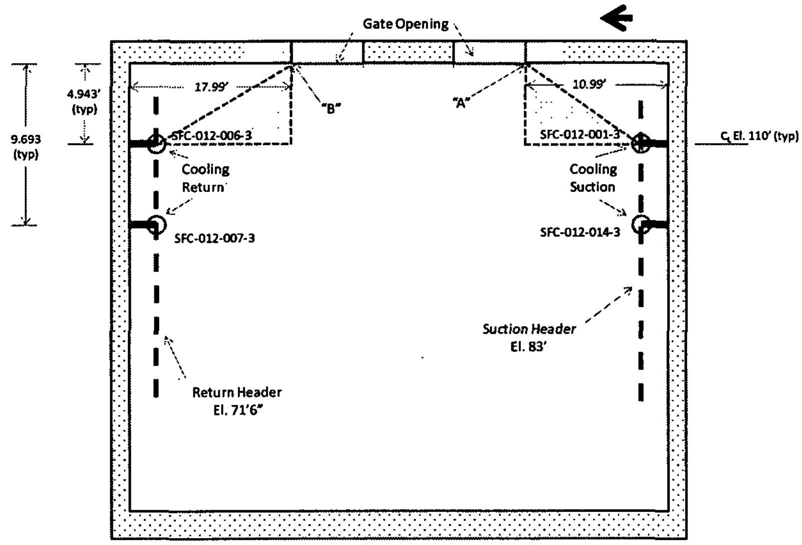
1. Calculating the horizontal distance between the following locations using the formula $a^2 + b^2 = c^2$. Refer to the previous general diagram for the locations of Points A and B.

   - Point A and line SFC-012-001-3.
   - Point A and line SFC-012-014-3.
   - Point B and line SFC-012-006-3.

2. Using the $a^2 + b^2 = c^2$ formula with the previously calculated horizontal distance and the 24.39' gate length, the vertical distance where the subject pipe will be struck by the top of the gate is determined. The vertical distance is added to the top elevation of the spent fuel storage racks of 84.86' to determine the elevation where the gate strikes the applicable line.
3. The elevation of the gate strike is compared to the minimum water level elevation. As long as any damage, such as distortion (denting), a crack or other opening, is below the elevation of the minimum water level, the cooling function can continue to be maintained as the flowpath via the line will still be intact.

Horizontal Distance

The triangles shown on the diagram below represent determination of the distance between Point A and line SFC-012-001-3 and the determination of the distance between Point B and line SFC-012-006-3. Determination of the distance for the remaining two lines is similar.



Distance Fuel Pool Cooling Piping Extends into Pool

SFC-012-001-3 = 1.302'	(Ref. II.18)
SFC-012-014-3 = 1.302'	(Ref. II.19)
SFC-012-006-3 = 1.5'	(Ref. II.20)
SFC-012-007-3 = 1.33'	(Ref. II.21)

Point A and line SFC-012-001-3. SFC-012-001-3 extends 1.302' into the pool. (Ref. II.18)

Distance from southeast pool corner to SFC-012-001-3 = 4.943'

North-South distance from Point A to line SFC-012-001-3 = 10.99' – 1.302'

Distance from Point A to SFC-012-001-3 = $[(4.943')^2 + (10.99'-1.302')^2]^{0.5}$ = **10.88'**

Point A and line SFC-012-014-3. SFC-012-014-3 extends 1.302' into the pool. (Ref. II.19)

Distance from southeast pool corner to SFC-012-014-3 = 9.693'

North-South distance from Point A to line SFC-012-001-3 = 10.99' – 1.302'

Distance from Point A to SFC-012-014-3 = $[(9.693')^2 + (10.99'-1.302')^2]^{0.5}$ = **13.70'**

Point B and line SFC-012-006-3. SFC-012-006-3 extends 1.5' into the pool. (Ref. II.20)

Distance from northeast pool corner to SFC-012-006-3 = 4.943'

North-South distance from Point B to line SFC-012-006-3 = 17.99' – 1.5'

Distance from Point B to SFC-012-006-3 = $[(4.943')^2 + (17.99'-1.5')^2]^{0.5}$ = **17.21'**

Point B and line SFC-012-007-3. SFC-012-007-3 extends 1.33' into the pool. (Ref. II.21)

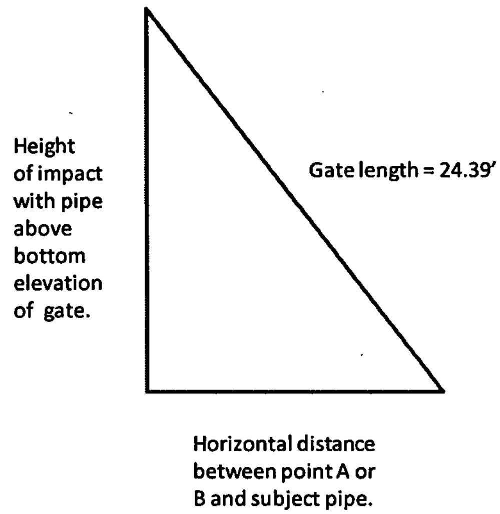
Distance from northeast pool corner to SFC-012-007-3 = 9.693'

North-South distance from Point B to line SFC-012-007-3 = 17.99' – 1.33'

Distance from Point B to SFC-012-007-3 = $[(9.693')^2 + (17.99'-1.33')^2]^{0.5}$ = **19.27'**

Vertical Distance and Gate Strike Elevation

The diagram below represents the determination of the vertical height above the gate bottom elevation where the top of the gate will impact the subject pipe.



SFC-012-001-3

Horizontal distance = 10.88'

Gate length = 24.39'

Vertical distance = $[(24.39')^2 - (10.88')^2]^{0.5} = 21.83'$

Gate strike elevation = Top of rack elevation + vertical distance

Gate strike elevation = 84.86 + 21.83 = 106.69' elevation

SFC-012-014-3

Horizontal distance = 13.70'

Gate length = 24.39'

Vertical distance = $[(24.39')^2 - (13.70')^2]^{0.5} = 20.18'$

Gate strike elevation = Top of rack elevation + vertical distance

Gate strike elevation = 84.86 + 20.18 = 105.04' elevation

SFC-012-006-3

Horizontal distance = 17.21'

Gate length = 24.39'

Vertical distance = $[(24.39')^2 - (17.21')^2]^{0.5}$ = 17.28'

Gate strike elevation = Top of rack elevation + vertical distance

Gate strike elevation = 84.86 + 17.28 = 102.14' elevation

SFC-012-007-3

Horizontal distance = 19.27'

Gate length = 24.39'

Vertical distance = $[(24.39')^2 - (19.27')^2]^{0.5}$ = 14.95'

Gate strike elevation = Top of rack elevation + vertical distance

Gate strike elevation = 84.86 + 14.95 = 99.81' elevation

Minimum spent fuel pool water level elevation = 107.7' (previously determined in Section 10.2.1)

Results Summary

Line Number	Gate Strike Elevation	Minimum Pool Level Elevation
SFC-012-001-3	106.69'	107.7'
SFC-012-014-3	105.04'	107.7'
SFC-012-006-3	102.14'	107.7'
SFC-012-007-3	99.81'	107.7'

To assess the structural response of the piping due to the impact of the gate, the strike velocity is estimated using the methodology in Section 10.2.3. Because the gate has already struck the racks/fuel after dropping vertically, and is moving to Position 2 or 3 as indicated in Section 10.1.1, the dimensions representing length, width, and thickness with respect to the velocity equation have changed, as the area moving approximately perpendicular to the piping is the dimension of 24.390' and either the dimension of 4.771' (transition to Position 2) or the dimension of 0.396' (transition to Position 3). For the purposes of the velocity determination the gate width will be established as the 24.390' dimension and the gate dimension of 0.396' as the thickness.

The Top of Gate drop distance is determined as follows:

Top of Gate drop distance = (Gate length + top of rack elevation) – Gate strike elevation

As the center of gravity of the gate is located at the halfway point of the gate length, the water drop distance of the center of gravity is determined as follows:

Water drop distance = Top of gate drop distance / 2

The piping is treated as a simply supported steel beam as indicated in Ref. II.4 page 4-5 description 2. This is based upon the upper end of the pipe being fixed in position via the attachment to the liner embedment above the strike elevation and supported by a pipe support below the strike elevation as shown on Ref. II.18, 19, 20, 21, 22.

Determine Top of Gate Drop Distance:

Top of gate drop distance = (Gate length + top of rack elevation) – Gate strike elevation

Gate length = 24.39'
Top of rack elevation = 84.86'
SFC-012-001-3 Gate Strike Elevation = 106.69'

SFC-012-001-3 Top of gate drop distance = (24.39' + 84.86') – 106.69' = 2.56'

Determine Water Drop Distance

As the center of gravity of the gate is located at the halfway point of the gate length, the water drop distance of the center of gravity is determined as follows:

Water drop distance = Top of gate drop distance / 2

SFC-012-001-3 Water drop distance = 2.56' / 2 = 1.28'

The water drop distance for the balance of the lines is shown in the table below.

Line Number	Gate Strike Elevation	Water Drop Distance
SFC-012-001-3	106.69'	1.28'
SFC-012-014-3	105.04'	2.105'
SFC-012-006-3	102.14'	3.555'
SFC-012-007-3	99.81'	4.72'

The strike velocity is calculated using the methodology from Section 10.2.3. The Excel spread sheet for each line is shown on the following pages.

Gate Tip Onto Piping SFC-012-001-3		
Gate Length L	4.771	ft
Gate Width, d	24.390	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.402	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	1.405	
drop distance in air	0.000	ft
drop distance in water	1.280	ft
Vo where h is drop distance in air, V = (2gh)^2	0.000	ft/s
Reynolds no =(Vo * d)/viscosity	0.000	
Check L/d using gate length and width	0.196	
Check L/D using gate width and thickness	61.591	
Drag Coefficient CD	1.000	
Ao = width * thickness	9.658	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.147	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.686	
bAo	9.476	
2ax	0.377	
Vo^2	0.000	
g/a	218.432	
bAo*[(1-2ax)]/2a^2	136.077	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-299.644	
Z1x	54.865	
Vs = (Zx)^0.5	**7.407**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	62.170	lb-s2/ft
thickness	0.133	in

Gate Tip Onto Piping SFC-012-014-3		
Gate Length L	4.771	ft
Gate Width, d	24.390	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.402	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	1.405	
drop distance in air	0.000	ft
drop distance in water	2.105	ft
Vo where h is drop distance in air, V = (2gh)^2	0.000	ft/s
Reynolds no =(Vo * d)/viscosity	0.000	
Check L/d using gate length and width	0.196	
Check L/D using gate width and thickness	61.591	
Drag Coefficient CD	1.000	
Ao = width * thickness	9.658	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.147	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.538	
bAo	9.476	
2ax	0.620	
Vo^2	0.000	
g/a	218.432	
bAo*[(1-2ax)]/2a^2	82.997	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-235.001	
Z1x	66.428	
Vs = (Zx)^0.5	**8.150**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	62.170	lb-s2/ft
thickness	0.151	in

Gate Tip Onto Piping SFC-012-006-3

Gate Length L	4.771	ft
Gate Width, d	24.390	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.402	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	1.405	
drop distance in air	0.000	ft
drop distance in water	3.555	ft
Vo where h is drop distance in air, V = (2gh)^2	0.000	ft/s
Reynolds no =(Vo * d)/viscosity	0.000	
Check L/d using gate length and width	0.196	
Check L/D using gate width and thickness	61.591	
Drag Coefficient CD	1.000	
Ao = width * thickness	9.658	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.147	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.351	
bAo	9.476	
2ax	1.047	
Vo^2	0.000	
g/a	218.432	
bAo*[(1-2ax)]/2a^2	-10.296	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-153.314	
Z1x	54.822	
Vs = (Zx)^0.5	**7.404**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	62.170	lb-s2/ft
thickness	0.133	in

Gate Tip Onto Piping SFC-012-007-3

Gate Length L	4.771	ft
Gate Width, d	24.390	ft
Gate thickness	0.396	ft
Gate weight, W	2000.000	lb
Gate density	43.402	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	4.390E-06	sq ft/sec
water density/gate density	1.405	
drop distance in air	0.000	ft
drop distance in water	4.720	ft
Vo where h is drop distance in air, V = (2gh)^2	0.000	ft/s
Reynolds no =(Vo * d)/viscosity	0.000	
Check L/d using gate length and width	0.196	
Check L/D using gate width and thickness	61.591	
Drag Coefficient CD	1.000	
Ao = width * thickness	9.658	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	0.147	
b = (water density * g)/W	0.981	
exp(-2*a*x) where x = drop distance in water	0.249	
bAo	9.476	
2ax	1.390	
Vo^2	0.000	
g/a	218.432	
bAo*[(1-2ax)]/2a^2	-85.252	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	-108.780	
Z1x	24.399	
Vs = (Zx)^0.5	**4.940**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	62.170	lb-s2/ft
thickness	0.078	in

For the structural evaluation of the piping, the piping is treated as a simply supported steel beam as indicated in Ref. II.4 page 4-5 description 2. This is based upon the upper end of the pipe being fixed in position via the attachment to the liner embedment above the strike elevation and supported by a pipe support below the strike elevation as shown on References II.16, 18, 19, 20, 21, and 22

Because the pipe has a round surface subject to impact rather than a flat surface subject to impact as in the case of the beam configuration, the contact length between the pipe and the gate is assumed to be 2" (Refer to Assumption 8.15).

Elevation of Fuel Pool Cooling Piping Connection to Liner Embed

SFC-012-001-3 = 110' 0"	(Ref. II.18)
SFC-012-014-3 = 110' 0"	(Ref. II.19)
SFC-012-006-3 = 110' 0"	(Ref. II.20, II.22)
SFC-012-007-3 = 110' 0"	(Ref. II.21)

Elevation of First Support below Liner Embed Connection

SFC-012-001-3 = 86' 0"	(Ref. II.18)
SFC-012-014-3 = 86' 0"	(Ref. II.19)
SFC-012-006-3 = 92' 0"	(Ref. II.20, II.22)
SFC-012-007-3 = 92' 0"	(Ref. II.21)

Distance between supports:

SFC-012-001-3	110' 0" – 86' 0" = 24'	(Ref. II.18
SFC-012-014-3	110' 0" - 86' 0" = 24'	(Ref. II.19)
SFC-012-006-3	110' 0" – 92' 0" = 18'	(Ref. II.20, II.22)
SFC-012-007-3	110' 0" – 92' 0" = 18'	(Ref. II.21)

Note: The following sections are performed for line SFC-012-001-3. These formulas have been included in an Excel spread sheet and the cases for the balance of the lines will be shown in the spread sheet format.

Determine Target Effective Mass

$M_e = (D_x + 2d) * M_x$ Ref. II.4 pg. 3-6

Where:

M_e = Average effective mass of target during impact, lb
M_x = Mass per unit length of steel beam
D_x = Maximum missile contact dimension in the x direction, inches
d = depth of steel beam, inches

Pipe weight per unit length = 49.56 lb / ft of length Ref. III.9 pg. B-17

d = Pipe Outer Diameter = 12.75" Ref. III.9 pg. B-17

D_x = 2" Assumption 8.15

$M_e = (D_x + 2d) * M_x$

M_e = (2"/12 in/ft + (2 * 12.75)/12 in/ft) * 49.56 lb/ft / 32.174 = 3.53 lb

Determine the Strain Energy resulting from the impact

$E_s = (M_m^2 * V_s^2) / [2* (M_m + M_e)]$ Ref. II.4 pg. 3-5

Where:

E_s = strain energy, in-lb
M_m = Mass of the missile, lb
M_e = Effective mass of target during impact, lb
V_s = Missile striking velocity, in/s

M_m = Mass of the gate = 2000 lb/ 32.174 = 62.162 lb

M_e = 3.53 lb

V = 7.407 ft/s * 12 in/ft = 88.884 in/s

$E_s = (M_m^2 * V_s^2) / [\ 2* (M_m + M_e)]$

$E_s = (62.162^2 * 88.884^2) / [\ 2* (62.162 + 3.530)] = 232{,}356.411$ in-lb

Determine the Plastic Resisting Force

$R_m = (8*I*f_{dy}) / (L*d)$ Ref. II.4 pg. E-3

Where:

R_m = plastic resisting force, lb
I = moment of inertia, in^4
f_{dy} = allowable dynamic strength value = (DIF) * f_{stat}
DIF = dynamic increase factor = 1
F_{stat} = static strength (yield strength), psi
L = Length of beam, inches
d = depth of steel beam, inches

I = moment of inertia, in^4 = 279.3 in^4 (Ref. III.9, pg. B-17)
F_{stat} = 30 ksi (Ref. III.13, pg. 76, 77)
L = 24' (convert to inches)
d = 12.75" (Ref. III.9, pg. B-17)

$R_m = (8*I*f_{dy}) / (L*d)$

R_m = (8* 279.3 in^4 * 30,000 psi) / (24 ft * 12 in/ft * 12.75 in) = 18,254.902 lb

Determine the Yield Displacement

$x_e = R_m L^3 / 48EI$ Ref. II.4 pg. 4-5

Where:

x_e = yield displacement, in
R_m = plastic resisting force, lb
L = Length of beam, inches
E = modulus of elasticity, lb/in^2
I = moment of inertia, in^4

Modulus of Elasticity, E, at 200 deg F for TP 304 SS = 27.7E6 lb / in^2 (Ref. III.12, pg. 6-92)

$x_e = R_m L^3 / 48EI$

$x_e = (18{,}254.902 \ * (24' * 12\ in/ft)^3\ ) / (48 * 27.7\ E6\ lb/in^2 * 279.3\ in^4) = 1.174\ in$

Determine the Ductility Ratio

$\mu_r = [(E_s / (x_e * R_m)] + 0.5$ Ref. II.4 pg. 3-8

Where:
μ_r = required ductility ratio
E_s = strain energy, in-lb
R_m = plastic resisting force, lb
x_e = yield displacement, in

E_s = 232,356.411 in-lb
R_m = 18,254.902 lb
x_e = 1.174 in

$\mu_r = [(E_s / (x_e * R_m)] + 0.5$

$\mu_r = [(232{,}356.411\ in\text{-}lb / (1.174\ in * 18{,}254.902\ lb)] + 0.5 = 11.342$

An Excel spread sheet has been developed reflecting these formulas and is shown below. As previously discussed, minor differences between the spread sheet values and those shown in the above hand calculation may occur. The spread sheet method is utilized for the balance of the lines.

Line SFC-012-001

g	32.174	ft/s2
mass per length	49.560	lb/ft length
Dx = 2 in	0.167	ft
d = 12.75 in	1.063	ft
(Dx+2d)	2.292	ft
Me = (Dx+2d)*Mx	3.530	lb
Mm = 2000/g	62.162	lb
Impact velocity	7.407	ft/s
Vs	88.884	in/s
Es = Mm2*Vs2/2(Mm+Me)	232356.302	
I	279.300	in4
E	2.770E+07	lb/in2
fdy	30000.000	lb/in2
length, ft	24.000	ft
L	288.000	in
Rm = 8*I*fdy/(L*d)	18254.902	lb
xe = RmL^3/48EI	1.174	in
mu	11.340	

Line SFC-012-014

g	32.174	ft/s2
mass per length	49.560	lb/ft length
Dx = 2 in	0.167	ft
d = 12.75 in	1.063	ft
(Dx+2d)	2.292	ft
Me = (Dx+2d)*Mx	3.530	lb
Mm = 2000/g	62.162	lb
Impact velocity	8.150	ft/s
Vs	97.800	in/s
Es = Mm2*Vs2/2(Mm+Me)	281309.879	
I	279.300	in4
E	2.770E+07	lb/in2
fdy	30000.000	lb/in2
length, ft	24.000	ft
L	288.000	in
Rm = 8*I*fdy/(L*d)	18254.902	
xe = RmL^3/48EI	1.174	
mu	13.623	

Line SFC-012-006

g	32.174	ft/s2
mass per length	49.560	lb/ft length
Dx = 2 in	0.167	ft
d = 12.75 in	1.063	ft
(Dx+2d)	2.292	ft
Me = (Dx+2d)*Mx	3.530	lb
Mm = 2000/g	62.162	lb
Impact velocity	7.404	ft/s
Vs	88.848	in/s
Es = Mm2*Vs2/2(Mm+Me)	232168.121	
I	279.300	in4
E	2.770E+07	lb/in2
fdy	30000.000	lb/in2
length, ft	18.000	ft
L	216.000	in
Rm = 8*I*fdy/(L*d)	24339.869	
xe = RmL^3/48EI	0.661	
mu	14.941	

Line SFC-012-007

g	32.174	ft/s2
mass per length	49.560	lb/ft length
Dx = 2 in	0.167	ft
d = 12.75 in	1.063	ft
(Dx+2d)	2.292	ft
Me = (Dx+2d)*Mx	3.530	lb
Mm = 2000/g	62.162	lb
Impact velocity	4.940	ft/s
Vs	59.280	in/s
Es = Mm2*Vs2/2(Mm+Me)	103353.137	
I	279.300	in4
E	2.770E+07	lb/in2
fdy	30000.000	lb/in2
length, ft	18.000	ft
L	216.000	in
Rm = 8*I*fdy/(L*d)	24339.869	
xe = RmL^3/48EI	0.661	
mu	6.929	

Results Summary

Line Number	Yield Displacement	Ductility Ratio
SFC-012-001-3	1.174"	11.340
SFC-012-014-3	1.174"	13.623
SFC-012-006-3	0.661"	14.941
SFC-012-007-3	0.661"	6.929

The calculated ductility ratio is less than the maximum recommended ductility ratio of 20. Based on the above yield displacements and ductility ratio values, it is expected that the pipe will experience deformation, most likely in the form of a dent at the point of impact. A steel thickness determination was performed in conjunction with the determination of the strike velocity using an impact area of 2 square inches. The maximum calculated perforation thickness was 0.151". The thickness required to prevent perforation would then be 0.151" *1.25 = 0.189". The pipe wall thickness is 0.375". On the basis of the above assessment, the Fuel Pool Cooling piping has adequate ductility to accommodate the impact of a fuel pool gate transitioning from an initial drop onto the spent fuel or racks and will not be perforated as a result of the impact.

This information, in conjunction with the level of impact being below the minimum water level in the pool such that any damage to the piping will not affect the ability of the pool water to be transferred to or from the Spent Fuel Pool Cooling system. As a result, a load drop of the gates will not affect the safe shutdown function to maintain spent fuel pool cooling.

ATTACHMENT A RADTRAD Nuclide Input File RBS_fhaRev1a266.nif

```
Nuclide Inventory Name: RBS_FHARev1.NIF
River Bend Fuel Handling Accident with AST
 Power Level:
  0.1000E+01
 Nuclides:
  60
 Nuclide 001:
 Co-58
   7
  0.6117120000E+07
  0.5800E+02
  0.0000E+00
 none       0.0000E+00
 none       0.0000E+00
 none       0.0000E+00
 Nuclide 002:
 Co-60
   7
  0.1663401096E+09
  0.6000E+02
  0.0000E+00
 none       0.0000E+00
 none       0.0000E+00
 none       0.0000E+00
 Nuclide 003:
 Kr-85
   1
  0.3382974720E+09
  0.8500E+02
  0.4217E+00
 none       0.0000E+00
 none       0.0000E+00
 none       0.0000E+00
 Nuclide 004:
 Kr-85m
   1
  0.1612800000E+05
  0.8500E+02
  0.4044E+01
 Kr-85      0.2100E+00
 none       0.0000E+00
 none       0.0000E+00
```

```
Nuclide 005:
Kr-87
  1
 0.4578000000E+04
 0.8700E+02
 0.7777E+01
Rb-87     0.1000E+01
none      0.0000E+00
none      0.0000E+00
Nuclide 006:
Kr-88
  1
 0.1022400000E+05
 0.8800E+02
 0.1089E+02
Rb-88     0.1000E+01
none      0.0000E+00
none      0.0000E+00
Nuclide 007:
Rb-86
  3
 0.1612224000E+07
 0.8600E+02
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 008:
Sr-89
  5
 0.4363200000E+07
 0.8900E+02
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 009:
Sr-90
  5
 0.9189573120E+09
 0.9000E+02
 0.0000E+00
Y-90      0.1000E+01
none      0.0000E+00
none      0.0000E+00
```

```
Nuclide 010:
Sr-91
  5
 0.3420000000E+05
 0.9100E+02
 0.0000E+00
Y-91m    0.5800E+00
Y-91     0.4200E+00
none     0.0000E+00
Nuclide 011:
Sr-92
  5
 0.9756000000E+04
 0.9200E+02
 0.0000E+00
Y-92     0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 012:
Y-90
  9
 0.2304000000E+06
 0.9000E+02
 0.0000E+00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
Nuclide 013:
Y-91
  9
 0.5055264000E+07
 0.9100E+02
 0.0000E+00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
Nuclide 014:
Y-92
  9
 0.1274400000E+05
 0.9200E+02
 0.0000E+00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
```

```
Nuclide 015:
Y-93
  9
 0.3636000000E+05
 0.9300E+02
 0.0000E+00
Zr-93    0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 016:
Zr-95
  9
 0.5527872000E+07
 0.9500E+02
 0.0000E+00
Nb-95m   0.7000E-02
Nb-95    0.9900E+00
none     0.0000E+00
Nuclide 017:
Zr-97
  9
 0.6084000000E+05
 0.9700E+02
 0.0000E+00
Nb-97m   0.9500E+00
Nb-97    0.5300E-01
none     0.0000E+00
Nuclide 018:
Nb-95
  9
 0.3036960000E+07
 0.9500E+02
 0.0000E+00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
Nuclide 019:
Mo-99
  7
 0.2376000000E+06
 0.9900E+02
 0.0000E+00
Tc-99m   0.8800E+00
Tc-99    0.1200E+00
none     0.0000E+00
```

```
Nuclide 020:
Tc-99m
  7
 0.2167200000E+05
 0.9900E+02
 0.0000E+00
Tc-99    0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 021:
Ru-103
  7
 0.3393792000E+07
 0.1030E+03
 0.0000E+00
Rh-103m  0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 022:
Ru-105
  7
 0.1598400000E+05
 0.1050E+03
 0.0000E+00
Rh-105   0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 023:
Ru-106
  7
 0.3181248000E+08
 0.1060E+03
 0.0000E+00
Rh-106   0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 024:
Rh-105
  7
 0.1272960000E+06
 0.1050E+03
 0.0000E+00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
```

```
Nuclide 025:
Sb-127
  4
 0.3326400000E+06
 0.1270E+03
 0.0000E+00
Te-127m   0.1800E+00
Te-127    0.8200E+00
none      0.0000E+00
Nuclide 026:
Sb-129
  4
 0.1555200000E+05
 0.1290E+03
 0.0000E+00
Te-129m   0.2200E+00
Te-129    0.7700E+00
none      0.0000E+00
Nuclide 027:
Te-127
  4
 0.3366000000E+05
 0.1270E+03
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 028:
Te-127m
  4
 0.9417600000E+07
 0.1270E+03
 0.0000E+00
Te-127    0.9800E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 029:
Te-129
  4
 0.4176000000E+04
 0.1290E+03
 0.0000E+00
I-129     0.1000E+01
none      0.0000E+00
none      0.0000E+00
```

```
Nuclide 030:
Te-129m
  4
 0.2903040000E+07
 0.1290E+03
 0.0000E+00
Te-129   0.6500E+00
I-129    0.3500E+00
none     0.0000E+00
Nuclide 031:
Te-131m
  4
 0.1080000000E+06
 0.1310E+03
 0.0000E+00
Te-131   0.2200E+00
I-131    0.7800E+00
none     0.0000E+00
Nuclide 032:
Te-132
  4
 0.2815200000E+06
 0.1320E+03
 0.0000E+00
I-132    0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 033:
I-131
  2
 0.6946560000E+06
 0.1310E+03
 0.1244E-00
Xe-131m  0.1100E-01
none     0.0000E+00
none     0.0000E+00
Nuclide 034:
I-132
  2
 0.8280000000E+04
 0.1320E+03
 0.1129E-00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
```

```
Nuclide 035:
I-133
  2
 0.7488000000E+05
 0.1330E+03
 0.1590E-00
Xe-133m  0.2900E-01
Xe-133   0.9700E+00
none     0.0000E+00
Nuclide 036:
I-134
  2
 0.3156000000E+04
 0.1340E+03
 0.1745E-00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
Nuclide 037:
I-135
  2
 0.2379600000E+05
 0.1350E+03
 0.1489E-00
Xe-135m  0.1500E+00
Xe-135   0.8500E+00
none     0.0000E+00
Nuclide 038:
Xe-133
  1
 0.4531680000E+06
 0.1330E+03
 0.3030E+02
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
Nuclide 039:
Xe-135
  1
 0.3272400000E+05
 0.1350E+03
 0.1146E+02
Cs-135   0.1000E+01
none     0.0000E+00
none     0.0000E+00
```

```
Nuclide 040:
Cs-134
  3
 0.6507177120E+08
 0.1340E+03
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 041:
Cs-136
  3
 0.1131840000E+07
 0.1360E+03
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 042:
Cs-137
  3
 0.9467280000E+09
 0.1370E+03
 0.0000E+00
Ba-137m   0.9500E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 043:
Ba-139
  6
 0.4962000000E+04
 0.1390E+03
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 044:
Ba-140
  6
 0.1100736000E+07
 0.1400E+03
 0.0000E+00
La-140    0.1000E+01
none      0.0000E+00
none      0.0000E+00
```

```
Nuclide 045:
La-140
  9
 0.1449792000E+06
 0.1400E+03
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 046:
La-141
  9
 0.1414800000E+05
 0.1410E+03
 0.0000E+00
Ce-141    0.1000E+01
none      0.0000E+00
none      0.0000E+00
Nuclide 047:
La-142
  9
 0.5550000000E+04
 0.1420E+03
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 048:
Ce-141
  8
 0.2808086400E+07
 0.1410E+03
 0.0000E+00
none      0.0000E+00
none      0.0000E+00
none      0.0000E+00
Nuclide 049:
Ce-143
  8
 0.1188000000E+06
 0.1430E+03
 0.0000E+00
Pr-143    0.1000E+01
none      0.0000E+00
none      0.0000E+00
```

```
Nuclide 050:
Ce-144
  8
 0.2456352000E+08
 0.1440E+03
 0.0000E+00
Pr-144m  0.1800E-01
Pr-144   0.9800E+00
none     0.0000E+00
Nuclide 051:
Pr-143
  9
 0.1171584000E+07
 0.1430E+03
 0.0000E+00
none     0.0000E+00
none     0.0000E+00
none     0.0000E+00
Nuclide 052:
Nd-147
  9
 0.9486720000E+06
 0.1470E+03
 0.0000E+00
Pm-147   0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 053:
Np-239
  8
 0.2034720000E+06
 0.2390E+03
 0.0000E+00
Pu-239   0.1000E+01
none     0.0000E+00
none     0.0000E+00
Nuclide 054:
Pu-238
  8
 0.2768863824E+10
 0.2380E+03
 0.0000E+00
U-234    0.1000E+01
none     0.0000E+00
none     0.0000E+00
```

```
Nuclide 055:
Pu-239
  8
 0.7594336440E+12
 0.2390E+03
 0.0000E+00
U-235     0.1000E+01
none      0.0000E+00
none      0.0000E+00
Nuclide 056:
Pu-240
  8
 0.2062920312E+12
 0.2400E+03
 0.0000E+00
U-236     0.1000E+01
none      0.0000E+00
none      0.0000E+00
Nuclide 057:
Pu-241
  8
 0.4544294400E+09
 0.2410E+03
 0.0000E+00
U-237     0.2400E-04
Am-241    0.1000E+01
none      0.0000E+00
Nuclide 058:
Am-241
  9
 0.1363919472E+11
 0.2410E+03
 0.0000E+00
Np-237    0.1000E+01
none      0.0000E+00
none      0.0000E+00
Nuclide 059:
Cm-242
  9
 0.1406592000E+08
 0.2420E+03
 0.0000E+00
Pu-238    0.1000E+01
none      0.0000E+00
none      0.0000E+00
```

```
Nuclide 060:
Cm-244
  9
 0.5715081360E+09
 0.2440E+03
 0.0000E+00
Pu-240   0.1000E+01
none     0.0000E+00
none     0.0000E+00
End of Nuclear Inventory File
```

ATTACHMENT B – RADTRAD Results File

```
######################################################################
          RADTRAD Version 3.02 run on  8/11/2014  at 15:33:00
######################################################################

######################################################################
                    File information
######################################################################

 Plant file name           = C:\FHAMelissa266wd.psf
 Inventory file name       = C:\radtrad files\Radtrad files\FHA\Rbs_fhaRev1a266.nif
 Scenario file name        = C:\FHAMelissa266wd.psf
 Release file name         = c:\radtrad files\radtrad files\fha\rbs_fharev1.rft
 Dose conversion file name = c:\program files\u s nuclear regulatory
commission\radtrad\defaults\fgr11&12.inp



     #####    ####   #####    #  #     #  #####   #    #  #####
     #    #  #       #        #  ##    #  #    #  #    #    #
     #    #  #       #        #  # #   #  #    #  #    #    #
     #####    ####   ####     #  #  #  #  #####   #    #    #
     #           #   #        #  #   # #  #       #    #    #
     #           #   #        #  #    ##  #       #    #    #
     #        ####   #        #  #     #  #        ####     #


 Radtrad 3.02 1/5/2000
 First Time Through
 Nuclide Inventory File:
 C:\radtrad files\Radtrad files\FHA\Rbs_fhaRev1a266.nif
 Plant Power Level:
  3.1000E+03
 Compartments:
   3
 Compartment 1:
 RBS Fuel Building
   3
  7.4200E+05
   0
   0
   0
   0
   0
```

```
Compartment 2:
RBS Environment
  2
 0.0000E+00
  0
  0
  0
  0
  0
Compartment 3:
RBS Control Room
  1
 1.8800E+05
  0
  0
  1
  0
  0
Pathways:
  5
Pathway 1:
RBS Fuel Building to RBS Environment
  1
  2
  2
Pathway 2:
RBS Environment to RBS Control Room
  2
  3
  2
Pathway 3:
RBS Environment to RBS Control Room
  2
  3
  2
Pathway 4:
RBS Environment to RBS Control Room
  2
  3
  2
Pathway 5:
RBS Control Room to RBS Environment
  3
  2
  2
End of Plant Model File
```

```
Scenario Description Name:

Plant Model Filename:

Source Term:
  1
  1   1.0000E+00
c:\program files\u s nuclear regulatory commission\radtrad\defaults\fgr11&12.inp
c:\radtrad files\radtrad files\fha\rbs_fharev1.rft
  3.3600E+02
  1
  0.0000E+00   5.7000E-01   4.3000E-01   1.0000E+00
Overlying Pool:
  0
  0.0000E+00
  0
  0
  0
  0
Compartments:
  3
Compartment 1:
  1
  1
  0
  0
  0
  0
  0
  0
  0
Compartment 2:
  1
  1
  0
  0
  0
  0
  0
  0
  0
Compartment 3:
  1
  1
  0
  0
  0
  0
  1
  2.0000E+03
  3
  3.3600E+02   1.0000E+02   0.0000E+00   0.0000E+00
  3.3602E+02   1.0000E+02   0.0000E+00   0.0000E+00
```

```
  1.0560E+03   0.0000E+00   0.0000E+00   0.0000E+00
  0
  0
Pathways:
  5
Pathway 1:
  0
  0
  0
  0
  0
  1
  2
  3.3600E+02   7.4200E+09   1.0000E+02   0.0000E+00   0.0000E+00
  1.0560E+03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0
  0
  0
  0
  0
  0
Pathway 2:
  0
  0
  0
  0
  0
  1
  3
  3.3600E+02   1.7000E+03   1.0000E+02   0.0000E+00   0.0000E+00
  3.3602E+02   0.0000E+00   1.0000E+02   1.0000E+02   1.0000E+02
  1.0560E+03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0
  0
  0
  0
  0
  0
Pathway 3:
  0
  0
  0
  0
  0
  1
  3
  3.3600E+02   0.0000E+00   1.0000E+02   1.0000E+02   1.0000E+02
  3.3602E+02   1.7000E+03   1.0000E+02   0.0000E+00   0.0000E+00
  1.0560E+03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0
  0
  0
  0
```

```
  0
  0
Pathway 4:
  0
  0
  0
  0
  0
  1
  2
  3.3600E+02   3.0000E+02   1.0000E+02   0.0000E+00   0.0000E+00
  1.0560E+03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0
  0
  0
  0
  0
  0
Pathway 5:
  0
  0
  0
  0
  0
  1
  2
  3.3600E+02   2.0000E+03   1.0000E+02   0.0000E+00   0.0000E+00
  1.0560E+03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0
  0
  0
  0
  0
  0
Dose Locations:
  3
Location 1:
EAB
  2
  1
  2
  3.3600E+02   8.5800E-04
  1.0560E+03   0.0000E+00
  1
  4
  3.3600E+02   3.5000E-04
  3.4400E+02   1.8000E-04
  3.6000E+02   2.3000E-04
  1.0560E+03   0.0000E+00
  0
Location 2:
LPZ
  2
```

```
  1
  5
  3.3600E+02   1.1300E-04
  3.4400E+02   7.8900E-05
  3.6000E+02   3.6500E-05
  4.3200E+02   1.2100E-05
  1.0560E+03   0.0000E+00
  1
  4
  3.3600E+02   3.5000E-04
  3.4400E+02   1.8000E-04
  3.6000E+02   2.3000E-04
  1.0560E+03   0.0000E+00
  0
Location 3:
Control Room
  3
  0
  1
  2
  3.3600E+02   3.5000E-04
  1.0560E+03   0.0000E+00
  1
  4
  3.3600E+02   1.0000E+00
  3.6000E+02   1.0000E+00
  4.3200E+02   1.0000E+00
  1.0560E+03   0.0000E+00
Effective Volume Location:
  1
  6
  3.3600E+02   1.6200E-03
  3.3633E+02   4.0500E-04
  3.4400E+02   3.0000E-04
  3.6000E+02   1.0100E-04
  4.3200E+02   6.2000E-05
  1.0560E+03   0.0000E+00
Simulation Parameters:
  1
  3.3600E+02   0.0000E+00
Output Filename:
C:\FHAMelissa266wd.o0
  1
  1
  1
  1
  1
End of Scenario File
```

```
##########################################################################
          RADTRAD Version 3.02 run on  8/11/2014  at 15:33:00
##########################################################################

##########################################################################
                    Plant Description
##########################################################################

Number of Nuclides =  60

Inventory Power =   1.0000E+00 MWth
Plant Power Level =   3.1000E+03 MWth

Number of compartments    =   3

Compartment information

Compartment number  1  (Source term fraction =   1.0000E+00
)
Name: RBS Fuel Building
Compartment volume =   7.4200E+05 (Cubic feet)
Pathways into and out of compartment  1
    Pathway to compartment number   2: RBS Fuel Building to RBS Environment

Compartment number  2
Name: RBS Environment
Pathways into and out of compartment  2
    Pathway to compartment number   3: RBS Environment to RBS Control Room
    Pathway to compartment number   3: RBS Environment to RBS Control Room
    Pathway to compartment number   3: RBS Environment to RBS Control Room
    Pathway from compartment number 1: RBS Fuel Building to RBS Environment
    Pathway from compartment number 3: RBS Control Room to RBS Environment

Compartment number  3
Name: RBS Control Room
Compartment volume =   1.8800E+05 (Cubic feet)
Removal devices within compartment:
     Filter(s)
Pathways into and out of compartment  3
    Pathway to compartment number   2: RBS Control Room to RBS Environment
    Pathway from compartment number 2: RBS Environment to RBS Control Room
    Pathway from compartment number 2: RBS Environment to RBS Control Room
    Pathway from compartment number 2: RBS Environment to RBS Control Room

Total number of pathways =   5
```

```
#########################################################################
         RADTRAD Version 3.02 run on  8/11/2014  at 15:33:00
#########################################################################

#########################################################################
                      Scenario Description
#########################################################################


Time between shutdown and first release =   3.3600E+02 (Hours)

Radioactive Decay is enabled
Calculation of Daughters is enabled
RELEASE_NAME = BWR, NUREG-1465, Tables 3.11 & 3.13, Jun
Release Fractions and Timings
                GAP        EARLY IN-VESSEL
             2.0000 hrs     1.5000 hrs
NOBLES       1.0000E+00     0.0000E+00
IODINE       1.0000E+00     0.0000E+00
CESIUM       0.0000E+00     0.0000E+00
TELLURIUM    0.0000E+00     0.0000E+00
STRONTIUM    0.0000E+00     0.0000E+00
BARIUM       0.0000E+00     0.0000E+00
RUTHENIUM    0.0000E+00     0.0000E+00
CERIUM       0.0000E+00     0.0000E+00
LANTHANUM    0.0000E+00     0.0000E+00

Iodine fractions
     Aerosol     =    0.0000E+00
     Elemental   =    5.7000E-01
     Organic     =    4.3000E-01

COMPARTMENT DATA

Compartment number   1: RBS Fuel Building

Compartment number   2: RBS Environment

Compartment number   3: RBS Control Room

     Compartment Filter Data

      Time (hr)      Flow Rate          Filter Efficiencies (%)
                       (cfm)       Aerosol      Elemental     Organic
       3.3600E+02    2.0000E+03   1.0000E+02   0.0000E+00   0.0000E+00
       3.3602E+02    2.0000E+03   1.0000E+02   0.0000E+00   0.0000E+00
       1.0560E+03    2.0000E+03   0.0000E+00   0.0000E+00   0.0000E+00

PATHWAY DATA

Pathway number  1: RBS Fuel Building to RBS Environment
```

Pathway Filter: Removal Data

Time (hr)	Flow Rate (cfm)	Filter Efficiencies (%) Aerosol	Elemental	Organic
3.3600E+02	7.4200E+09	1.0000E+02	0.0000E+00	0.0000E+00
1.0560E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Pathway number 2: RBS Environment to RBS Control Room

Pathway Filter: Removal Data

Time (hr)	Flow Rate (cfm)	Filter Efficiencies (%) Aerosol	Elemental	Organic
3.3600E+02	1.7000E+03	1.0000E+02	0.0000E+00	0.0000E+00
3.3602E+02	0.0000E+00	1.0000E+02	1.0000E+02	1.0000E+02
1.0560E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Pathway number 3: RBS Environment to RBS Control Room

Pathway Filter: Removal Data

Time (hr)	Flow Rate (cfm)	Filter Efficiencies (%) Aerosol	Elemental	Organic
3.3600E+02	0.0000E+00	1.0000E+02	1.0000E+02	1.0000E+02
3.3602E+02	1.7000E+03	1.0000E+02	0.0000E+00	0.0000E+00
1.0560E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Pathway number 4: RBS Environment to RBS Control Room

Pathway Filter: Removal Data

Time (hr)	Flow Rate (cfm)	Filter Efficiencies (%) Aerosol	Elemental	Organic
3.3600E+02	3.0000E+02	1.0000E+02	0.0000E+00	0.0000E+00
1.0560E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Pathway number 5: RBS Control Room to RBS Environment

Pathway Filter: Removal Data

Time (hr)	Flow Rate (cfm)	Filter Efficiencies (%) Aerosol	Elemental	Organic
3.3600E+02	2.0000E+03	1.0000E+02	0.0000E+00	0.0000E+00
1.0560E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

LOCATION DATA

Location EAB is in compartment 2

Location X/Q Data

Time (hr)	X/Q (s * m^-3)
3.3600E+02	8.5800E-04
1.0560E+03	0.0000E+00

```
Location Breathing Rate Data
 Time (hr)          Breathing Rate (m^3 * sec^-1)
  3.3600E+02                  3.5000E-04
  3.4400E+02                  1.8000E-04
  3.6000E+02                  2.3000E-04
  1.0560E+03                  0.0000E+00
Location LPZ     is in compartment   2

Location X/Q Data
 Time (hr)          X/Q (s * m^-3)
  3.3600E+02           1.1300E-04
  3.4400E+02           7.8900E-05
  3.6000E+02           3.6500E-05
  4.3200E+02           1.2100E-05
  1.0560E+03           0.0000E+00

Location Breathing Rate Data
 Time (hr)          Breathing Rate (m^3 * sec^-1)
  3.3600E+02                  3.5000E-04
  3.4400E+02                  1.8000E-04
  3.6000E+02                  2.3000E-04
  1.0560E+03                  0.0000E+00
Location Control Room     is in compartment   3

Location X/Q Data
 Time (hr)          X/Q (s * m^-3)
  3.3600E+02           1.6200E-03
  3.3633E+02           4.0500E-04
  3.4400E+02           3.0000E-04
  3.6000E+02           1.0100E-04
  4.3200E+02           6.2000E-05
  1.0560E+03           0.0000E+00

Location Breathing Rate Data
 Time (hr)          Breathing Rate (m^3 * sec^-1)
  3.3600E+02                  3.5000E-04
  1.0560E+03                  0.0000E+00

Location Occupancy Factor Data
 Time (hr)          Occupancy Factor
  3.3600E+02             1.0000E+00
  3.6000E+02             1.0000E+00
  4.3200E+02             1.0000E+00
  1.0560E+03             0.0000E+00

USER SPECIFIED TIME STEP DATA - SUPPLEMENTAL TIME STEPS
     Time              Time step
      0.0000E+00         0.0000E+00
```

```
#######################################################################
          RADTRAD Version 3.02 run on  8/11/2014  at 15:33:00
#######################################################################



     ####   #    #  #####  #####   #    #  #####
    #    #  #    #    #    #    #  #    #    #
    #    #  #    #    #    #    #  #    #    #
    #    #  #    #    #    #####   #    #    #
    #    #  #    #    #    #       #    #    #
    #    #  #    #    #    #       #    #    #
     ####    ####     #    #        ####     #


####################################################################
           Dose, Detailed model and Detailed Inventory Output
####################################################################

Detailed model information at time (H) =  336.0200

EAB Doses:

Time (h) = 336.0200    Whole Body  Thyroid      TEDE
Delta dose (rem)        8.0357E-04  3.7421E-01  1.2196E-02
Accumulated dose (rem)  8.0357E-04  3.7421E-01  1.2196E-02

LPZ Doses:

Time (h) = 336.0200    Whole Body  Thyroid      TEDE
Delta dose (rem)        1.0583E-04  4.9284E-02  1.6063E-03
Accumulated dose (rem)  1.0583E-04  4.9284E-02  1.6063E-03

Control Room Doses:

Time (h) = 336.0200    Whole Body  Thyroid      TEDE
Delta dose (rem)        4.9747E-07  4.4823E-03  1.3696E-04
Accumulated dose (rem)  4.9747E-07  4.4823E-03  1.3696E-04

RBS Fuel Building Compartment Nuclide Inventory:

Time (h) = 336.0200       Ci          kg          Atoms          Bq
Kr-85                  1.0868E-03  2.7701E-09  1.9626E+16  4.0212E+07
I-131                  9.6114E-05  7.7527E-13  3.5640E+12  3.5562E+06
I-133                  5.6298E-09  4.9698E-18  2.2503E+07  2.0830E+02
Xe-133                 1.2317E-02  6.5802E-11  2.9795E+14  4.5572E+08
```

RBS Fuel Building Transport Group Inventory:

Time (h) = 336.0200	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	1.9924E+16	0.0000E+00	0.0000E+00
Elemental I (atoms)	2.0316E+12	0.0000E+00	0.0000E+00
Organic I (atoms)	1.5326E+12	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 336.0200	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment Integral Nuclide Release:

Time (h) = 336.0200	Ci	kg	Atoms	Bq
Kr-85	1.3041E+01	3.3239E-05	2.3549E+20	4.8250E+11
I-131	1.1533E+00	9.3026E-09	4.2765E+16	4.2672E+10
I-133	6.7555E-05	5.9635E-14	2.7002E+11	2.4996E+06
Xe-133	1.4779E+02	7.8957E-07	3.5751E+18	5.4683E+12
Xe-135	2.7249E-09	1.0670E-18	4.7598E+06	1.0082E+02

RBS Environment Transport Group Inventory:

Time (h) = 336.0200	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	2.3907E+20	3.3204E+18	2.3244E+20
Elemental I (atoms)	2.4378E+16	3.3858E+14	2.3702E+16
Organic I (atoms)	1.8390E+16	2.5542E+14	1.7881E+16
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room Compartment Nuclide Inventory:

Time (h) = 336.0200	Ci	kg	Atoms	Bq
Kr-85	1.9814E-02	5.0502E-08	3.5780E+17	7.3311E+08
I-131	1.7523E-03	1.4134E-11	6.4976E+13	6.4835E+07
I-133	1.0264E-07	9.0606E-17	4.1026E+08	3.7977E+03
Xe-133	2.2455E-01	1.1997E-09	5.4319E+15	8.3085E+09

RBS Control Room Transport Group Inventory:

Time (h) = 336.0200	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	3.6324E+17	0.0000E+00	0.0000E+00
Elemental I (atoms)	3.7039E+13	0.0000E+00	0.0000E+00
Organic I (atoms)	2.7942E+13	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 336.0200	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 336.0200	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Detailed model information at time (H) = 338.0000

EAB Doses:

Time (h) = 338.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	7.9181E-02	3.6934E+01	1.2036E+00
Accumulated dose (rem)	7.9985E-02	3.7308E+01	1.2158E+00

LPZ Doses:

Time (h) = 338.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.0428E-02	4.8643E+00	1.5852E-01
Accumulated dose (rem)	1.0534E-02	4.9136E+00	1.6013E-01

Control Room Doses:

Time (h) = 338.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.6832E-03	1.5193E+01	4.6425E-01
Accumulated dose (rem)	1.6837E-03	1.5198E+01	4.6438E-01

RBS Fuel Building Compartment Nuclide Inventory:

Time (h) = 338.0000	Ci	kg	Atoms	Bq
Kr-85	1.0868E-03	2.7700E-09	1.9625E+16	4.0211E+07
I-131	9.5433E-05	7.6978E-13	3.5387E+12	3.5310E+06
I-133	5.2704E-09	4.6525E-18	2.1066E+07	1.9500E+02
Xe-133	1.2183E-02	6.5088E-11	2.9471E+14	4.5078E+08

RBS Fuel Building Transport Group Inventory:

Time (h) = 338.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	1.9920E+16	0.0000E+00	0.0000E+00
Elemental I (atoms)	2.0177E+12	0.0000E+00	0.0000E+00
Organic I (atoms)	1.5221E+12	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 338.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 338.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment Integral Nuclide Release:

Time (h) = 338.0000	Ci	kg	Atoms	Bq
Kr-85	1.3046E+03	3.3252E-03	2.3558E+22	4.8269E+13
I-131	1.1495E+02	9.2720E-07	4.2624E+18	4.2531E+12
I-133	6.5314E-03	5.7656E-12	2.6106E+13	2.4166E+08
Xe-133	1.4702E+04	7.8542E-05	3.5563E+20	5.4396E+14
Xe-135	2.5224E-07	9.8775E-17	4.4062E+08	9.3330E+03

RBS Environment Transport Group Inventory:

Time (h) = 338.0000	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	2.3914E+22	3.3214E+18	2.3908E+22
Elemental I (atoms)	2.4304E+18	3.3756E+14	2.4298E+18
Organic I (atoms)	1.8335E+18	2.5465E+14	1.8330E+18
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 338.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 338.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 338.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 338.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 338.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room Compartment Nuclide Inventory:

Time (h) = 338.0000	Ci	kg	Atoms	Bq
Kr-85	3.8219E-01	9.7413E-07	6.9016E+18	1.4141E+10
I-131	3.3561E-02	2.7071E-10	1.2444E+15	1.2417E+09
I-133	1.8534E-06	1.6361E-15	7.4082E+09	6.8576E+04
Xe-133	4.2845E+00	2.2889E-08	1.0364E+17	1.5853E+11
Xe-135	6.8663E-11	2.6887E-20	1.1994E+05	2.5405E+00

RBS Control Room Transport Group Inventory:

Time (h) = 338.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	7.0059E+18	0.0000E+00	0.0000E+00
Elemental I (atoms)	7.1216E+14	0.0000E+00	0.0000E+00
Organic I (atoms)	5.3724E+14	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 338.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 338.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

	Pathway
Time (h) = 338.0000	Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

	Pathway
Time (h) = 338.0000	Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

	Pathway
Time (h) = 338.0000	Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Detailed model information at time (H) = 339.5000

EAB Doses:

Time (h) = 339.5000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.4381E-05	6.7268E-03	2.1918E-04
Accumulated dose (rem)	7.9999E-02	3.7315E+01	1.2161E+00

LPZ Doses:

Time (h) = 339.5000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.8940E-06	8.8593E-04	2.8866E-05
Accumulated dose (rem)	1.0536E-02	4.9144E+00	1.6016E-01

Control Room Doses:

Time (h) = 339.5000	Whole Body	Thyroid	TEDE
Delta dose (rem)	9.1384E-04	8.2707E+00	2.5272E-01
Accumulated dose (rem)	2.5975E-03	2.3468E+01	7.1710E-01

RBS Fuel Building Compartment Nuclide Inventory:

Time (h) = 339.5000	Ci	kg	Atoms	Bq

RBS Fuel Building Transport Group Inventory:

Time (h) = 339.5000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 339.5000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 339.5000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment Integral Nuclide Release:

Time (h) = 339.5000	Ci	kg	Atoms	Bq
Kr-85	1.3048E+03	3.3258E-03	2.3563E+22	4.8278E+13
I-131	1.1497E+02	9.2737E-07	4.2632E+18	4.2539E+12
I-133	6.5325E-03	5.7666E-12	2.6111E+13	2.4170E+08
Xe-133	1.4704E+04	7.8556E-05	3.5570E+20	5.4406E+14
Xe-135	2.5228E-07	9.8790E-17	4.4069E+08	9.3345E+03

RBS Environment Transport Group Inventory:

Time (h) = 339.5000	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	2.3919E+22	1.8983E+18	2.3912E+22
Elemental I (atoms)	2.4309E+18	1.9293E+14	2.4302E+18
Organic I (atoms)	1.8338E+18	1.4554E+14	1.8333E+18
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 339.5000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 339.5000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 339.5000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 339.5000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 339.5000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room Compartment Nuclide Inventory:

Time (h) = 339.5000	Ci	kg	Atoms	Bq
Kr-85	1.4676E-01	3.7407E-07	2.6503E+18	5.4302E+09
I-131	1.2818E-02	1.0340E-10	4.7532E+14	4.7428E+08
I-133	6.7703E-07	5.9766E-16	2.7061E+09	2.5050E+04
Xe-133	1.6318E+00	8.7175E-09	3.9472E+16	6.0375E+10

RBS Control Room Transport Group Inventory:

Time (h) = 339.5000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	2.6904E+18	0.0000E+00	0.0000E+00
Elemental I (atoms)	2.7348E+14	0.0000E+00	0.0000E+00
Organic I (atoms)	2.0631E+14	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

```
                              Deposition Recirculating
Time (h) = 339.5000            Surfaces     Filter
Noble gases (atoms)           0.0000E+00  0.0000E+00
Elemental I (atoms)           0.0000E+00  0.0000E+00
Organic I (atoms)             0.0000E+00  0.0000E+00
Aerosols (kg)                 0.0000E+00  0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

                               Pathway
Time (h) = 339.5000             Filter
Noble gases (atoms)           0.0000E+00
Elemental I (atoms)           0.0000E+00
Organic I (atoms)             0.0000E+00
Aerosols (kg)                 0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

                               Pathway
Time (h) = 339.5000             Filter
Noble gases (atoms)           0.0000E+00
Elemental I (atoms)           0.0000E+00
Organic I (atoms)             0.0000E+00
Aerosols (kg)                 0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

                               Pathway
Time (h) = 339.5000             Filter
Noble gases (atoms)           0.0000E+00
Elemental I (atoms)           0.0000E+00
Organic I (atoms)             0.0000E+00
Aerosols (kg)                 0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

                               Pathway
Time (h) = 339.5000             Filter
Noble gases (atoms)           0.0000E+00
Elemental I (atoms)           0.0000E+00
Organic I (atoms)             0.0000E+00
Aerosols (kg)                 0.0000E+00
```

Detailed model information at time (H) = 344.0000

EAB Doses:

Time (h) = 344.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	8.3225E-06	3.9074E-03	1.2728E-04
Accumulated dose (rem)	8.0008E-02	3.7319E+01	1.2162E+00

LPZ Doses:

Time (h) = 344.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.0961E-06	5.1461E-04	1.6763E-05
Accumulated dose (rem)	1.0537E-02	4.9150E+00	1.6017E-01

Control Room Doses:

Time (h) = 344.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	5.3130E-04	4.8264E+00	1.4747E-01
Accumulated dose (rem)	3.1288E-03	2.8295E+01	8.6457E-01

RBS Fuel Building Compartment Nuclide Inventory:

Time (h) = 344.0000	Ci	kg	Atoms	Bq

RBS Fuel Building Transport Group Inventory:

Time (h) = 344.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 344.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment Integral Nuclide Release:

Time (h) = 344.0000	Ci	kg	Atoms	Bq
Kr-85	1.3050E+03	3.3261E-03	2.3565E+22	4.8283E+13
I-131	1.1498E+02	9.2747E-07	4.2636E+18	4.2543E+12
I-133	6.5331E-03	5.7672E-12	2.6113E+13	2.4173E+08
Xe-133	1.4706E+04	7.8564E-05	3.5573E+20	5.4412E+14
Xe-135	2.5230E-07	9.8798E-17	4.4072E+08	9.3352E+03

RBS Environment Transport Group Inventory:

Time (h) = 344.0000	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	2.3921E+22	8.3059E+17	2.3914E+22
Elemental I (atoms)	2.4311E+18	8.4415E+13	2.4305E+18
Organic I (atoms)	1.8340E+18	6.3681E+13	1.8335E+18
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room Compartment Nuclide Inventory:

Time (h) = 344.0000	Ci	kg	Atoms	Bq
Kr-85	8.3107E-03	2.1183E-08	1.5008E+17	3.0749E+08
I-131	7.1425E-04	5.7613E-12	2.6485E+13	2.6427E+07
I-133	3.3000E-08	2.9131E-17	1.3190E+08	1.2210E+03
Xe-133	9.0143E-02	4.8158E-10	2.1805E+15	3.3353E+09

RBS Control Room Transport Group Inventory:

Time (h) = 344.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	1.5235E+17	0.0000E+00	0.0000E+00
Elemental I (atoms)	1.5487E+13	0.0000E+00	0.0000E+00
Organic I (atoms)	1.1683E+13	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 344.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 344.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Detailed model information at time (H) = 360.0000

EAB Doses:

Time (h) = 360.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	4.8707E-07	1.1857E-04	4.0970E-06
Accumulated dose (rem)	8.0008E-02	3.7319E+01	1.2162E+00

LPZ Doses:

Time (h) = 360.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	4.4790E-08	1.0903E-05	3.7675E-07
Accumulated dose (rem)	1.0537E-02	4.9150E+00	1.6017E-01

Control Room Doses:

Time (h) = 360.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	3.1138E-05	2.8518E-01	8.7135E-03
Accumulated dose (rem)	3.1599E-03	2.8580E+01	8.7328E-01

RBS Fuel Building Compartment Nuclide Inventory:

Time (h) = 360.0000	Ci	kg	Atoms	Bq

RBS Fuel Building Transport Group Inventory:

Time (h) = 360.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 360.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment Integral Nuclide Release:

Time (h) = 360.0000	Ci	kg	Atoms	Bq
Kr-85	1.3050E+03	3.3261E-03	2.3565E+22	4.8284E+13
I-131	1.1498E+02	9.2747E-07	4.2636E+18	4.2544E+12
I-133	6.5331E-03	5.7672E-12	2.6113E+13	2.4173E+08
Xe-133	1.4706E+04	7.8565E-05	3.5574E+20	5.4412E+14
Xe-135	2.5230E-07	9.8799E-17	4.4072E+08	9.3353E+03

RBS Environment Transport Group Inventory:

Time (h) = 360.0000	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	2.3921E+22	2.7687E+17	2.3915E+22
Elemental I (atoms)	2.4312E+18	2.8138E+13	2.4305E+18
Organic I (atoms)	1.8340E+18	2.1227E+13	1.8335E+18
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room Compartment Nuclide Inventory:

Time (h) = 360.0000	Ci	kg	Atoms	Bq
Kr-85	3.0584E-07	7.7954E-13	5.5229E+12	1.1316E+04
I-131	2.4820E-08	2.0020E-16	9.2033E+08	9.1833E+02
Xe-133	3.0379E-06	1.6230E-14	7.3487E+10	1.1240E+05

RBS Control Room Transport Group Inventory:

Time (h) = 360.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	5.6073E+12	0.0000E+00	0.0000E+00
Elemental I (atoms)	5.6999E+08	0.0000E+00	0.0000E+00
Organic I (atoms)	4.2999E+08	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 360.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 360.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Detailed model information at time (H) = 432.0000

EAB Doses:

Time (h) = 432.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.6498E-11	5.2711E-09	1.7698E-10
Accumulated dose (rem)	8.0008E-02	3.7319E+01	1.2162E+00

LPZ Doses:

Time (h) = 432.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	7.0186E-13	2.2424E-10	7.5288E-12
Accumulated dose (rem)	1.0537E-02	4.9150E+00	1.6017E-01

Control Room Doses:

Time (h) = 432.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.0884E-09	1.0238E-05	3.1280E-07
Accumulated dose (rem)	3.1599E-03	2.8580E+01	8.7328E-01

RBS Fuel Building Compartment Nuclide Inventory:

Time (h) = 432.0000	Ci	kg	Atoms	Bq

RBS Fuel Building Transport Group Inventory:

Time (h) = 432.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 432.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment Integral Nuclide Release:

Time (h) = 432.0000	Ci	kg	Atoms	Bq
Kr-85	1.3050E+03	3.3261E-03	2.3565E+22	4.8284E+13
I-131	1.1498E+02	9.2747E-07	4.2636E+18	4.2544E+12
I-133	6.5331E-03	5.7672E-12	2.6113E+13	2.4173E+08
Xe-133	1.4706E+04	7.8565E-05	3.5574E+20	5.4412E+14
Xe-135	2.5230E-07	9.8799E-17	4.4072E+08	9.3353E+03

RBS Environment Transport Group Inventory:

Time (h) = 432.0000	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	2.3921E+22	6.9217E+16	2.3915E+22
Elemental I (atoms)	2.4312E+18	7.0346E+12	2.4305E+18
Organic I (atoms)	1.8340E+18	5.3068E+12	1.8335E+18
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room Compartment Nuclide Inventory:

Time (h) = 432.0000	Ci	kg	Atoms	Bq

RBS Control Room Transport Group Inventory:

Time (h) = 432.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	6.1886E-08	0.0000E+00	0.0000E+00
Elemental I (atoms)	6.2907E-12	0.0000E+00	0.0000E+00
Organic I (atoms)	4.7456E-12	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 432.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) = 432.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Detailed model information at time (H) = 1056.0000

EAB Doses:

Time (h) =1056.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.2447E-31	4.4915E-29	1.4919E-30
Accumulated dose (rem)	8.0008E-02	3.7319E+01	1.2162E+00

LPZ Doses:

Time (h) =1056.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	1.7553E-33	6.3342E-31	2.1040E-32
Accumulated dose (rem)	1.0537E-02	4.9150E+00	1.6017E-01

Control Room Doses:

Time (h) =1056.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	8.2110E-30	8.7242E-26	2.6643E-27
Accumulated dose (rem)	3.1599E-03	2.8580E+01	8.7328E-01

RBS Fuel Building Compartment Nuclide Inventory:

Time (h) =1056.0000	Ci	kg	Atoms	Bq

RBS Fuel Building Transport Group Inventory:

Time (h) =1056.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) =1056.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment Integral Nuclide Release:

Time (h) =1056.0000	Ci	kg	Atoms	Bq
Kr-85	1.3050E+03	3.3261E-03	2.3565E+22	4.8284E+13
I-131	1.1498E+02	9.2747E-07	4.2636E+18	4.2544E+12
I-133	6.5331E-03	5.7672E-12	2.6113E+13	2.4173E+08
Xe-133	1.4706E+04	7.8565E-05	3.5574E+20	5.4412E+14
Xe-135	2.5230E-07	9.8799E-17	4.4072E+08	9.3353E+03

RBS Environment Transport Group Inventory:

Time (h) =1056.0000	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	2.3921E+22	9.2289E+15	2.3915E+22
Elemental I (atoms)	2.4312E+18	9.3795E+11	2.4305E+18
Organic I (atoms)	1.8340E+18	7.0757E+11	1.8335E+18
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

RBS Fuel Building to RBS Environment Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room Compartment Nuclide Inventory:

Time (h) =1056.0000	Ci	kg	Atoms	Bq

RBS Control Room Transport Group Inventory:

Time (h) =1056.0000	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	6.6550-181	0.0000E+00	0.0000E+00
Elemental I (atoms)	6.7648-185	0.0000E+00	0.0000E+00
Organic I (atoms)	5.1033-185	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) =1056.0000	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Environment to RBS Control Room Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

RBS Control Room to RBS Environment Transport Group Inventory:

Time (h) =1056.0000	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

##

I-131 Summary

##

Time (hr)	RBS Fuel Building I-131 (Curies)	RBS Environment I-131 (Curies)	RBS Control Room I-131 (Curies)
336.001	9.6121E-05	3.1944E-02	4.8838E-05
336.020	9.6114E-05	1.1533E+00	1.7523E-03
336.420	9.5976E-05	2.4205E+01	3.2447E-02
336.720	9.5873E-05	4.1474E+01	3.2769E-02
337.020	9.5770E-05	5.8725E+01	3.3029E-02
337.320	9.5667E-05	7.5958E+01	3.3237E-02
337.620	9.5563E-05	9.3172E+01	3.3402E-02
337.920	9.5461E-05	1.1037E+02	3.3531E-02
338.000	9.5433E-05	1.1495E+02	3.3561E-02
338.300	0.0000E+00	1.1496E+02	2.7684E-02
338.600	0.0000E+00	1.1496E+02	2.2837E-02
338.900	0.0000E+00	1.1496E+02	1.8838E-02
339.200	0.0000E+00	1.1497E+02	1.5539E-02
339.500	0.0000E+00	1.1497E+02	1.2818E-02
339.800	0.0000E+00	1.1497E+02	1.0574E-02
340.100	0.0000E+00	1.1497E+02	8.7224E-03
340.400	0.0000E+00	1.1498E+02	7.1951E-03
340.700	0.0000E+00	1.1498E+02	5.9353E-03
341.000	0.0000E+00	1.1498E+02	4.8960E-03
341.300	0.0000E+00	1.1498E+02	4.0387E-03
341.600	0.0000E+00	1.1498E+02	3.3315E-03
341.900	0.0000E+00	1.1498E+02	2.7482E-03
342.200	0.0000E+00	1.1498E+02	2.2670E-03
342.500	0.0000E+00	1.1498E+02	1.8700E-03
342.800	0.0000E+00	1.1498E+02	1.5426E-03
343.100	0.0000E+00	1.1498E+02	1.2725E-03
343.400	0.0000E+00	1.1498E+02	1.0497E-03
343.700	0.0000E+00	1.1498E+02	8.6586E-04
344.000	0.0000E+00	1.1498E+02	7.1425E-04
344.300	0.0000E+00	1.1498E+02	5.8917E-04
344.600	0.0000E+00	1.1498E+02	4.8600E-04
344.900	0.0000E+00	1.1498E+02	4.0089E-04
345.200	0.0000E+00	1.1498E+02	3.3069E-04
345.500	0.0000E+00	1.1498E+02	2.7278E-04
345.800	0.0000E+00	1.1498E+02	2.2501E-04
346.100	0.0000E+00	1.1498E+02	1.8561E-04
346.400	0.0000E+00	1.1498E+02	1.5311E-04
360.000	0.0000E+00	1.1498E+02	2.4820E-08
432.000	0.0000E+00	1.1498E+02	2.1150E-28
1056.000	0.0000E+00	1.1498E+02	2.4176-202

##
Cumulative Dose Summary
##

	EAB		LPZ		Control Room	
Time (hr)	Thyroid (rem)	TEDE (rem)	Thyroid (rem)	TEDE (rem)	Thyroid (rem)	TEDE (rem)
336.001	1.0364E-02	3.3780E-04	1.3650E-03	4.4489E-05	3.4690E-06	1.0600E-07
336.020	3.7421E-01	1.2196E-02	4.9284E-02	1.6063E-03	4.4823E-03	1.3696E-04
336.420	7.8558E+00	2.5604E-01	1.0346E+00	3.3720E-02	1.8171E+00	5.5525E-02
336.720	1.3461E+01	4.3871E-01	1.7728E+00	5.7779E-02	4.3195E+00	1.3199E-01
337.020	1.9060E+01	6.2118E-01	2.5102E+00	8.1811E-02	6.8441E+00	2.0913E-01
337.320	2.4653E+01	8.0345E-01	3.2468E+00	1.0582E-01	9.3866E+00	2.8682E-01
337.620	3.0240E+01	9.8552E-01	3.9827E+00	1.2979E-01	1.1943E+01	3.6494E-01
337.920	3.5821E+01	1.1674E+00	4.7177E+00	1.5375E-01	1.4511E+01	4.4341E-01
338.000	3.7308E+01	1.2158E+00	4.9136E+00	1.6013E-01	1.5198E+01	4.6438E-01
338.300	3.7310E+01	1.2159E+00	4.9138E+00	1.6014E-01	1.7541E+01	5.3598E-01
338.600	3.7312E+01	1.2160E+00	4.9140E+00	1.6014E-01	1.9474E+01	5.9504E-01
338.900	3.7313E+01	1.2160E+00	4.9142E+00	1.6015E-01	2.1068E+01	6.4376E-01
339.200	3.7314E+01	1.2160E+00	4.9143E+00	1.6015E-01	2.2383E+01	6.8395E-01
339.500	3.7315E+01	1.2161E+00	4.9144E+00	1.6016E-01	2.3468E+01	7.1710E-01
339.800	3.7316E+01	1.2161E+00	4.9145E+00	1.6016E-01	2.4363E+01	7.4445E-01
340.100	3.7316E+01	1.2161E+00	4.9146E+00	1.6016E-01	2.5102E+01	7.6700E-01
340.400	3.7317E+01	1.2161E+00	4.9147E+00	1.6017E-01	2.5711E+01	7.8561E-01
340.700	3.7317E+01	1.2161E+00	4.9147E+00	1.6017E-01	2.6213E+01	8.0096E-01
341.000	3.7318E+01	1.2161E+00	4.9148E+00	1.6017E-01	2.6627E+01	8.1362E-01
341.300	3.7318E+01	1.2162E+00	4.9148E+00	1.6017E-01	2.6969E+01	8.2407E-01
341.600	3.7318E+01	1.2162E+00	4.9148E+00	1.6017E-01	2.7251E+01	8.3268E-01
341.900	3.7318E+01	1.2162E+00	4.9149E+00	1.6017E-01	2.7484E+01	8.3979E-01
342.200	3.7318E+01	1.2162E+00	4.9149E+00	1.6017E-01	2.7676E+01	8.4565E-01
342.500	3.7319E+01	1.2162E+00	4.9149E+00	1.6017E-01	2.7834E+01	8.5049E-01
342.800	3.7319E+01	1.2162E+00	4.9149E+00	1.6017E-01	2.7965E+01	8.5448E-01
343.100	3.7319E+01	1.2162E+00	4.9149E+00	1.6017E-01	2.8072E+01	8.5777E-01
343.400	3.7319E+01	1.2162E+00	4.9149E+00	1.6017E-01	2.8161E+01	8.6048E-01
343.700	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8234E+01	8.6272E-01
344.000	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8295E+01	8.6457E-01
344.300	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8345E+01	8.6609E-01
344.600	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8386E+01	8.6735E-01
344.900	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8420E+01	8.6839E-01
345.200	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8448E+01	8.6924E-01
345.500	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8471E+01	8.6995E-01
345.800	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8490E+01	8.7053E-01
346.100	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8506E+01	8.7101E-01
346.400	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8519E+01	8.7141E-01
360.000	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8580E+01	8.7328E-01
432.000	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8580E+01	8.7328E-01
1056.000	3.7319E+01	1.2162E+00	4.9150E+00	1.6017E-01	2.8580E+01	8.7328E-01

```
######################################################################
                        Worst Two-Hour Doses
   Note: All of the dose locations are shown below but the
         worst two-hour dose is only meaningful for the EAB
         dose location.  Please disregard the two-hour worst
         doses for the other dose locations
######################################################################

EAB
   Time    Whole Body     Thyroid         TEDE
   (hr)      (rem)         (rem)          (rem)
  336.0   7.9963E-02   3.7298E+01   1.2155E+00

LPZ
   Time    Whole Body     Thyroid         TEDE
   (hr)      (rem)         (rem)          (rem)
  336.0   1.0531E-02   4.9122E+00   1.6008E-01

Control Room
   Time    Whole Body     Thyroid         TEDE
   (hr)      (rem)         (rem)          (rem)
  336.4   1.8224E-03   1.6459E+01   5.0291E-01
```

ATTACHMENT C - Water Dynamic and Kinematic Viscosity

The Engineering ToolBox
Home www.EngineeringToolBox.com
Resources, Tools and Basic Information for Engineering and Design of Technical Applications! - *adapts seamlessly to phones, pads and desktops!*

Search - *"the most efficient way to navigate the Engineering ToolBox!"*

Water - Dynamic and Kinematic Viscosity

Viscosity of water at temperatures between *0 - 100°C (32 - 212°F)* - in Imperial and SI Units

Dynamic (Absolute) and Kinematic Viscosity of Water in Imperial Units (BG units):

Temperature - t - (°F)	Dynamic Viscosity - μ - $(lb_f s/ft^2) \times 10^{-5}$	Kinematic Viscosity - ν - $(ft^2/s) \times 10^{-5}$
32	3.732	1.924
40	3.228	1.664
50	2.730	1.407
60	2.344	1.210
70	2.034	1.052
80	1.791	0.926
90	1.580	0.823
100	1.423	0.738
120	1.164	0.607
140	0.974	0.511
160	0.832	0.439
180	0.721	0.383
200	0.634	0.339
212	0.589	0.317

Dynamic (Absolute) and Kinematic Viscosity of Water in SI Units:

Temperature - t - (°C)	Dynamic Viscosity - μ - $(Pa\ s,\ N\ s/m^2) \times 10^{-3}$	Kinematic Viscosity - ν - $(m^2/s) \times 10^{-6}$
0	1.787	1.787
5	1.519	1.519
10	1.307	1.307
20	1.002	1.004
30	0.798	0.801
40	0.653	0.658
50	0.547	0.553
60	0.467	0.475
70	0.404	0.413
80	0.355	0.365
90	0.315	0.326
100	0.282	0.29

Related Mobile Apps from The Engineering ToolBox

- Kinematic Viscosity Converter App

ATTACHMENT D – Excel Spread Sheet Formula Views, Sections 10.2 through 10.4

Load Drop Max Lift

Gate Drop from Max Lift Height to Pool Floor 70'

Gate Length L	24.39	ft
Gate Width, d	4.771	ft
Gate thickness (reduced to obtain density greater than water)	0.275	ft
Gate weight, W	2000	lb
Gate density	=B5/(B2*B3*B4)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/s
water density/gate density	=B7/B6	
drop distance in air	7.3	ft
drop distance in water	37.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B10)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B12*B3)/B8	
Check L/d using gate length and width	=B2/B3	
Check L/D using gate width and thickness	=B3/B4	
Drag Coefficient CD	1.2	
Ao = width * thickness	=B3*B4	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B7*B16*B17)/(2*B5)	
b = (water density * g)/W	=(B7*32.17)/B5	
Terminal Velocity, V2 = SQRT((g*(1-density water/density gate)/a)	=((32.17/B18)*(1-B9))^0.5	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B18*B11)	
bAo	=B19*B17	
exp(2aL)	=EXP(2*B18*B2)	
2aL	=2*B18*B2	
V2^2	=B20^2	
Vo^2	=B12^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B22*(B23*(1-B24)-1)/(2*(B18^2))	
g*(exp(2aL) * wtr dens/gate dens -1)/a	=32.17*(B23*B9-1)/B18	
Z2x	=B25+(B21*(B27+B26+B28))	
Vs = (Zx)^0.5	=SQRT(B29)	ft/s
Convert impact area to equivalent diameter	=2*(((B17*144)/3.142)^0.5)	in
mass = weight/g	=B5/32.17	lb-s2/ft
thickness	**=((B34*B31^2/2)^(2/3))/(672*B33)**	in

Gate Drop from Max Lift Height to Cask Shelf 93' El

Gate Length L	24.39	ft
Gate Width, d	4.771	ft
Gate thickness	0.3958	ft
Gate weight, W	2000	lb
Gate density	=B42/(B39*B40*B41)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/s
water density/gate density	=B44/B43	
drop distance in air	7.3	ft
drop distance in water	14.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B47)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B49*B40)/B45	
Check L/d using gate length and width	=B39/B40	
Check L/D using gate width and thickness	=B40/B41	
Drag Coefficient CD	1.2	
Ao = width * thickness	=B40*B41	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B44*B53*B54)/(2*B42)	
b = (water density * g)/W	=(B44*32.17)/B42	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B55*B48)	
bAo	=B56*B54	
2ax	=2*B55*B48	
Vo^2	=B49^2	
g/a	=32.17/B55	
bAo*[(1-2ax)]/2a^2	=B58*((1-B59)/(2*(B55^2)))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B57*(B49^2-B61-(B58/(2*B55^2)))	
Z1x	=B61+B62+B63	
Vs = (Zx)^0.5	=SQRT(B64)	ft/s
Convert impact area to equivalent diameter	=2*(((B54*144)/3.142)^0.5)	in
mass = weight/g	=B42/32.17	lb-s2/ft
thickness	**=((B69*B66^2/2)^(2/3))/(672*B68)**	in

Gate Drop from Max Lift Height to Gate Opening

Gate Length L	24.39	ft
Gate Width, d	4.771	ft
Gate thickness	0.3958	ft
Gate weight, W	2000	lb
Gate density	=B77/(B74*B75*B76)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/s
water density/gate density	=B79/B78	
drop distance in air	7.3	ft
drop distance in water	19.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B82)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B84*B75)/B80	
Check L/d using gate length and width	=B74/B75	
Check L/D using gate width and thickness	=B75/B76	
Drag Coefficient CD	1.2	
Ao = width * thickness	=B75*B76	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B79*B88*B89)/(2*B77)	
b = (water density * g)/W	=(B79*32.17)/B77	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B90*B83)	
bAo	=B91*B89	
2ax	=2*B90*B83	
Vo^2	=B84^2	
g/a	=32.17/B90	
bAo*[(1-2ax)]/2a^2	=B93*(1-B94)/(2*(B90^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B92*(B84^2-B96-(B93/(2*B90^2)))	
Z1x	=B96+B97+B98	
Vs = (Zx)^0.5	=SQRT(B99)	ft/s
Convert impact area to equivalent diameter	=2*(((B89*144)/3.142)^0.5)	in
mass = weight/g	=B77/32.17	lb-s2/ft
thickness	**=((B104*B101^2/2)^(2/3))/(672*B103)**	in

Intermediate Beam Drop from Max Lift Height to Pool Floor 70'

Beam Length L	4.75	ft
Beam Width, d	0.4167	ft
Beam thickness	0.4167	ft
Beam weight, W	175	lb
Beam density	=B112/(B109*B110*B111)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B114/B113	
drop distance in air	32.3	ft
drop distance in water	37.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B117)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B119*B110)/B115	
Check L/d using beam length and width	=B109/B110	
Check L/D using beam width and thickness	1	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B110*B111	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B114*B123*B124)/(2*B112)	
b = (water density * g)/W	=(B114*32.17)/B112	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=((32.17/B125)*(1-B116))^0.5	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B125*B118)	
bAo	=B126*B124	
exp(2aL)	=EXP(2*B125*B109)	
2aL	=2*B125*B109	
V2^2	=B127^2	
Vo^2	=B119^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B129*(B130*(1-B131)-1)/(2*(B125^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B130*B116-1)/B125	
Z2x	=B132+(B128*(B134+B133+B135))	
Vs = (Zx)^0.5	=SQRT(B136)	ft/s
Convert impact area to equivalent diameter	=2*(((B124*144)/3.142)^0.5)	in
mass = weight/g	=B112/32.17	lb-s2/ft
thickness	**=((B141*B138^2/2)^(2/3))/(672*B140)**	in

Intermediate Beam Drop from Max Lift Height to to Cask Shelf 93' El

Beam Length L	4.75	ft
Beam Width, d	0.4167	ft
Beam thickness	0.4167	ft
Beam weight, W	175	lb
Beam density	=B149/(B146*B147*B148)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/s
water density/gate density	=B151/B150	
drop distance in air	32.3	ft
drop distance in water	14.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B154)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B156*B147)/B152	
Check L/d using beam length and width	=B146/B147	
Check L/D using beam width and thickness	1	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B147*B148	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B151*B160*B161)/(2*B149)	
b = (water density * g)/W	=(B151*32.17)/B149	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=((32.17/B162)*(1-B153))^0.5	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B162*B155)	
bAo	=B163*B161	
exp(2aL)	=EXP(2*B162*B146)	
2aL	=2*B162*B146	
V2^2	=B164^2	
Vo^2	=B156^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B166*(B167*(1-B168)-1)/(2*(B162^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B167*B153-1)/B162	
Z2x	=B169+(B165*(B171+B170+B172))	
Vs = (Zx)^0.5	=SQRT(B173)	ft/s
Convert impact area to equivalent diameter	=2*(((B161*144)/3.142)^0.5)	in
mass = weight/g	=B149/32.17	lb-s2/ft
thickness	**=((B178*B175^2/2)^(2/3))/(672*B177)**	in

Intermediate Beam Drop from Max Lift Height to to Gate Opening 88'

Beam Length L	4.75	ft
Beam Width, d	0.4167	ft
Beam thickness	0.4167	ft
Beam weight, W	175	lb
Beam density	=B186/(B183*B184*B185)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/s
water density/gate density	=B188/B187	
drop distance in air	32.3	ft
drop distance in water	19.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B191)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B193*B184)/B189	
Check L/d using beam length and width	=B183/B184	
Check L/D using beam width and thickness	=B184/B185	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B184*B185	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B188*B197*B198)/(2*B186)	
b = (water density * g)/W	=(B188*32.17)/B186	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=((32.17/B199)*(1-B190))^0.5	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B199*B192)	
bAo	=B200*B198	
exp(2aL)	=EXP(2*B199*B183)	
2aL	=2*B199*B183	
V2^2	=B201^2	
Vo^2	=B193^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B203*(B204*(1-B205)-1)/(2*(B199^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B204*B190-1)/B199	
Z2x	=B206+(B202*(B208+B207+B209))	
Vs = (Zx)^0.5	=SQRT(B210)	ft/s
Convert impact area to equivalent diameter	=2*(((B198*144)/3.142)^0.5)	in
mass = weight/g	=B186/32.17	lb-s2/ft
thickness	**=((B215*B212^2/2)^(2/3))/(672*B214)**	in

Alternate Beam Drop from Max Lift Height to Pool Floor 70'

Beam Length L	12	ft
Beam Width, d	0.5	ft
Beam thickness	0.333	ft
Beam weight, W	200	lb
Beam density	=B223/(B220*B221*B222)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B225/B224	
drop distance in air	40.3	ft
drop distance in water	37.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B228)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B230*B221)/B226	
Check L/d using beam length and width	=B220/B221	
Check L/D using beam width and thickness	=B221/B222	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B221*B222	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B225*B234*B235)/(2*B223)	
b = (water density * g)/W	=(B225*32.17)/B223	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=((32.17/B236)*(1-B227))^0.5	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B236*B229)	
bAo	=B237*B235	
exp(2aL)	=EXP(2*B236*B220)	
2aL	=2*B236*B220	
V2^2	=B238^2	
Vo^2	=B230^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B240*(B241*(1-B242)-1)/(2*(B236^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B241*B227-1)/B236	
Z2x	=B243+(B239*(B245+B244+B246))	
Vs = (Zx)^0.5	=SQRT(B247)	ft/s
Convert impact area to equivalent diameter	=2*(((B235*144)/3.142)^0.5)	in
mass = weight/g	=B223/32.17	lb-s2/ft
thickness	**=((B252*B249^2/2)^(2/3))/(672*B251)**	in

Alternate Beam Drop from Max Lift Height to to Cask Shelf 93' El

Beam Length L	12	ft
Beam Width, d	0.5	ft
Beam thickness	0.333	ft
Beam weight, W	200	lb
Beam density	=B260/(B257*B258*B259)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B262/B261	
drop distance in air	40.3	ft
drop distance in water	14.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B265)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B267*B258)/B263	
Check L/d using beam length and width	=B257/B258	
Check L/D using beam width and thickness	=B258/B259	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B258*B259	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B262*B271*B272)/(2*B260)	
b = (water density * g)/W	=(B262*32.17)/B260	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=((32.17/B273)*(1-B264))^0.5	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B273*B266)	
bAo	=B274*B272	
exp(2aL)	=EXP(2*B273*B257)	
2aL	=2*B273*B257	
V2^2	=B275^2	
Vo^2	=B267^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B277*(B278*(1-B279)-1)/(2*(B273^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B278*B264-1)/B273	
Z2x	=B280+(B276*(B282+B281+B283))	
Vs = (Zx)^0.5	=SQRT(B284)	ft/s
Convert impact area to equivalent diameter	=2*(((B272*144)/3.142)^0.5)	in
mass = weight/g	=B260/32.17	lb-s2/ft
thickness	**=((B289*B286^2/2)^(2/3))/(672*B288)**	in

Alternate Beam Drop from Max Lift Height to to Gate Opening 88'

Beam Length L	12	ft
Beam Width, d	0.5	ft
Beam thickness	0.333	ft
Beam weight, W	200	lb
Beam density	=B297/(B294*B295*B296)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B299/B298	
drop distance in air	40.3	ft
drop distance in water	19.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B302)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B304*B295)/B300	
Check L/d using beam length and width	=B294/B295	
Check L/D using beam width and thickness	=B295/B296	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B295*B296	ft2
a ≈ (water density * Drag Coeff * Ao)/ (2*W)	=(B299*B308*B309)/(2*B297)	
b ≈ (water density * g)/W	=(B299*32.17)/B297	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=((32.17/B310)*(1-B301))^0.5	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B310*B303)	
bAo	=B311*B309	
exp(2aL)	=EXP(2*B310*B294)	
2aL	=2*B310*B294	
V2^2	=B312^2	
Vo^2	=B304^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B314*(B315*(1-B316)-1)/(2*(B310^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B315*B301-1)/B310	
Z2x	=B317+(B313*(B319+B318+B320))	
Vs = (Zx)^0.5	=SQRT(B321)	ft/s
Convert impact area to equivalent diameter	=2*(((B309*144)/3.142)^0.5)	in
mass = weight/g	=B297/32.17	lb-s2/ft
thickness	**=((B326*B323^2/2)^(2/3))/(672*B325)**	in

Load Drop in Pool

Gate Drop to Pool Floor		
Gate Length L	24.39	ft
Gate Width, d	4.771	ft
Gate thickness	0.3958	ft
Gate weight, W	2000	lb
Gate density	=B5/(B2*B3*B4)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B7/B6	
drop distance in air	0	ft
drop distance in water	20	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B10)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B12*B3)/B8	
Check L/d using gate length and width	=B2/B3	
Check L/D using gate width and thickness	=B3/B4	
Drag Coefficient CD	1	
*Ao = width * thickness*	=B3*B4	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B7*B16*B17)/(2*B5)	
b = (water density * g)/W	=(B7*32.17)/B5	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B18*B11)	
bAo	=B19*B17	
2ax	=2*B18*B11	
Vo^2	=B12^2	
g/a	=32.17/B18	
bAo*[(1-2ax)]/2a^2	=B21*(1-B22)/(2*(B18^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B20*(B12^2-B24-(B21/(2*B18^2)))	
Z1x	=B24+B25+B26	
Vs = (Zx)^0.5	=SQRT(B27)	ft/s
Convert impact area to equivalent diameter	=2*(((B17*144)/3.142)^0.5)	in
mass = weight/g	=B5/32.17	lb-s2/ft
thickness	=((B32*B29^2/2)^(2/3))/(672*B31)	in

Gate Drop in Gate Opening		
Gate Length L	24.39	ft
Gate Width, d	4.771	ft
Gate thickness	0.3958	ft
Gate weight, W	2000	lb
Gate density	=B39/(B36*B37*B38)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B41/B40	
drop distance in air	0	ft
drop distance in water	2	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B44)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B46*B37)/B42	
Check L/d using gate length and width	=B36/B37	
Check L/D using gate width and thickness	=B37/B38	
Drag Coefficient CD	1	
Ao = width * thickness	=B37*B38	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B41*B50*B51)/(2*B39)	
b = (water density * g)/W	=(B41*32.17)/B39	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B52*B45)	
bAo	=B53*B51	
2ax	=2*B52*B45	
Vo^2	=B46^2	
g/a	=32.17/B52	
bAo*[(1-2ax)]/2a^2	=B55*(1-B56)/(2*(B52^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B54*(B46^2-B58-(B55/(2*B52^2)))	
Z1x	=B58+B59+B60	
Vs = (Zx)^0.5	=SQRT(B61)	ft/s
Convert impact area to equivalent diameter	=2*(((B51*144)/3.142)^0.5)	in
mass = weight/g	=B39/32.17	lb-s2/ft
thickness	=((B66*B63^2/2)^(2/3))/(672*B65)	in

Intermediate Beam Drop to Pool Floor		
Beam Length L	4.75	ft
Beam Width, d	0.4167	ft
Beam thickness	0.4167	ft
Beam weight, W	175	lb
Beam density	=B74/(B71*B72*B73)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B76/B75	
drop distance in air	7.3	ft
drop distance in water	37.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B79)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B81*B72)/B77	
Check L/d using beam length and width	=B71/B72	
Check L/D using beam width and thickness	=B72/B73	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B72*B73	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B76*B85*B86)/(2*B74)	
b = (water density * g)/W	=(B76*32.17)/B74	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=SQRT((32.17*((1-B78)/B87))	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B87*B80)	
bAo	=B88*B86	
exp(2aL)	=EXP(2*B87*B71)	
2aL	=2*B87*B71	
V2^2	=B89^2	
Vo^2	=B81^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B91*(B92*(1-B93)-1)/(2*(B87^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B92*B78-1)/B87	
Z2x	=B94+(B90*(B96+B95+B98))	
Vs = (Zx)^0.5	=SQRT(B99)	ft/s
Convert impact area to equivalent diameter	=2*(((B86*144)/3.142)^0.5)	in
mass = weight/g	=B74/32.17	lb-s2/ft
thickness	**=((B104*B101^2/2)^(2/3))/(672*B103)**	in

Intermediate Beam Drop to Gate Opening		
Beam Length L	4.75	ft
Beam Width, d	0.4167	ft
Beam thickness	0.4167	ft
Beam weight, W	175	lb
Beam density	=B112/(B109*B110*B111)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B114/B113	
drop distance in air	7.3	ft
drop distance in water	19.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B117)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B119*B110)/B115	
Check L/d using beam length and width	=B109/B110	
Check L/D using beam width and thickness	=B110/B111	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B110*B111	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B114*B123*B124)/(2*B112)	
b = (water density * g)/W	=(B114*32.17)/B112	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=SQRT((32.17*((1-B116)/B125)))	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B125*B118)	
bAo	=B126*B124	
exp(2aL)	=EXP(2*B125*B109)	
2aL	=2*B125*B109	
V2^2	=B127^2	
Vo^2	=B119^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B129*(B130*(1-B131)-1)/(2*(B125^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B130*B116-1)/B125	
Z2x	=B132+(B128*(B134+B133+B135))	
Vs = (Zx)^0.5	=SQRT(B136)	ft/s
Convert impact area to equivalent diameter	=2*(((B124*144)/3.142)^0.5)	in
mass = weight/g	=B112/32.17	lb-s2/ft
thickness	**=((B141*B138^2/2)^(2/3))/(672*B140)**	in

Alternate Beam Drop to Pool Floor

Beam Length L	12	ft
Beam Width, d	0.5	ft
Beam thickness	0.333	ft
Beam weight, W	200	lb
Beam density	=B149/(B146*B147*B148)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B151/B150	
drop distance in air	15.3	ft
drop distance in water	37.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B154)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B156*B147)/B152	
Check L/d using beam length and width	=B146/B147	
Check L/D using beam width and thickness	=B147/B148	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B147*B148	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B151*B160*B161)/(2*B149)	
b = (water density * g)/W	=(B151*32.17)/B149	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=SQRT((32.17*((1-B153)/B162))	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B162*B155)	
bAo	=B163*B161	
exp(2aL)	=EXP(2*B162*B146)	
2aL	=2*B162*B146	
V2^2	=B164^2	
Vo^2	=B156^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B166*(B167*(1-B168)-1)/(2*(B162^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B167*B153-1)/B162	
Z2x	=B169+(B165*(B171+B170+B172))	
Vs = (Zx)^0.5	=SQRT(B173)	ft/s
Convert impact area to equivalent diameter	=2*(((B161*144)/3.142)^0.5)	in
mass = weight/g	=B149/32.17	lb-s2/ft
thickness	**=((B178*B175^2/2)^(2/3))/(672*B177)**	in

Alternate Beam Drop to Gate Opening		
Beam Length L	12	ft
Beam Width, d	0.5	ft
Beam thickness	0.333	ft
Beam weight, W	200	lb
Beam density	=B186/(B183*B184*B185)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B188/B187	
drop distance in air	15.3	ft
drop distance in water	19.7	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B191)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B193*B184)/B189	
Check L/d using beam length and width	=B183/B184	
Check L/D using beam width and thickness	=B184/B185	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B184*B185	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B188*B197*B198)/(2*B186)	
b = (water density * g)/W	=(B188*32.17)/B186	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=SQRT((32.17*(1-B190)/B199))	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B199*B192)	
bAo	=B200*B198	
exp(2aL)	=EXP(2*B199*B183)	
2aL	=2*B199*B183	
V2^2	=B201^2	
Vo^2	=B193^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B203*(B204*(1-B205)-1)/(2*(B199^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B204*B190-1)/B199	
Z2x	=B206+(B202*(B208+B207+B209))	
Vs = (Zx)^0.5	=SQRT(B210)	ft/s
Convert impact area to equivalent diameter	=2*(((B198*144)/3.142)^0.5)	in
mass = weight/g	=B186/32.17	lb-s2/ft
thickness	**=((B215*B212^2/2)^(2/3))/(672*B214)**	in

Load Drop to Racks

Gate Drop to Racks		
Gate Length L	24.39	ft
Gate Width, d	4.771	ft
Gate thickness	0.3958	ft
Gate weight, W	2000	lb
Gate density	=B5/(B2*B3*B4)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B7/B6	
drop distance in air	0	ft
drop distance in water	5.14	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B10)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B12*B3)/B8	
Check L/d using gate length and width	=B2/B3	
Check L/D using gate width and thickness	=B3/B4	
Drag Coefficient CD	1	
Ao = width * thickness	=B3*B4	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B7*B16*B17)/(2*B5)	
b = (water density * g)/W	=(B7*32.17)/B5	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B18*B11)	
bAo	=B19*B17	
2ax	=2*B18*B11	
Vo^2	=B12^2	
g/a	=32.17/B18	
bAo*[(1-2ax)]/2a^2	=B21*(1-B22)/(2*(B18^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B20*(B12^2-B24-(B21/(2*B18^2)))	
Z1x	=B24+B25+B26	
Vs = (Zx)^0.5	**=SQRT(B27)**	ft/s

Intermediate Beam Drop to Racks		
Beam Length L	4.75	ft
Beam Width, d	0.4167	ft
Beam thickness	0.4167	ft
Beam weight, W	175	lb
Beam density	=B35/(B32*B33*B34)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/beam density	=B37/B36	
drop distance in air	7.3	ft
drop distance in water	22.841	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B40)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B42*B33)/B38	
Check L/d using beam length and width	=B32/B33	
Check L/D using beam width and thickness	=B33/B34	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B33*B34	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B37*B46*B47)/(2*B35)	
b = (water density * g)/W	=(B37*32.17)/B35	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=SQRT((32.17*(1-B39)/B48))	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B48*B41)	
bAo	=B49*B47	
exp(2aL)	=EXP(2*B48*B32)	
2aL	=2*B48*B32	
V2^2	=B50^2	
Vo^2	=B42^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B52*(B53*(1-B54)-1)/(2*(B48^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B53*B39-1)/B48	
Z2x	=B55+(B51*(B57+B56+B58))	
Vs = (Zx)^0.5	**=SQRT(B59)**	ft/s

Alternate Beam Drop to Racks

Beam Length L	12	ft
Beam Width, d	0.5	ft
Beam thickness	0.333	ft
Beam weight, W	200	lb
Beam density	=B68/(B65*B66*B67)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/beam density	=B70/B69	
drop distance in air	15.3	ft
drop distance in water	22.84	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B73)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B75*B66)/B71	
Check L/d using beam length and width	=B65/B66	
Check L/D using beam width and thickness	=B66/B67	
Drag Coefficient CD	1.16	
Ao = width * thickness	=B66*B67	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B70*B79*B80)/(2*B68)	
b = (water density * g)/W	=(B70*32.17)/B68	
Terminal Velocity, V2 = SQRT((g*(1-density water/density beam)/a)	=SQRT((32.17*(1-B72)/B81))	ft/s
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B81*B74)	
bAo	=B82*B80	
exp(2aL)	=EXP(2*B81*B65)	
2aL	=2*B81*B65	
V2^2	=B83^2	
Vo^2	=B75^2	
bAo*[exp(2aL)*(1-2aL)-1]/2a^2	=B85*(B86*(1-B87)-1)/(2*(B81^2))	
g*(exp(2aL) * wtr dens/beam dens -1)/a	=32.17*(B86*B72-1)/B81	
Z2x	=B88+(B84*(B90+B89+B91))	
Vs = (Zx)^0.5	**=SQRT(B92)**	ft/s

Gate Tip On Piping Velocity Cases

Gate Tip Onto Piping SFC-012-001-3		
Gate Length L	4.771	ft
Gate Width, d	24.39	ft
Gate thickness	0.396	ft
Gate weight, W	2000	lb
Gate density	=B5/(B2*B3*B4)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B7/B6	
drop distance in air	0	ft
drop distance in water	1.28	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B10)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B12*B3)/B8	
Check L/d using gate length and width	=B2/B3	
Check L/D using gate width and thickness	=B3/B4	
Drag Coefficient CD	1	
Ao = width * thickness	=B3*B4	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B7*B16*B17)/(2*B5)	
b = (water density * g)/W	=(B7*32.17)/B5	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B18*B11)	
bAo	=B19*B17	
2ax	=2*B18*B11	
Vo^2	=B12^2	
g/a	=32.17/B18	
bAo*[(1-2ax)]/2a^2	=B21*(1-B22)/(2*(B18^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B20*(B12^2-B24-(B21/(2*B18^2)))	
Z1x	=B24+B25+B26	
Vs = (Zx)^0.5	**=SQRT(B27)**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	=B5/32.17	lb-s2/ft
thickness	=((B32*B29^2/2)^(2/3))/(672*B31)	in

Gate Tip On Piping SFC-012-014-3		
Gate Length L	4.771	ft
Gate Width, d	24.39	ft
Gate thickness	0.396	ft
Gate weight, W	2000	lb
Gate density	=B39/(B36*B37*B38)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B41/B40	
drop distance in air	0	ft
drop distance in water	2.105	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B44)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B46*B37)/B42	
Check L/d using gate length and width	=B36/B37	
Check L/D using gate width and thickness	=B37/B38	
Drag Coefficient CD	1	
Ao = width * thickness	=B37*B38	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B41*B50*B51)/(2*B39)	
b = (water density * g)/W	=(B41*32.17)/B39	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B52*B45)	
bAo	=B53*B51	
2ax	=2*B52*B45	
Vo^2	=B46^2	
g/a	=32.17/B52	
bAo*[(1-2ax)]/2a^2	=B55*(1-B56)/(2*(B52^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B54*(B46^2-B58-(B55/(2*B52^2)))	
Z1x	=B58+B59+B60	
Vs = (Zx)^0.5	**=SQRT(B61)**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	=B39/32.17	lb-s2/ft
thickness	=((B66*B63^2/2)^(2/3))/(672*B65)	in

Gate Tip On Piping SFC-012-006-3		
Gate Length L	4.771	ft
Gate Width, d	24.39	ft
Gate thickness	0.396	ft
Gate weight, W	2000	lb
Gate density	=B74/(B71*B72*B73)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B76/B75	
drop distance in air	0	ft
drop distance in water	3.555	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B79)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B81*B72)/B77	
Check L/d using gate length and width	=B71/B72	
Check L/D using gate width and thickness	=B72/B73	
Drag Coefficient CD	1	
Ao = width * thickness	=B72*B73	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B76*B85*B86)/(2*B74)	
b = (water density * g)/W	=(B76*32.17)/B74	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B87*B80)	
bAo	=B88*B86	
2ax	=2*B87*B80	
Vo^2	=B81^2	
g/a	=32.17/B87	
bAo*[(1-2ax)]/2a^2	=B90*(1-B91)/(2*(B87^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B89*(B81^2-B93-(B90/(2*B87^2)))	
Z1x	=B93+B94+B95	
Vs = (Zx)^0.5	**=SQRT(B96)**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	=B74/32.17	lb-s2/ft
thickness	=((B101*B98^2/2)^(2/3))/(672*B100)	in

Gate Tip On Piping SFC-012-007-3		
Gate Length L	4.771	ft
Gate Width, d	24.39	ft
Gate thickness	0.396	ft
Gate weight, W	2000	lb
Gate density	=B109/(B106*B107*B108)	lb/cu ft
water density @ 160F	60.994	lb/ cu ft
water kinematic viscosity @ 160F	0.00000439	sq ft/sec
water density/gate density	=B111/B110	
drop distance in air	0	ft
drop distance in water	4.72	ft
Vo where h is drop distance in air, V = (2gh)^2	=SQRT(2*32.17*B114)	ft/s
Reynolds no =(Vo * d)/viscosity	=(B116*B107)/B112	
Check L/d using gate length and width	=B106/B107	
Check L/D using gate width and thickness	=B107/B108	
Drag Coefficient CD	1	
Ao = width * thickness	=B107*B108	ft2
a = (water density * Drag Coeff * Ao)/ (2*W)	=(B111*B120*B121)/(2*B109)	
b = (water density * g)/W	=(B111*32.17)/B109	
exp(-2*a*x) where x = drop distance in water	=EXP(-2*B122*B115)	
bAo	=B123*B121	
2ax	=2*B122*B115	
Vo^2	=B116^2	
g/a	=32.17/B122	
bAo*[(1-2ax)]/2a^2	=B125*(1-B126)/(2*(B122^2))	
exp(-2ax) *[(Vo^2-(g/a)-(bAo/2*a^2)]	=B124*(B116^2-B128-(B125/(2*B122^2)))	
Z1x	=B128+B129+B130	
Vs = (Zx)^0.5	**=SQRT(B131)**	ft/s
Convert impact area to equivalent diameter	1.596	in
mass = weight/g	=B109/32.17	lb-s2/ft
thickness	=((B136*B133^2/2)^(2/3))/(672*B135)	in

Piping Yield and Ductility Ratio

Line SFC-012-001		
g	32.174	ft/s2
mass per length	49.56	lb/ft length
Dx = 2 in	=2/12	ft
d = 12.75 in	=12.75/12	ft
(Dx+2d)	=B4+(2*B5)	ft
Me = (Dx+2d)*Mx	=(B6*B3)/B2	lb
Mm = 2000/g	=2000/B2	lb
Impact velocity	7.407	ft/s
Vs	=B10*12	in/s
Es = Mm2*Vs2/2(Mm+Me)	=(B9^2*B11^2)/(2*(B9+B7))	
I	279.3	in4
E	27700000	lb/in2
fdy	30000	lb/in2
length, ft	24	ft
L	=B17*12	in
Rm = 8*I*fdy/(L*d)	=(8*B14*B16)/(B18*12.75)	lb
xe = RmL^3/48EI	=(B19*B18^3)/(48*B15*B14)	in
mu	=B12/(B21*B19) + 0.5	

Line SFC-012-014

g	32.174	ft/s2
mass per length	49.56	lb/ft length
Dx = 2 in	=2/12	ft
d = 12.75 in	=12.75/12	ft
(Dx+2d)	=B30+(2*B31)	ft
Me = (Dx+2d)*Mx	=(B32*B29)/B28	lb
Mm = 2000/g	=2000/B28	lb
Impact velocity	8.15	ft/s
Vs	=B36*12	in/s
Es = Mm2*Vs2/2(Mm+Me)	=(B35^2*B37^2)/(2*(B35+B33))	
I	279.3	in4
E	27700000	lb/in2
fdy	30000	lb/in2
length, ft	24	ft
L	=B43*12	in
Rm = 8*I*fdy/(L*d)	=(8*B40*B42)/(B44*12.75)	
xe = RmL^3/48EI	=(B45*B44^3)/(48*B41*B40)	
mu	=B38/(B47*B45)+0.5	

Line SFC-012-006

g	32.174	ft/s2
mass per length	49.56	lb/ft length
Dx = 2 in	=2/12	ft
d = 12.75 in	=12.75/12	ft
(Dx+2d)	=B56+(2*B57)	ft
Me = (Dx+2d)*Mx	=(B58*B55)/B54	lb
Mm = 2000/g	=2000/B54	lb
Impact velocity	7.404	ft/s
Vs	=B62*12	in/s
Es = Mm2*Vs2/2(Mm+Me)	=(B61^2*B63^2)/(2*(B61+B59))	
I	279.3	in4
E	27700000	lb/in2
fdy	30000	lb/in2
length, ft	18	ft
L	=B69*12	in
Rm = 8*I*fdy/(L*d)	=(8*B66*B68)/(B70*12.75)	
xe = RmL^3/48EI	=(B71*B70^3)/(48*B67*B66)	
mu	=B64/(B73*B71)+0.5	

Line SFC-012-007		
g	32.174	ft/s2
mass per length	49.56	lb/ft length
Dx = 2 in	=2/12	ft
d = 12.75 in	=12.75/12	ft
(Dx+2d)	=B82+(2*B83)	ft
Me = (Dx+2d)*Mx	=(B84*B81)/B80	lb
Mm = 2000/g	=2000/B80	lb
Impact velocity	4.94	ft/s
Vs	=B88*12	in/s
Es = Mm2*Vs2/2(Mm+Me)	=(B87^2*B89^2)/(2*(B87+B85))	
I	279.3	in4
E	27700000	lb/in2
fdy	30000	lb/in2
length, ft	18	ft
L	=B95*12	in
Rm = 8*I*fdy/(L*d)	=(8*B92*B94)/(B96*12.75)	
xe = RmL^3/48EI	=(B97*B96^3)/(48*B93*B92)	
mu	=B90/(B99*B97)+0.5	

Attachment 3
RBG-47505

Licensee Commitment
(1 page)

This table identifies actions discussed in this letter for which Entergy commits to perform. Any other actions discussed in this submittal are described for the NRC's information and are not commitments.

COMMITMENT	TYPE (Check one)		SCHEDULED COMPLETION DATE (If Required)
	ONE-TIME ACTION	CONTINUING COMPLIANCE	
During movement of pool gates, no fuel in the affected pools will have been part of a critical core within the preceding 14 days.		x	Upon implementation of this amendment