Approved 9-28-99 Effective 10-5-99

CALCULATION TITLE PAGE

Total Number of Pages: 62

MP3- Fuel Handling Accident In Containment - 10 Minute Closure Time

TITLE

M3FHA-01791-R3	0	NA
CALCULATION No.	**Revision No.**	**System Name**

NA	NA	NA	NA
VENDOR CALCULATION No.	**Structure**	**System Number**	**Component**

NA
VENDOR NAME

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NUCLEAR INDICATOR:	Safety Evaluation or Screen Attached	Calc. Supports DCR/MMOD?	Calc. Supports Other Process?
☒CAT1 ☐RWQA ☐SBOQA ☐FPQA ☐ATWSQA ☐NON-QA	☐YES ☒NO	☐YES ☒NO	☒YES ☐NO

NA	TSCR 3-6-00
DCR/MMOD No.	**Reference**

INCORPORATES:

CCN NO:	AGAINST REV.
NA	NA

Executive Summary

This calculation will support a TSCR which will allow the MP3 personnel hatch to be open during fuel movement in containment. Since this will support a TSCR, a safety screen and safety evaluation are not necessary. The dose summary is listed below.

	Beta Dose, rem	Thyroid dose, rem	Whole Body Dose, rem
EAB	NA	6.81E+01	2.80E-01
LPZ	NA	3.66E+00	1.50E-02
MP3 Control Room Totals	3.44E-01	2.44E+01	3.21E-01
MP2 Control Room Totals	5.30E+00	9.18E+00	1.76E-01
TSC Totals	3.28E+00	2.44E+01	5.70E-01

The doses associated with an MP3 FHA in containment, assuming 1)failure of 1 fuel bundle plus 50 rods, and 2) containment closure within 10 minutes of initiation of a FHA, are within GDC 19 requirements for the control room (<5 rem whole body or equivalent) and "well within" 10 CFR 100 requirements as defined by SRP 15.7.4 of 75 rem - thyroid and 6 rem - whole body.

Approvals (Print & Sign Name)		
Preparer: S. M. Torf		Date: 5/30/00
Interdiscipline Reviewer: NA	Discipline:	Date:
Interdiscipline Reviewer :NA	Discipline:	Date:
Independent Reviewer: K. R. Ju/ W. J. Eakin		Date: 5/31/00
Supervisor: M.S. Kai /		Date: 5/31/00

Installation Verification

☐ Calculation represents the installed configuration and approved licensing condition (Calculation of Record)

☐ N/A does not affect plant configuration (e.g., study, hypothetical analysis, etc.)

Preparer/Designer Engineer: (Print and Sign) Date:

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PassPort DATABASE INPUTs

Page 2

Calculation Number: M3FHA-01791-R3 Revision: 0

Vendor Calculation Number/Other: NA Revision: NA

CCN # NA QA ☒ Yes ☐ No Calc Voided: ☐ Yes ☒ No

Superseded By: NA Supersedes Calc: NA

Discipline (Up to 10) Z

Unit (M1, M2, M3)	Project Reference (EWA, DCR or MMOD)	Component Id	Computer Code	Rev. No./ Level No.
M3	NA	NA	TACT III	83.0
			CRADLE	82.2

PMMS CODES*					
Structure	System	Component	Reference Calculation	Rev No.	CCN
NA	NA	NA	PR-194	0	NA
			UR(B)-450	0	1
			WM(B)-06	0	NA
			WM(B)-04	0	NA
			XX-XXX-37RA	2	NA
			UR(B)-453	0	1
			M2M3CR-01671R3	0	NA
			UR(B)-451	0	NA
			3-ENG-244	1	NA

*The codes required must be alpha codes designed for structure, system and component.

Reference Drawing	Sheet	Rev. No.
12179-EM-156A	1	5
12179-EM-2D-13	1	13

Comments:

NA

NOTE: Avoid multiple item references on a line, e.g., LT 1210 A-D requires four separate lines.

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1. PURPOSE

The purpose of this calculation is to determine the dose consequences of a fuel handling accident (FHA) in containment assuming the personnel hatch is open but can be closed within 10 minutes of initiation of the FHA.

This calculation supports AR # 99014682-04. It also supports a proposed Technical Specification change that will allow the personnel hatch to remain open during fuel movement provided that containment can be closed within 10 minutes of a fuel handling accident. In addition, this calculation will address AR # 98020342-52 which questions the adequacy of the iodine DF used in the fuel pools if less than 23' of water is over the fuel.

2. SUMMARY OF RESULTS

The MP3 Control Room, EAB and LPZ doses are summarized below along with the MP2 Control Room and TSC doses. Table A provides the dose consequences associated with failure of 1 fuel bundle. Table B provides the dose consequences of Table A with a 25% margin factored in which encompasses a total fuel failure of 1 bundle plus 50 additional rods.

The intent of this calculation is to show that a 10 minute closure requirement for the containment, including personnel hatch will ensure that GDC19, Reg. Guide 1.25, and SRP 15.7.4 dose limits are met. It should be noted that the dose modeling for the control rooms and TSC assume a full 2 hour release of activity with no requirement for personnel hatch closure, whereas offsite doses are determined based upon a 10 minute containment closure requirement.

TABLE A - Dose Consequences from Failure of 1 Fuel Bundle

	Beta Dose, rem	Thyroid dose, rem	Whole Body Dose, rem
EAB	NA	5.45E+01	2.24E-01
LPZ	NA	2.93E+00	1.20E-02
MP3 Control Room - Aux Bldg/ Vent path - submersion & inhalation	2.75E-01	1.95E+01	1.74E-01
Plume shine component	na	na	6.00E-03
Filter shine component	na	na	7.60E-02
MP3 Control Room Totals - Vent Release	2.75E-01	1.95E+01	2.56E-01
MP3 Control Room -CTMT/ ground path - inhalation & submersion	2.31E-01	1.75E+01	1.47E-02
Plume shine component	na	na	5.00E-03
Filter shine component	na	na	7.60E-02
MP3 Control Room Totals - Ground Release	2.31E-01	1.75E+01	9.57E-02
MP2 Control Room - Aux Bldg/ Vent path - submersion & inhalation	4.24E+00	7.34E+00	1.38E-01
Plume shine component	na	na	2.00E-03
Filter shine component	na	na	6.00E-04
MP2 Control Room Totals	4.24E+00	7.34E+00	1.41E-01
TSC	2.62E+00	1.95E+01	8.49E-02
Plume shine component	na	na	2.00E-01
Filter shine component	na	na	1.71E-01
TSC Totals	2.62E+00	1.95E+01	4.56E-01

TABLE B - Dose Consequences from Failure of 1 Fuel Bundle plus 50 Rods plus margin (Equivalent to Table A * 1.25)

	Beta Dose, rem	Thyroid dose, rem	Whole Body Dose, rem
EAB	NA	6.81E+01	2.80E-01
LPZ	NA	3.66E+00	1.50E-02
MP3 Control Room - Aux Bldg/ Vent path - submersion & inhalation	3.44E-01	2.44E+01	2.18E-01
Plume shine component	na	na	7.50E-03
Filter shine component	na	na	9.50E-02
MP3 Control Room Totals - Vent Release	3.44E-01	2.44E+01	3.21E-01
MP3 Control Room -CTMT/ ground path - inhalation & submersion	2.89E-01	2.19E+01	1.84E-02
Plume shine component	na	na	6.25E-03
Filter shine component	na	na	9.50E-02
MP3 Control Room Totals - Ground Release	2.89E-01	2.19E+01	1.20E-01
MP2 Control Room - Aux Bldg/ Vent path - submersion & inhalation	5.30E+00	9.18E+00	1.73E-01
Plume shine component	na	na	2.50E-03
Filter shine component	na	na	7.50E-04
MP2 Control Room Totals	5.30E+00	9.18E+00	1.76E-01
TSC	3.28E+00	2.44E+01	1.06E-01
Plume shine component	na	na	2.50E-01
Filter shine component	na	na	2.14E-01
TSC Totals	3.28E+00	2.44E+01	5.70E-01

The doses associated with an MP3 FHA in containment, assuming containment closure within 10 minutes of initiation of a FHA are within GDC 19 requirements for the control room (less than 5 rem whole body or equivalent) and "well within" 10 CFR 100 requirements as defined by SRP 15.7.4 (Radiological Consequences of a Fuel Handling Accident) of 75 rem - thyroid and 6 rem - whole body. The doses in Table B bound the worst case fuel failure of 1 complete bundle plus 50 rods from another.

The offsite dose determinations evaluated both ground and vent release pathways. The dose determinations for both pathways are very similar, but the EAB thyroid dose associated with the ground release was the most challenging relative to the SRP 15.7.4 limits. Therefore the bounding release pathway for offsite dose consequences is via the ground release.

The bounding control room dose is based on the release pathway from MP3 containment to the Auxiliary Building and subsequently exhausted to the environment via the Ventilation Vent. The basis for this release path being bounding is due to the thyroid dose. *(It should be noted that the control room and TSC calculations took no credit for containment closure after 10 minutes, but assumed a full 2 hour release consistent with Reg. Guide 1.25. It was later identified that offsite dose was limiting based on a 2 hour release and therefore was recalculated and limited to a 10 minute release from containment, but the control room and TSC determinations still use the 2 hour release which is conservative.)*

In addition, the impact on iodine DF due to reduced pool water height above a dropped fuel bundle is discussed. Regulatory Guide 1.25 allows use of a DF of 100 provided there is 23 feet of water over the bundle. In the event that a bundle is lying on the pool floor, the water height may be reduced by as much as 1 foot because of the dimensions of the bundle, leaving 22 feet of coverage instead of 23 feet. Based on the results of this calculation, the resultant DF for 22 feet of water coverage is 188. Therefore use of a DF of 100 is conservative.

3. REFERENCES

1. ERC 25212-ER-98-0031, Rev. 0, "Control Room Dose Calc - Time to Open 3HVC*AOV25 & 26", dated 1/26/98
2. MP3 Technical Requirements Manual
3. Calc. PR-194, Rev. 0, "MP3 source Terms - FSAR", dated 7/27/77
4. Intentionally Blank
5. Regulatory Guide 1.25, Rev. 0, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors"
6. NUREG/ CR-5009, "Assessment of the Use of Extended Burnup Fuel in Light Water Power Reactors", dated 1/88
7. ERC 25203-ER-98-0050, Rev. 02, "Control Room Filtration system Design Basis Parameters for Inputs to Revise Millstone Unit 2 Control Room Post Accident Radiological Habitability Analyses", dated 6/11/98
8. Intentionally Blank
9. Intentionally Blank
10. Letter to the NRC, Proposed Revision to Technical Specification Spent Fuel Pool Rerack (TSCR 3-22-98), B17343, dated 3/19/99
11. MP3 Technical Specifications
12. Calc. UR(B)-450, Rev. 0, CCN 1, "MP3 LOCA Doses at the Site Boundary, Control Room, and TSC Assuming Duct Leakage and Damper Bypass", dated 1/17/2000
13. Calc. WM(B)-06, Rev. 0, X/Qs at Unit 2 Control Room Intake from the Unit 3 Containment Structure and Turbine Building Vent", dated 6/3/98
14. Calc. WM(B)-04, Rev. 0, Normalized X/Qs at Unit 3 Control Room for Releases from the Unit 3 Containment and Turbine Vent", dated 5/27/98
15. ICRP 30
16. Regulatory Guide 1.109, Reviision 1, "Calculation of Annual Doses to Manfrom Routine Releases of Reactor Effluents....", 10/97
17. P&ID 12179-EM-156A, Rev. 05, Tech Support Center HVAC
18. CRADLE - Control Room Accident Dose Level Evaluations, QA Category 1 Calculation #XX-XXX-37 RA, Rev. 2, Donald Miller Nov. 22, 1982.
19. TACT III, Atmospheric Transport Code System, Oak Ridge National Laboratory, CCC-447, version 83.0
20. Calc.UR(B)-453, Rev 0, CCN 1, "Millstone Unit 2 Control Room Operator Doses following a LOCA at the MP3 Reactor Assuming Unfiltered Duct Leakage and Damper Bypass", dated 11/1/98
21. Intentionally Blank
22. Radiological Health Handbook, January 1970
23. DWG 12179-EM-2D-13, Rev. 13, "Machine Location - containment Structure - Plan El 51'4""
24. Calc. M2M3CR-01671R3, Rev 0, "MP2 Radiological consequences to the MP3 Control Room"
25. UR(B)-451, Rev. 0 , "Radiological Consequences of a MP3 Rod Ejection Acident Based on duct Leakage & Damper bypass", dated 5/29/98
26. ERC 25212-ER-98-0183, Rev. 0, "Millstone 3 Control Room Air Inlet Radiation Monitor Time Constant", 5/22/98
27. Intentionally Blank
28. Intentionally Blank
29. WCAP-7828, "Radiological Consequences of a Fuel Handling Accident", 12/71
30. Standard Review Plan 6.4, "Control Room Habitability System"
31. Proc OP 2315A, Rev. 12, "Control Room Air Conditioning System"
32. Calc. # 3-ENG-244, Rev. 01, "Analysis of Stroke Time for Containment Purge and Exhaust Dampers", dated 5/30/97

4. BASIC DATA AND ASSUMPTIONS

ASSUMPTIONS	BASIS
1) Power Level = 3636 MW thermal	Ref. 3
2) Core Inventory	Ref. 3
3) Core Release Fractions: 10% Core Noble Gases (except KR-85) 30% Core KR-85 12% Core Iodines (Ref. 6)	Ref. 5 and Ref. 6. I-131is released at 12% due to high fuel burnup but the 12% is applied to all iodines for conservatism
4) Iodine Chemical Form: 75% elemental 25% organic	Ref. 5
5) MP3 Control room damper closure time = 5 sec (does not include Control Room Inlet Rad Monitor Response time)	Ref. 2, Section 3.3.2 lists a control building isolation time of 6 seconds which includes rad monitor response time. It credits 3 seconds for damper closure time in footnote 10 of TRM section 3.3.2. 5 seconds is credited for damper closure in this calculation for conservatism.
6) MP3 Control room is pressurized from bottled air instantaneously 1 minute following control building isolation signal and bottle lasts 1 hour.	Ref. 11 Section 4.7.8
7) MP3 Control room intake prior to pressurization (<1 min) = 115 cfm At T= 10 seconds post FHA, the unfiltered inleakage is assumed to be 115 CFM. This is a conservative assumption because the control room has been isolated, there is no forced flow into the control room and the only unfiiltered leakage is from access to and from the control room. SRP 6.4 recommends 10 CFM for this access/egress leakage, but this calculation is using 50% of the full inleakage value when ventilation is aligned (50% of 230 CFM, 230 CFM is from Assumption 9).	This is the minimal inleakage used. Unlike a LOCA analysis where the accident is of extended duration and greater inleakage would be conservative, that is not the case for a FHA. Use of 115 CFM inleakage for a FHA is conservative because SRP 6.4 recommends 10 CFM occuring as a result of control room doors being opened, exfiltration, etc. Since there is no forced input to the control room at this time, the use of 115 CFM is conservative. 115 CFM is also consistent with Ref. 12 (Datum 44, pg 47)
8) Release Points: ground & Ventilation vent	Both ground and ventilation vent release paths are evaluated to ensure completeness and conservatism.
9) MP3 Control Room Unfiltered inleakage is 230 cfm following the 60 minute control room pressurization for 37 minutes until filtered intake and recirc are established	Reference 1 (37 minutes). It is conservatively assumed that intake is aligned but unfiltered until after 37 minutes, after which it is filtered.
10) MP3 Control Room Unfiltered inleakage after initiation of recirculation due to ingress/ egress = 10 cfm. This is also applicable to the MP2 Control Room.	This is the minimal inleakage used. Unlike a LOCA analysis where the accident is of extended duration and greater inleakage would be conservative, that is not the case for a FHA. Use of 10 CFM inleakage for a FHA is conservative because it results in a greater residence time for radioactivity in control room air. (Ref. 30)
11) MP3 Control room emergency ventilation rate after 1 hr 37 min: Filtered intake = 230 cfm Filtered recirc = 666 cfm	Ref. 11 - 4.7.7 for 230 cfm. 666 CFM is based on TS 4.7.7 flow rate of 1120 less 20% and subtracting 230 CFM
12) MP3 Control room iodine cleanup rate = .1595/hr @ T = 1 hr, 38 min, 10 sec TSC iodine cleanup rate = 3.434/ hr , T = 0 - 30 min = 3.262/ hr, T>30 min	The iodine cleanup rate (1/hr) is defined as: $\lambda_{Cleanup} = \frac{(F_R)(E_F)}{V} \times 60\ \text{min/hr}$ where, F_R = Recirculation flow rate ft^3/min) E_F = Filter Efficiency V = Volume (ft^3) For the Unit 3 control room: F_R = 666 ft^3/min (Assumption 11) E_F = 95% (Assumption 13) V = 2.38E+5 ft^3 (Assumption 15) $\lambda_{cleanup}$ = 0.1595/hr For the TSC F_R = 2000 ft^3/min,T=0-30 min(Assumption 22) F_R = 1900 ft^3/min,T=>30 min (Assumption 22) E_F = 95% (Assumption 23) V = 3.32E+4 ft^3 (Assumption 24) $\lambda_{cleanup}$ = 3.434/hr, T= 0 - 30 min $\lambda_{cleanup}$ = 3.262/hr, T > 30 min
13) MP3 Control room filter efficiency = 95% for all forms of iodine	Reference 11 - Tech Spec Surveillance 4.7.7.c.2 requires "...a methyl iodide penetration of less than 0.175%....". This implies a removal efficiency of >99.1%. 95% will be used for conservatism.

ASSUMPTIONS	BASIS
14) MP2 Control Room is on filtered recirculation 10 minutes after receipt of high radiation signal on MP2 Control Room Ventilation Intake Rad monitors, RM9799A&B	Per Ref. 31, "a dedicated operator is stationed to ensure CRACS s properly aligned within 10 minutes following annunciation of "CRACS IN AUTO RECIRC MODE" (window C-40....."
15) MP3 Control Room Free Air Volume = 2.38E5 ft^3	Ref. 12
16) X/Q's (sec/m3) from the MP3 Ventilation Vent MP2 Control Rm / MP3 Control Rm & TSC (0-2) hr 1.25E-03 / 3.75E-3 X/Q's (sec/m3) from the MP3 Containment (ground release) (0-2) hr 9.19E-04 / 1.52E-3	Ref. 13 (MP2) Ref. 14 (MP3)
17) X/Q's (sec/m3) EAB - ground release (0-2) hr 5.42E-04 LPZ - ground release (0-8) hr 2.91E-05 EAB - vent release (0-2) hr 4.30E-04 LPZ - vent release (0-8) hr 2.91E-05	Ref. 12 NOTE: The LPZ for ground and vent release are the same.
18) Thyroid Dose Conversion Factors - thyroid, adult, inhalation, rem/ Ci inhaled ICRP 30 / TACT / ICRP30 / TACT I-131 1.073E+06 / 1.490E+06 / 0.720 I-132 6.290E+03 / 1.430E+04 / 0.440 I-133 1.813E+05 / 2.690E+05 / 0.674 I-134 1.073E+03 / 3.730E+03 / 0.288 I-135 3.145E+04 / 5.600E+04 / 0.562	Ref. 20, pg 28 provides ICRP 30 DCFs in units of "rem/ Ci inhaled" The TACT code provides the DCFs used by TACT. The ICRP 30: TACT DCF ratio listed is used to adjust TACT thyroid doses to an ICRP 30 equivalent.
19) TSC is isolated on CBI signal from MP3 Control Room Inlet Ventilation Radiation Monitor. CBI also initiates filtered intake and recirc.	Ref. 17
20) TSC Damper Closure Time = 2 seconds - assume 10 seconds total time for isolation from receipt of CBI to damper closure	Ref 12 and conservative assumption
21)TSC Unfiltered inleakage (T= 0 to 30 minutes) prior to pressurization / after pressurization unfiltered inleakage 50 CFM / 10 CFM It will be assumed for conservatism that personnel will be in the TSC from T=0.	Ref 12
22) TSC Emergency Ventilation Rate (0 - 30 minutes post-accident) / (30 minutes - 720 hours) filtered intake 0 CFM / 100 CFM filtered recirculation 2000 CFM / 1900 CFM	Ref 12
23) TSC filter efficiency for all iodines = 95%	Ref 12
24) TSC free air volume = 3.32E+04 ft^3	Ref 12
25) Reactor is shutdown 100 hours prior to fuel movement	Reference 11 - Tech. Spec 3.9.3
26) MP2 control room damper closing time = 5 seconds	Ref 20
27) The MP 3 control room ceiling is 2 feet thick concrete.	Ref 12
28) The MP 2 control room ceiling is 2 feet thick concrete.	Ref 7
29) The TSC roof provides at least 1 foot thickness of concrete.	Ref 12
30) MP3 Control Room Filters and TSC Filters have 1 foot of concrete shielding	Ref 12
31) MP2 Control Room Filter has 18" of concrete shielding	Ref 20
32) MP3 Radial Peaking Factor = 1.7	Ref 10
33) One complete fuel assembly is assumed to fail in a FHA in containment.	This is an assumption made for calculational purposes and is adjusted to 1assembly plus 50 rods in the calculation.
34) Refuel Pool DF for iodines is 100, retention of nobles gases by the pool is negligible	Ref 5 based on at least 23 feet of water above the fuel.
35) There is at least 23 feet of water over the damaged fuel. (A fuel bundle which falls on the refuel pool floor would be covered by slightly less than 23 feet of water but this deviation is not significant, in addition only the one bundle would be damaged without the additional 50 rods.) Further proof of this is provided in Section 6.1.	Ref. 11 - Tech. Spec 3.9.10
36) MP2 Control Room iodine cleanup rate = 3.408 /hr (See Assumption 14 for start time)	Ref. 20 (using method of Assumption 12: 2,250 cfm * 90% * 60 min/hr / 35,650 ft3 = 3.408 / hr)
37) The radioactive material that escapes from the pool is released from the building at an exponential rate over a 2 hour time period.	Ref. 5

ASSUMPTIONS	BASIS
38) MP3 containment purge valves isolate prior to release of activity from containment.	MP3 TRM, pg 3 TRM-3.3.2 requires total response time (from time of detectability of release from pool to isolation of purge valves) to be <= 16 seconds. Ref 32 states that for an istrument response time of 7 seconds, a valve closure time of 9.7 seconds is required to ensure no activity is released from the purge ductwork. Based on a review of Attachment 1, response time testing for RE 41, the worst case response time is 6.28 seconds. Since the worst case response time, 6.28 seconds plus the worst case valve closure time of 9.7 seconds is a total of 16 seconds, this meets the TRM criteria of <= 16 seconds, resulting in assurance that the purge valves isolate prior to releasing activity.
39) The MP3 core contains 193 fuel assemblies.	Tech Spec Section 5.3.1 "Fuel Assemblies"
40) The MP3 Control Room ventilation intake is normally 1450 CFM	Ref. 25, (datum 1 of pg A3)
41) The MP2 control room ventilation intake is normally 800 CFM	Ref. 7
42) The MP2 unfiltered inleakage prior to control room isolation is 130 CFM.	Ref. 7 It will be assumed that this inleakage rate continues until the control room is aligned for filtered recirculation (10 minutes after isolation). After the 10 minutes, the inleakage rate is assumed to drop to 10 CFM for the duration of the accident. This provides a greater challenge to the GDC 19 dose limits rather than assuming 130 CFM inleakage for the duration of the accident.
43) MP3 Containment Free Volume = 2.32E+06 ft3	Ref. 12
44) MP2 Control Room Volume = 3.565E+04 ft3	Ref. 20

5. METHOD OF ANALYSIS

This analysis will evaluate the dose consequences of a fuel handling accident (FHA) in containment assuming that:
1) fuel movement (and accident) occurs 100 hours after reactor shutdown, and
2) the personnel hatch is open but containment closure is achieved within 10 minutes of initiation of a FHA in containment.

Two separate FHA scenarios will be analyzed. The first assumes a simple ground release from containment with essentially all airborne activity being released at an exponential rate over a 2 hour period. This implies an air change rate of 3/ hour (3 containment volumes per hour) which results in releasing greater than 99.75% of all airborne activity in containment to the environment within 2 hours. The second scenario assumes that activity is released from the containment to the Auxiliary Bldg to the environment over a 2 hour period via the ventilation vent. In this scenario, a containment release rate of 4 / hour and an Auxiliary Building release of 6 / hour is used. This ensures that greater than 99.75% of all activity released to containment is released to the environment within 2 hours. Since 2 scenarios will be evaluated, the worst case one will be used to evaluate the MP2 and MP3 control room and TSC doses. The dose components evaluated for the worst case accident scenario will consist of

1. offsite dose - determined by running the TACT code with appropriate inputs
2. MP2 & 3 control room dose comprised of :
   - inhalation and submersion dose within the control room - by running CRADLE code
   - plume shine to the control room - from TACT code
   - filter shine
3. Technical Support Center TSC) dose comprised of :
   - inhalation and submersion dose within the TSC- by running CRADLE code
   - plume shine to the TSC - from TACT code
   - filter shine

A basic timeline of pertinent events is listed below.

@ T = 0 hours: FHA in containment is initiated, MP3 containment purge isolates based on signal from fuel drop rad monitor

@T = 10 seconds: the TSC and MP3 control room isolate based on control room inlet rad monitor and damper response time

@T = 1 minute: MP2 control room isolates based on MP2 control room inlet rad monitor and isolation damper response time

@T = 1 minute and 10 seconds: MP3 control room pressurizes (duration of 1 hour)

@T = 10 minutes: FHA release stops (containment is closed).

@T = 11 minutes: MP2 control room is on filtered recirculation

@T = 30 minutes, 10 seconds: TSC goes on filtered recirculation and filtered makeup

@T = 1 hour, 1 minute, 10 seconds: MP3 control room is no longer pressurized

@T= 1 hour, 38 minutes, 10 seconds: MP3 control room is on filtered recirculation and filtered makeup

@T =2 hours: for control room and TSC analyses, the release stops (this is conservative relative to intent to stop release at 10 minutes)

@T = 720 hours: dose determination ends

The source term is based on the full core inventory and adjusted for the release fractions and 100 hours decay.

The effect of the containment release on fuel drop radiation monitors and control room inlet radiation monitors is evaluated based on area dose rate and airborne concentration determinations.

Plume shine to the control rooms and TSC will be determined by ratioing the appropriate control room X/Qs to the TACT results for offsite dose. Filter shine will be determined by summing all iodine activity within the control rooms and treating it as a point source with dose calculated for 30 days. Credit will be taken for shielding from plume and filter shine.

Information provided in Section 4 will be used to evaluate the dose consequences. The computer codes used to model the releases are TACT and CRADLE and are further explained below.

The CRADLE (version 2) (Ref. 18) computer code was used for the direct exposure calculations in this analysis. CRADLE was validated per NEO 2.24/QS-3 and was last benchmarked April 2000. CRADLE calculates the activity which enters the control room after an accident. The effects of filtration, buildup, decay and plateout are taken into account in the transport of activity from the core into containment to the environment and eventually to the control room. From the activity in the control room, CRADLE calculates the resulting thyroid, whole body and beta doses to the control room operators inhabitants. In addition, CRADLE will be used to determine the amount of iodine built up on the control room charoal filters.

The TACT III (version 83.0) (Ref. 19) computer code was used to determine the doses at the EAB and LPZ and to determine the cloud shine dose component to the control room. TACT III (ver. 83) was validated per NEO 2.24/QS-3 and was last benchmarked April 2000. TACT III simulates the movement of radioactivity released from a reactor core as it migrates through user-defined regions (nodes) of the containment, is immobilized by filters and sprays, and leaks to the outside environment. Outputs are shown for the end of each time interval and include the level of radioactivity in each node of the containment and in the environment, broken down as iodines, noble gases, and solids; and the radiation dose to reference individuals at the exclusion radius, the boundary of the low population zone, and in the control room. TACT will also be used to evaluate plume shine to the control room.

The CRADLE code uses a generic source term inventory which will be adjusted for the MP3 inventory that reflects this FHA. In addition, both codes use thyroid dose conversion factors from Regulatory Guide 1.109 (Reference 16) which are outdated and will be adjusted using thyroid dose conversion factors from ICRP 30. Both adjustments require multiplication of the isotope specific response by a simple ratio of the old value/ new value.

6. BODY OF CALCULATION

6.1. Iodine Decontamination Factor for Water Depth < 23 feet

Per Assumption 35, there is 23 feet of water over the damaged fuel bundle. In the event that a bundle falls on the reactor vessel flange, there is slightly less than 23 feet of water over the bundle because of the apparent height of that bundle. This brings into question the validity of the iodine DF of 100 from Assumption 34 which requires 23' of water coverage. Table 3-5 of Reference 29 provides empirical data associated with measurements of iodine removal in varying depths of water (26' and 40'). At 26' for the high release pressure, a DF of 810 is observed whereas for 40', a DF of 3000 is observed. By linear extrapolation from those 2 data points, the equation of the line passing through those 2 points is :

$Y = 156.43 * X - 3257.2$ (Equation 1)

where
Y = the DF
X = pool depth in feet.

At 26' and 40' the results from Equation 1 agree with the empirical results.

Since fuel assemblies are typically less than 9" wide on a side (assume 1 foot for conservatism), then a DF determined at 22' depth would be approximately 184 based on Equation 1. This is greater than the DF of 100 assumed and used in this calculation. Therefore there is no significant impact from a fuel assembly lying on its side in the refuel pool resulting in a water depth over the assembly of only 22 feet.

It should be noted that Reference 29 implies that the DFs determined in that reference are for total iodine released. Since Regulatory Guide 1.25 provides a DF of 133 for inorganic iodine and 1 for organic at a 23 foot depth, it would be conservative to apply the DF of 184 at 22 feet determined in the previous paragraph to the inorganic iodines and 1 for the organic. The resultant overall DF , using the Reg. Guide 1.25 method (where the iodine composition above the pool is 75% organic and 25% inorganic) is 138 (= 184 * 0.75 + 1 * 0.25). It should also be noted that if an effective DF is determined based on the gap inventory, which is comprised of 99.75% inorganic iodine and 0.25% organic, then the resultant DF is 183.5 (= 184 * 0.9975 + 1 * 0.0025). In any case, the DF based on only 22 feet of water is greater than the Reg. Guide 1.25 assumption of 100.

In conclusion, a DF of 100 is acceptable and conservative when used with a fuel bundle having only 22 feet of water coverage as opposed to the 23 feet required by Reg. Guide 1.25.

6.2. Source Term Determination

Table 1 below contains the information supporting the release fractions that will be used in TACT and CRADLE. The release fraction RF is determined using the equation: RF = A x PF x GR / (CD x DF)
where
A - the isotope specific core activity (Assumption 2)
PF - radial peaking factor (Assumption 32)
GR - Gap Release (Assumption 3)
CD - amount of core damage (1 damaged ass'y/ 193 ass'ys in a core)
DF - refuel pool DF (Assumption 34)

Table 1 provides a listing of all applicable iodines and nobles gases used in this calculation, as well as the release fraction determination. The full core inventory is based on Assumption 2.

To summarize Table 1, the release fractions are as follows (please note that these fractions are based on 1 fuel bundle and do not include the additional 50 rods, which will be addressed in Section 6.8 of this calculation):

iodines -	1.06E-05
noble gases (except KR-85) -	8.81E-04
KR-85 -	2.64E-03.

These release fractions will be used to support the CRADLE and TACT runs.

In addition to release fractions, Table 1 also provides the conversion factors used to correct the CRADLE dose output based on the MP3 core inventory instead of the default CRADLE library. The default library is based on TID 14844 core inventory generation rates which are not based on high burnup inventories. These conversion factors are used as multipliers to the isotope specific doses in all of the sections in this calculation concerning control room and TSC doses. The CRADLE activity listed in Table 1 is based on the isotopic inventory library in CRADLE and printed on all CRADLE output. The activity is determined by multiplying the MP3 power level (3636 MWt) by the isotope specific Ci/MWt conversion factor (obtained from the CRADLE INPUT DATA LIBRARY provided with each CRADLE output). For example, I-131 has the following Ci/MWt conversion factors: 2.282E+04 (elemental), 1.003E+03 (organic) and 1.254E+03 (particulate). The sum of these factors is 2.508E+04 Ci/ MWt. Multiplied by the 3636 MWt power level results in a CRADLE I-131 inventory of 9.12E+07 Ci. Dividing the full core inventory located in the second column of Table 1 by the CRADLE inventory results in a correction factor of 0.999 (= 9.11E+07 / 9.12E+07).

Table 1 - Source Term Identification and Release Fraction Determination

Isotope	Full Core Inventory, Ci*@ T = 0	Radial Peaking Factor	Fraction of Core in Gap	Number of Damaged Assemblies	# of Assemblies in Core (Sec 4.39)	Refuel Pool DF	Release Fraction from pool	CRADLE Activity, Ci @ T = 0	MP3 to CRADLE Source Term Ratio used for CRADLE output correction
I-131	9.11E+07	1.70	0.12	1.00	193	100	1.06E-05	9.12E+07	9.99E-01
I-132	1.30E+08	1.70	0.12	1.00	193	100	1.06E-05	1.38E+08	9.38E-01
I-133	2.04E+08	1.70	0.12	1.00	193	100	1.06E-05	2.04E+08	9.97E-01
I-134	2.38E+08	1.70	0.12	1.00	193	100	1.06E-05	2.39E+08	9.94E-01
I-135	1.88E+08	1.70	0.12	1.00	193	100	1.06E-05	1.86E+08	1.01E+00
Kr-83m	1.58E+07	1.70	0.10	1.00	193	1	8.81E-04	1.51E+07	1.05E+00
Kr-85	8.83E+05	1.70	0.30	1.00	193	1	2.64E-03	1.49E+06	5.92E-01
Kr-85m	3.96E+07	1.70	0.10	1.00	193	1	8.81E-04	4.72E+07	8.40E-01
Kr-87	7.71E+07	1.70	0.10	1.00	193	1	8.81E-04	8.49E+07	9.08E-01
Kr-88	1.08E+08	1.70	0.10	1.00	193	1	8.81E-04	1.16E+08	9.32E-01
Kr-89	1.40E+08	1.70	0.10	1.00	193	1	8.81E-04	1.45E+08	9.66E-01
Xe-131m	8.01E+04	1.70	0.10	1.00	193	1	8.81E-04	9.44E+05	8.49E-02
Xe-133m	4.89E+06	1.70	0.10	1.00	193	1	8.81E-04	5.03E+06	9.72E-01
Xe-133	2.03E+08	1.70	0.10	1.00	193	1	8.81E-04	2.04E+08	9.94E-01
Xe-135m	5.50E+07	1.70	0.10	1.00	193	1	8.81E-04	5.66E+07	9.72E-01
Xe-135	5.38E+07	1.70	0.10	1.00	193	1	8.81E-04	1.95E+08	2.76E-01
Xe-137	1.83E+08	1.70	0.10	1.00	193	1	8.81E-04	1.86E+08	9.85E-01
Xe-138	1.80E+08	1.70	0.10	1.00	193	1	8.81E-04	1.74E+08	1.04E+00

6.3. *Radiation monitor impact*

There are 3 radiation monitoring systems that must be addressed because they may impact isolation of MP2/3 control rooms and the TSC, in addition they impact isolation of MP3 containment purge valves. They are the MP3 Fuel Drop rad monitor, the MP3 Control Room Inlet Vent rad Monitor and the MP2 Control Room Ventilation Intake rad monitor. They will be addressed individually below.

6.3.1. MP3 Fuel Drop Radiation Monitor, 3RMS*RE41,42

Determination of the rad monitor response will be performed assuming the fission gas release from the refuel pool reaches the surface as a bubble. This is then treated as a point source and an exposure rate determination made relative to the rad monitor locations. From Reference 23 it can be shown that the farthest distance between the bubble and the rad monitors is based on the bubble rising in the north end of the refuel pool and the farthest rad monitor is approximately 60 feet away. The farthest distance is used because it results in the lowest dose rates and associated instrument response time. Since these rad monitors are ion chamber devices, their energy response is essentially flat for the energies associated with the fission gases, so no energy correction is required. The exposure rate is determined using equations J.1 and J.4 from page 32 of Reference 22. The equations are :

J.1: $\Gamma = 0.156\ n\ E\ (10^5\ \mu_a)$, mR/hr at 1 meter per mCi

and

J.4: Exposure Rate, mR/hr = $N\ \Gamma / s^2$

where

n = gamma quanta per disintegration
E = gamma energy, Mev
μ_a = energy absorption coefficient for gamma in air, cm^{-1}
N = number of millicuries
s = distance in meters
Γ = results of equation J.1,

The parameters used in the exposure rate determination are listed in Table 2. The total activity released is based on the release fraction from Table 1 times the core activity in Table 1. This activity is then decayed for 100 hours due to Tech Spec requirements (Assumption 25) . Decay constants, gamma energy per disintegration and the linear absorption coefficient are taken from Reference 22 (pgs 261 - 301 for half life and energy spectrum and pg 135 for linear absorption coefficient). From Table 2, the exposure rate at the furthest rad monitor is 4.7 R/hr. This exceeds its alarm setpoint of 1 R/hr (Tech Spec Table 3.3-4) and does indeed result in purge isolation. Therefore, no activity is released via purge (See Assumption 38 for details).

Table 2 - Exposure Rate Determination at Fuel Drop Rad Monitor

Isotope	Total Activity Released (no decay correction), Ci	100 hour Decayed activity, uCi	Decay constant, hr-1*	Average Gamma Energy per disintegration, Mev/ dis **	Gammas/ dis	Distance, ft	distance, meters	U, linear absorption coefficient for air, cm-1	Fuel Drop Rad Monitor Exposure rate @ 18.3 m, mr/hr
I-131	9.63E+02	6.73E+08	3.58E-03	3.53E-01	1	60	18.3	3.00E-05	3.3E+02
I-132	1.37E+03	1.13E-04	3.01E-01	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
I-133	2.15E+03	7.82E+07	3.32E-02	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
I-134	2.51E+03	4.71E-26	8.00E-01	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
I-135	1.99E+03	6.40E+04	1.03E-01	1.56E+00	1	60	18.3	3.00E-05	1.4E-01
Kr-83m	1.40E+04	2.02E-06	3.65E-01	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
Kr-85	2.33E+03	2.33E+09	7.68E-06	2.11E-03	1	60	18.3	3.00E-05	6.9E+00
Kr-85m	3.49E+04	5.04E+03	1.58E-01	1.51E-01	1	60	18.3	3.00E-05	1.1E-03
Kr-87	6.79E+04	1.18E-13	5.47E-01	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
Kr-88	9.55E+04	1.30E+00	2.50E-01	1.65E+00	1	60	18.3	3.00E-05	3.0E-06
Kr-89	1.23E+05	0.00E+00	1.30E+01	2.00E+00	1	60	18.3	3.00E-05	0.0E+00
Xe-131m	7.06E+01	5.55E+07	2.41E-03	3.28E-03	1	60	18.3	3.00E-05	2.5E-01
Xe-133m	4.31E+03	1.20E+09	1.28E-02	3.26E-02	1	60	18.3	3.00E-05	5.5E+01
Xe-133	1.79E+05	1.03E+11	5.48E-03	3.00E-02	1	60	18.3	3.00E-05	4.3E+03
Xe-135m	4.85E+04	8.49E-106	2.67E+00	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
Xe-135	4.74E+04	2.42E+07	7.58E-02	2.46E-01	1	60	18.3	3.00E-05	8.3E+00
Xe-137	1.61E+05	0.00E+00	1.07E+01	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
Xe-138	1.58E+05	9.46E-96	2.45E+00	0.00E+00	1	60	18.3	3.00E-05	0.0E+00
								Dose Rate, mR/hr	4.7E+03

* - slight differences may occur between CRADLE inventories and the 100 hour decayed inventory in this table due to minor differences in the decay constants used

** - a number of isotopes were totally decayed by the time T= 100 hours has occurred. Since those isotopes did not affect the results of this calculation, the average gamma energy per disintegration was not used and for simplicity was assumed to be zero.

6.3.2. MP3 Control Building Inlet Vent Monitors, 3HVC*RE16A&B

Per Tech Spec Table 3.3-4, the alarm setpoint for this rad monitor is 1.5E-05 uCi/cc. To determine the activity that will reach the rad monitor, the release rate must be determined and then multiplied by the appropriate control room x/q. The release rate is determined by taking the maximum airborne Xe-133 activity in containment (or Aux Bldg when appropriate), multiply it by the air change rate and the X/Q. Xe-133 provides a representative response to these rad monitors for this isotope mix because for this accident, it is the dominant isotope, as can be seen in Table 2.

Since there are 2 different release scenarios, each must be evaluated separately. The next 2 sections provide justification for allowing use of a 10 second period from time of detection by these rad monitors to the time that the isolation dampers are closed.

Alarm by these rad monitors will result in a CBI which isolates both the MP3 Control Room and the TSC.

6.3.2.1. 3HVC*RE16A&B Response Based on vent release from Auxiliary Building

The impact from the Auxiliary Building Release

An air change rate of 6/hr was used for the Aux. Bldg and 4 / hr for containment. This ensures that essentially all airborne activity is released from containment to the environment within 2 hours. From CRADLE run # 23591 it has been determined that the Xe-133 activity in the Auxiliary Building at T = 1 sec post-FHA is 125 Ci. It should be noted that the Xe-133 activity from CRADLE does not need to be converted to a 3636 MWt equivalent because the CRADLE conversion factor from TABLE 1 is essentially 1. A determination at 1 second was made to identify the earliest possible time for detection.

The release rate from the Aux Bldg at T= 1 second is 125 Ci * 6 / hour = 750 Ci/ hour = 0.2 Ci/sec. With a X/Q to the control room for the Ventilation Vent of 3.75E-03 sec /m^3, the resultant activity concentration at the MP3 control room inlet is 7.5E-04 uCi/cc. This will alarm the inlet rad monitor based on the alarm setpoint of 1.5E-05 uCi/cc. Since the alarm setpoint for this rad monitor is 1.5E-05 uCi/cc, the control room will isolate.

The response time of the rad monitor must be determined to address impact on MP3 control room isolation time. The Xe-133 activity at the control room inlet as determined in the above paragraph is 7.8E-04 uCi/cc. The method that's used in reference 25 (page A5 - A6) will be used below to show how quickly that the MP3 control room inlet radiation monitor will detect the release.

Alarm setpoint: 1.5E-05 uCi/cc Xe-133
Time constant[1]: 10 sec for a count rate > 1000 cpm
5.3 sec for a count rate > 2000 cpm
1 sec for a count rate > 3000 cpm
Detector response conversion factor: 1.3E-08 uCi/cc per cpm Xe-133
Set-point count rate (Cs) = 1.5E-05 uCi/cc / 1.3E-08 uCi/cc per cpm = 1154 cpm
Concentration = 7.5E-04 uCi/cc
Step increase (Cf) = 7.5E-04 uCi/cc / 1.3E-08 uCi uCi/cc/cpm = 5.4E+04 cpm
Since the detector instantaneous count rate (5.4E+04 cpm) is greater than 3000 cpm, the time constant (RC) is 1 sec. The monitor response time, T, to reach the setpoint is determined by:
$Cs = Cf\,(1-e^{-T/RC})$
$Cs / Cf = (1-e^{-T/RC})$
$1154 / 5.4E{+}04 = (1-e^{-T/1\,sec})$
$T = 0.02$ sec

The response time is 0.02 seconds. For conservatism, 5 seconds will be used which includes the release at 1 second. In addition, using Assumption 5, 5 seconds is used for damper closure time. Therefore it takes 10 seconds for the control room to isolate following detection by the MP3 control room air inlet detectors.

6.3.2.2. 3HVC*RE16A&B Response Based on ground release from containment

For the release from containment.
The released activity is decay corrected for 100 hours shutdown time and multiplied by the air change rate of 3 / hour. From the CRADLE run # 09065, the initial Xe-133 activity in containment at T = 100 hours is 1.042E+05 Ci. It should be noted that the Xe-133 activity from CRADLE does not need to be converted to a 3636 MWt equivalent because the CRADLE conversion factor from TABLE 1 is essentially 1. The resulting initial (and maximum) release rate is 1.042E+05 Ci * 3 / hour = 3.13E+05 Ci/hour which is equivalent to 87 Ci/ second. This release rate is then multiplied by the x/q for the containment to control room. The result is the air activity at the rad monitor. The x/q to be used is 1.52E-03 sec/m3 from Assumption 16. Doing the math, 87 Ci/ sec * 1.52E-03 sec/m^3 is 1.32E-01 Ci/m3 of Xe-133 activity (equivalent to 1.32E-01 uCi/cc). It should be noted that the contribution from the other isotopes has not been addressed but they are not significant. All of the other isotopes result in no significant increase in the rad monitor response above the Xe-133 response.

Since the activity expected at the rad monitor from the accident (1.32E-01 uCi/cc) is almost a factor of 10000 higher than the rad monitor alarm setpoint (1.5E-05 uCi/cc), the MP3 control room and TSC will isolate. The activity released from containment at T=100 hours is higher than at any other time and is therefore conservative to use. Since the airborne activity is much greater than that determined in the previous section, the rad monitor response will be quicker. For simplicity, it will be assumed that the 10 second period between release of activity and control room isolation determined in the previous section is still applicable.

[1] time constant is calculated based on information from Reference 26

6.3.3. MP2 Control Room Ventilation Intake, RM9799A&B

The MP2 control room rad monitor response will be determined using the methods of Section 6.3.2.1 because most of it is still applicable. Use of the Aux Building ventilation release path is conservative over the containment release path because it will result in the lowest airborne activity at the detector and slowest response time for MP2 control room isolation. The primary difference in airborne activity at the inlet is that the x/q should be 1.25E-03 sec/m3 versus the 3.75E-03 sec/m3 used for MP3. A simple ratio of 1.25E-03 / 3.75E-03 is multiplied by the 7.5E-04 uCi/cc from Section 6.3.2.2 to arrive at the air concentration at the Unit 2 Control room. The resulting value is 1.25E-03/ 3.75E-03 x 7.8E-04 = 2.5E-04 uCi/cc. Therefore activity the MP2 control room rad monitor sees is 2.5E-04 uCi/cc.

Reference 3.20, pages 31 & 32 provides a model for evaluation of the MP2 rad monitor response time and is used as follows.The detector has a response conversion factor of 1 mr/hr = 0.009 uCi/cc dose equivalent XE-133. For a 2.5E-04 uCi/cc activity, the rad monitor will see approximately 0.028 mr/hr. This exposure rate is too low for an adequate response and has an associated time constant (RC) of > 0.3 min (20 sec). More activity must be released from the MP3 Auxiliary Building before the MP2 rad monitors will alarm. The MP2 control room CRADLE run# 00871, dated 5/31/2000 provides the activity in the MP3 Aux Bldg at T = 45 seconds and this value is 4894 Ci - XE-133. The activity seen at the rad monitor detector based on a release rate from MP3 of 6 / hr is 4894 Ci * 6/ hr = 2.94E+04 Ci/hr = 8.16E+00 Ci/ sec. Applying the X/Q of 1.25E-03 sec/ m3, results in a XE-133 activity at the detector of 1.02E-02 uCi/ cc. With the response conversion factor of 0.009 uCi/cc / mR/hr, the monitor will see 1.13E+00 mR/hr. The time constant, RC, (per Ref 20, pg 31) for this exposure rate is 0.033 min (1.98 seconds).

The monitor response time to reach the setpoint is :

$C_s = C_f * (1-e^{-T/RC})$

where

C_s = monitor setpoint of 1 mr/hr

C_f = exposure rate at the detector, 1.13 mr/hr

$1/ 1.13 = 1 - e^{-(T/1.98)}$

T = 4.28 sec

Therefore rad monitor response time is 49.28 seconds (= 4.28 sec + 45 seconds release time) and will be assumed to be 50 seconds. From Assumption 26, the MP2 control room isolation damper closing time is 5 seconds. This results in an isolation time once detected to isolation of 55 seconds.

Since it takes 50 seconds from T = 0 for sufficient activity to be released from the MP3 Auxiliary Building to be alarmed by these rad monitors, plus 5 seconds for MP2 control room isolation, the MP2 control room will not isolate until T=55 seconds, post- FHA. For this calculation, isolation is assumed to occur at T = 60 seconds for conservatism.

6.4. *Offsite dose*

TACT III was used to evaluate offsite dose based on a 10 minute ground release using 3 air changes per hour from containment. The 10 minute release assumes that the containment will be closed within 10 minutes of initiation of the accident. A similar run assuming a vent release (with vent X/Q of 4.3E-04 sec/m3) and 4/ hour release rate was performed with results that were lower than the ground level release. Therefore the ground level release is bounding.

The ground release TACT input dataset is listed below.

```
MP3 FHA IN CONTAINMENT                                   00000100
1 3 1 21 5 15 00 0 0                                     00000200
3636. 0.0 1.06E-5 8.81E-4 0.0 0.75 0.25 0.00             00000300
1  2   0 0.0 100.0                                       00000400
2  1   2 9.63E2                                          00000502
2  1   3 1.37E3                                          00000510
2  1   4 2.15E3                                          00000520
2  1   5 2.51E3                                          00000530
2  1   6 1.99E3                                          00000540
```

```
2  1   9 1.4E4                                              00000550
2  1   11 2.33E3                                            00000560
2  1   10 3.49E4                                            00000570
2  1   12 6.79E4                                            00000580
2  1   13 9.55E4                                            00000590
2  1   14 1.23E5                                            00000591
2  1   15 7.06E1                                            00000592
2  1   16 4.31E3                                            00000593
2  1   17 1.79E5                                            00000594
2  1   18 4.85E4                                            00000595
2  1   19 4.74E4                                            00000596
2  1   20 1.61E5                                            00000597
2  1   21 1.58E5                                            00000598
3  1   0 2.32E6                                             00000610
11 1   1 0.0                                                00000620
17 6   0 0.00E-0 0.00E-0 0.00E-0 0.0 0.0 0.0                00000630
1  2   0 100.0 100.167                                      00000640
11 1   1 7.2E3                                              00000700
17 6   0 5.42E-4 2.91E-5 3.47E-4 0.0 0.0 0.0                00000800
1  2   0 100.167 102.0                                      00000900
11 1   1 0.0                                                00001000
17 6   0 0.00E-0 0.00E-0 0.00E-0 0.0 0.0 0.0                00001100
0/                                                          00001500
```

TACT runs # 15205 and 15881, performed on 5/15/2000, provides the following dose information for ground and vent releases.

	(TACT #15205) GROUND	(TACT #15881) VENT
EAB - whole body:	2.238E-01 rem	2.195E-01 rem
LPZ - whole body:	1.201E-02 rem	1.486E-02 rem

Thyroid dose from that TACT run must be adjusted to reflect ICRP 30 DCFs. This is performed below. The end results are the following EAB and LPZ thyroid doses.

	(TACT #15205) GROUND	(TACT #15881) VENT
EAB - thyroid:	5.454E+01 rem	5.350E+01 rem
LPZ - thyroid:	2.928E+00 rem	3.620E+00 rem

Since the ground release thyroid dose provides the most challenge to the dose limits (6 rem -whole body and 75 rem- thyroid), the ground release will be used to bound the offsite dose analysis.

The corrections to thyroid dose conversion factors (DCFs) are listed in Assumption 18 and repeated below. The DCFs are multiplied by the isotope specific thyroid dose fraction for the time step in TACT. The dose fraction is found in the TACT run. This value provides the weighted multiplier to the total dose. The TACT thyroid doses are multiplied by the weighted correction factor to determine the ICRP 30 based thyroid doses.

Since only 1 time interval was considered in TACT, only 1 time interval need be evaluated.

The conversion for the ground release thyroid dose is listed below

Offsite Thyroid Doses

DCF Ratio				
I-131	I-132	I-133	I-134	I-135
0.720	0.440	0.674	0.288	0.562

	TACT III Iodine Dose Fraction					Combined
Release Type	I-131	I-132	I-133	I-134	I-135	Factor
10 minute release	9.795E-01	0.000E+00	2.055E-02	0.000E+00	3.634E-06	*7.1909E-01*

Combined Factor(t) = Summation of [DCF Ratio(i) x Iodine Dose Fraction(i)] over i for time interval (t), where i=iodine isotope.

		Filtered Release Thyroid Doses (Rem)			
		TACT III		*ICRP 30*	
Release Type		EAB	LPZ	*EAB*	*LPZ*
10 minute release		7.584E+01	4.072E+00	*5.454E+01*	*2.928E+00*

ICRP 30 EAB(t), or LPZ(t) = TACT III EAB(t), or LPZ(t), x Combined Factor(t) for time interval (t).

The conversion for the vent release thyroid dose is listed below

Offsite Thyroid Doses

DCF Ratio				
I-131	I-132	I-133	I-134	I-135
0.720	0.440	0.674	0.288	0.562

	TACT III Iodine Dose Fraction					Combined
Release Type	I-131	I-132	I-133	I-134	I-135	Factor
10 minute release	9.794E-01	0.000E+00	2.055E-02	0.000E+00	3.635E-06	*7.1902E-01*

Combined Factor(t) = Summation of [DCF Ratio(i) x Iodine Dose Fraction(i)] over i for time interval (t), where i=iodine isotope.

		Filtered Release Thyroid Doses (Rem)			
		TACT III		*ICRP 30*	
Release Type		EAB	LPZ	*EAB*	*LPZ*
10 minute release		7.440E+01	5.035E+00	*5.350E+01*	*3.620E+00*

ICRP 30 EAB(t), or LPZ(t) = TACT III EAB(t), or LPZ(t), x Combined Factor(t) for time interval (t).

6.5. MP 3 control room dose

6.5.1. inhalation and submersion dose within the control room

Dose results for each scenario (ground and ventilation vent release) are listed in this section. Whole body and beta doses are listed based on CRADLE output and corrected for inventory using release fractions (Section 6.2). Thyroid dose is adjusted for inventory (Section 6.2) and thyroid dose conversion factors (Assumption 18). The CRADLE input datasets are listed below for the 2 scenarios.

Based on a review of the output from both scenarios, using the KR-85 inventory as a benchmark, the activity released from the refuel pool is essentially removed in entirety from the Containment (and Auxiliary Building) within the 2 hour time constraint specified by Regulatory guide 1.25. KR-85 is used because of its relatively long half-life. The use of shorter lived isotopes is not recommended because they may misrepresent the extent of activity released from containment due to their shorter half-lives.

In both cases, the initial airborne KR-85 activity in containment at T = 100 hours, is 1.313E+03 Ci. This value was taken from the CRADLE runs for the MP3 control room analyses.

At 2 hours post FHA, for the containment-ground release scenario, the remaining KR-85 activity in containment is 3.255 Ci (this value is from the MP3 Control room - ground release CRADLE run # 09065) . This means that 99.75% of the activity was released within 2 hours.

For the Aux Bldg- ventilation vent elevated release pathway, after 2 hours, the remaining KR-85 activity in containment is 0.44 Ci and the Auxiliary Building activity is 0.87 Ci, for a total of 1.31 Ci (0.44 Ci + 0.87 Ci, these values are from the MP3 control room/ vent release CRADLE run # 23591) remaining in the containment and Auxiliary buildings. This means that of the original 1313 Ci of KR-85 released, more than 99.75% of the activity was released to the environment. Figure 1 provides an approximate visual explanation of the KR-85 release from containment to the Aux Bldg and out from the ventilation vent.

It should be noted that the dose modeling for the control rooms and TSC assume a full 2 hour release of activity with no requirement for personnel hatch closure. This is a conservative approach that will show compliance with regulatory dose limits. The intent of this calculation is to show that a 10 minute closure requirement for the containment, including personnel hatch will ensure that GDC19, Reg. Guide 1.25, and SRP 15.7.4 dose limits are met.

As will be shown, releasing activity through the Auxiliary Building via the Ventilation vent results in a higher MP3 control room thyroid dose than the ground release.

6.5.1.1. AUX BLDG RELEASE PATHWAY

The CRADLE input to support the MP3 control room dose determination from the Aux Bldg/ Vent release pathway is listed below. Following it are the source term corrected (and DCF corrected for thyroid) CRADLE outputs. These are based on CRADLE run # 09033, dated 5/26/2000 (provided on floppy with Attachment 2).

CRADLE Input for MP3 Control Room - Aux Bldg / Vent release path

```
MP-3 CR FROM CTMT RELEASE:2 HOUR RELEASE TO AUX. BLDG                           200000100
     3636.    2.38E+5        1.          0        12                             00000200
       0.0       100.  100.0028  100.0194  100.1667  100.1861  101.0194          00000300
  101.6361      102.0     108.0     124.0     196.0     820.0                    00000400
       0.0        0.0                                                            00000410
   1.06-05    8.81E-4                                                            00000500
       0.0        0.0                                                            00000600
       0.0        0.0                                                            00000700
       0.0        0.0                                                            00000800
       0.0        0.0                                                            00000801
       0.0        0.0                                                            00000802
       0.0        0.0                                                            00000803
       0.0        0.0                                                            00000810
       0.0        0.0                                                            00000820
       0.0        0.0                                                            00000830
       0.0        0.0                                                            00000900
     1450.      1450.     115.0       10.      10.0      10.0     115.0          00001000
       10.        10.       10.       10.       10.                              00001010
     0.000        0.0       0.0        0.       0.0       0.0       0.0          00001100
     230.0      230.0     230.0      230.     230.0                              00001110
     1450.      1450.     115.0       10.      10.0      10.0     115.0          00001200
      240.       240.      240.      240.     240.0                              00001210
      95.0       95.0      95.0                                                  00001300
      0.00       0.00      0.00                                                  00001400
      0.00       0.00      0.00                                                  00001500
      0.00       0.00      0.00                                                  00001600
      0.00       0.00      0.00                                                  00001700
      0.00       0.00      0.00                                                  00001701
      0.00       0.00      0.00                                                  00001702
      0.00       0.00      0.00                                                  00001710
    0.1595     0.1595    0.1595                                                  00001720
    0.1595     0.1595    0.1595                                                  00001730
    0.1595     0.1595    0.1595                                                  00001740
    0.1595     0.1595    0.1595                                                  00001800
    0.1595     0.1595    0.1595                                                  00001900
       0.0    3.75E-3   3.75E-3   3.75E-3   3.75E-3   3.75E-3   3.75E-3          00002000
   3.75E-3    3.75E-3   3.75E-3   3.75E-3   3.75E-3                              00002010
       4.0    4.00000   4.00000   4.00000   4.00000   4.00000   4.00000          00002100
       4.0    4.00000   4.00000   4.00000   4.00000                              00002110
       6.0    6.00000   6.00000   6.00000   6.00000   6.00000   6.00000          00002120
       6.0    6.00000   6.00000   6.00000   6.00000                              00002130
      0.00       0.00      0.00                                                  00002200
      0.00       0.00      0.00                                                  00002300
      0.00       0.00      0.00                                                  00002310
      0.00       0.00      0.00                                                  00002400
      0.00       0.00      0.00                                                  00002410
      0.00       0.00      0.00                                                  00002500
      0.00       0.00      0.00                                                  00002501
      0.00       0.00      0.00                                                  00002502
      0.00       0.00      0.00                                                  00002510
      0.00       0.00      0.00                                                  00002600
      0.00       0.00      0.00                                                  00002700
      0.00       0.00      0.00                                                  00002800
      0.00       0.00      0.00                                                  00002900
```

0.00	0.00	0.00	00003000
0.00	0.00	0.00	00003100
0.00	0.00	0.00	00003200
0.00	0.00	0.00	00003300
0.00	0.00	0.00	00003400
0.00	0.00	0.00	00003500
0.00	0.00	0.00	00003600
0.00	0.00	0.00	00003700
0.00	0.00	0.00	00003800
0.00	0.00	0.00	00003900
0.00	0.00	0.00	00004000
0.00	0.00	0.00	00004100
0.00	0.00	0.00	00004200

6.5.1.2. CTMT - GROUND LEVEL RELEASE PATHWAY

The CRADLE input to support the MP3 control room dose determination from the containment/ground release pathway is listed below. Following it are the source term corrected (and DCF corrected for thyroid) CRADLE outputs. These are based on CRADLE run # 09065, dated 5/26/2000 (provided on floppy with Attachment 2).

CRADLE Input for MP3 Control Room - containment/ ground release path

```
MP-3 CR FROM CTMT RELEASE:2 HOUR GROUND RELEASE                                   100000100
    3636.   2.38E+5        1.         0         12                                00000200
      0.0      100.  100.0028  100.0194  100.1667  100.1861  101.0194             00000300
 101.6361     102.0     108.0     124.0     196.0     820.0                       00000400
  1.06-05   8.81E-4                                                               00000410
      0.0       0.0                                                               00000500
      0.0       0.0                                                               00000600
      0.0       0.0                                                               00000700
      0.0       0.0                                                               00000800
      0.0       0.0                                                               00000801
      0.0       0.0                                                               00000802
      0.0       0.0                                                               00000803
      0.0       0.0                                                               00000810
      0.0       0.0                                                               00000820
      0.0       0.0                                                               00000830
      0.0       0.0                                                               00000900
    1450.     1450.     115.0       10.      10.0      10.0     115.0             00001000
      10.       10.       10.       10.       10.                                 00001010
    0.000       0.0       0.0        0.       0.0       0.0       0.0             00001100
    230.0     230.0     230.0      230.     230.0                                 00001110
    1450.     1450.     115.0       10.      10.0      10.0     115.0             00001200
     240.      240.      240.      240.     240.0                                 00001210
     95.0      95.0      95.0                                                     00001300
     0.00      0.00      0.00                                                     00001400
     0.00      0.00      0.00                                                     00001500
     0.00      0.00      0.00                                                     00001600
     0.00      0.00      0.00                                                     00001700
     0.00      0.00      0.00                                                     00001701
     0.00      0.00      0.00                                                     00001702
     0.00      0.00      0.00                                                     00001710
   0.1595    0.1595    0.1595                                                     00001720
   0.1595    0.1595    0.1595                                                     00001730
   0.1595    0.1595    0.1595                                                     00001740
   0.1595    0.1595    0.1595                                                     00001800
   0.1595    0.1595    0.1595                                                     00001900
      0.0   1.52E-3   1.52E-3   1.52E-3   1.52E-3   1.52E-3   1.52E-3             00002000
  1.52E-3       0.0       0.0       0.0       0.0                                 00002010
      0.0   3.00000   3.00000   3.00000   3.00000   3.00000   3.00000             00002100
      3.0       0.0       0.0       0.0       0.0                                 00002110
     0.00      0.00      0.00                                                     00002200
     0.00      0.00      0.00                                                     00002300
     0.00      0.00      0.00                                                     00002310
```

0.00	0.00	0.00	00002400
0.00	0.00	0.00	00002410
0.00	0.00	0.00	00002500
0.00	0.00	0.00	00002501
0.00	0.00	0.00	00002502
0.00	0.00	0.00	00002510
0.00	0.00	0.00	00002600
0.00	0.00	0.00	00002700
0.00	0.00	0.00	00002800
0.00	0.00	0.00	00002900

6.5.2. Plume shine to the control room

Ground release plume shine is determined by taking the EAB dose from the ground release TACT run # 15205 (provided in Attachment 2), ratioing the worst case X/Q (which happens to be the Vent to Control Room X/Q) to it and then adjusting for dose reduction as a result of MP3 control room shielding.

The EAB whole body dose from the TACT run is 0.2238 rem based on a X/Q of 5.42E-04 sec/ m^3.

The Vent to MP3 control room X/Q is 3.75E-03 sec/ m^3. (Assumption 16)

The control room shielding provides 2 feet of concrete (Assumption 27) which provides a radiation reduction factor of approximately 0.003. (Ref. 22 pg 149)

Plume dose to control room, rem =EAB dose * (vent to control rm X/Q) / (EAB X/Q) * shielding reduction factor.

Plume dose to control room, rem = 0.2238 rem * (3.75E-03/ 5.42E-04) * 0.003
= 0.005 rem plume shine from the ground release

Vent release plume shine is determined by taking the EAB dose from the vent release TACT run # 15881 (provided in Attachment 2), ratioing the worst case X/Q (which happens to be the Vent to Control Room X/Q) to it and then adjusting for dose reduction as a result of MP3 control room shielding.

The EAB whole body dose from the TACT run is 0.2195 rem based on a X/Q of 4.3E-04 sec/ m^3.

The Vent to MP3 control room X/Q is 3.75E-03 sec/ m^3. (Assumption 16)

The control room shielding provides 2 feet of concrete (Assumption 27) which provides a radiation reduction factor of approximately 0.003. (Ref. 22 pg 149)

Plume dose to control room, rem =EAB dose * (vent to control rm X/Q) / (EAB X/Q) * shielding reduction factor.

Plume dose to control room, rem = 0.2195 rem * (3.75E-03/ 4.30E-04) * 0.003
= 0.006 rem plume shine from the vent release

6.5.3. Filter shine from charcoal filter beds

Reference 20, pg A9, lists the distance from the filter to the control room as 12' 8 1/2". From Assumption 30, the MP3 control room has 1' of shielding. Using Cradle run #09033, the iodine activity in the control room is provided. It will be assumed that 100% of the iodine activity is trapped on the filter at each time step in the CRADLE run. This activity will be added to the decay corrected activity of the previous time step to determine iodine activity on the filter at the beginning of each time step. This activity will be treated as a point source and dose/ dose rate determined as follows.

From CRADLE run # 09033, the amount of iodine in the control room has been determined. I-131 and I-133 are the dominant iodines in the control room (with average gamma energies of 0.39 Mev and 0.444 Mev, respectively). It will be conservatively assumed that all of the iodine activity in each time step is deposited on the filter at the beginnning of the time step and treated as a point source sourrounded by 1' of concrete (Assumption 30). Each time step will have the decay corrected activity from the previous step added to it. From the CRADLE run, the time dependent iodine activity in the control room is listed below. Also listed is the time dependent iodine buildup (and decay) on the filter. Since the gamma energies of I-131 and I-133 are so similar, the I 133 will be treated as I-131 for simplicity. Dose rate is calculated using the gamma constant, Γ, for I-131 from Ref 22, pg 131 of 2.2 . Per Ref 22:

$\Gamma / 10$ = R/hr at 1 meter/ Ci

2.2 / 10 = 0.22 R/hr at 1 meter/ Ci

In order to account for distance and shielding, the inverse square law will be used to correct the above equation to a 12' 8 1/2" distance. 12' 8 1/2" is equivalent to 3.9 meters. Dividing 0.22 R/hr @ 1 meter/Ci by 15 (same as 3.9^2) provides an approximate inverse square correction to the 12' 8 1/2" distance. The corrected equation is now 1.5E-02 R/hr @ 12' 8 1/2"/ Ci.

In order to account for the shielding effectivenesss of the 1' of concrete, the transmission factor of 0. 1 from Ref. 22, pg 149 will be used. This results in a dose rate to the control of 1.5E-03 R/hr - Ci. Total iodine activity in the control room is estimated from CRADLE at less than 7E-02 Ci of iodine.

Applying 7E-02 Ci of iodine to 1.5E-03 R/hr - Ci results in a dose rate of 1.05E-04 R/hr. Multiplying this by 30 days (720 hours) results in a dose of 7.6E-02 Rem.

Since the Aux Bldg/ vent release path results in the highest thyroid dose to the control room it will also result in the highest filter shine dose using the above method. Therefore it will be conservatively used as the basis for filter shine dose based on the containment/ ground release path.

6.6. MP 2 Control Room

6.6.1. Submersion and inhalation dose

The CRADLE input to support the MP2 control room dose determination from the MP3 Aux Bldg/ vent release pathway is listed below. Following it are the source term corrected (and DCF corrected for thyroid) CRADLE outputs. These are based on CRADLE run # 5490, dated 5/1/2000 (provided on floppy with Attachment 2).

CRADLE Input for MP2 Control Room - Aux Bldg/ vent release path

```
MP-2 CR FROM CTMT RELEASE:2 HOUR RELEASE TO AUX. BLDG                   200000100
    3636.  3.565E+4        1.         0        12                        00000200
      0.0      100.  100.0014  100.0167  100.1833  100.1861  101.0194   00000300
 101.6278     102.0     108.0     124.0     196.0     820.0             00000400
      0.0       0.0                                                      00000410
  1.06-05   8.81E-4                                                      00000500
      0.0       0.0                                                      00000600
      0.0       0.0                                                      00000700
      0.0       0.0                                                      00000800
      0.0       0.0                                                      00000801
      0.0       0.0                                                      00000802
      0.0       0.0                                                      00000803
      0.0       0.0                                                      00000810
      0.0       0.0                                                      00000820
      0.0       0.0                                                      00000830
      0.0       0.0                                                      00000900
     800.      800.     800.0      130.      10.0      10.0      10.0   00001000
      10.       10.       10.       10.       10.                        00001010
     000.       0.0       0.0        0.       0.0       0.0       0.0   00001100
      0.0       0.0       0.0        0.       0.0                        00001110
     800.      800.     800.0      130.      10.0      10.0      10.0   00001200
      10.       10.       10.       10.       10.                        00001210
     0.00      0.00      0.00                                            00001300
     0.00      0.00      0.00                                            00001400
     0.00      0.00      0.00                                            00001500
     0.00      0.00      0.00                                            00001600
     0.00      0.00      0.00                                            00001700
    3.408     3.408     3.408                                            00001701
    3.408     3.408     3.408                                            00001702
    3.408     3.408     3.408                                            00001710
    3.408     3.408     3.408                                            00001720
    3.408     3.408     3.408                                            00001730
    3.408     3.408     3.408                                            00001740
    3.408     3.408     3.408                                            00001800
    3.408     3.408     3.408                                            00001900
      0.0   1.25E-3   1.25E-3   1.25E-3   1.25E-3   1.25E-3   1.25E-3   00002000
  1.25E-3   1.25E-3   1.25E-3   1.25E-3   1.25E-3                        00002010
      4.0   4.00000   4.00000   4.00000   4.00000   4.00000   4.00000   00002100
      4.0   4.00000   4.00000   4.00000   4.00000                        00002110
```

```
      6.0   6.00000   6.00000   6.00000   6.00000   6.00000   6.00000  00002120
      6.0   6.00000   6.00000   6.00000   6.00000                      00002130
     0.00      0.00      0.00                                          00002200
     0.00      0.00      0.00                                          00002300
     0.00      0.00      0.00                                          00002310
     0.00      0.00      0.00                                          00002400
     0.00      0.00      0.00                                          00002410
     0.00      0.00      0.00                                          00002500
     0.00      0.00      0.00                                          00002501
     0.00      0.00      0.00                                          00002502
     0.00      0.00      0.00                                          00002510
     0.00      0.00      0.00                                          00002600
     0.00      0.00      0.00                                          00002700
     0.00      0.00      0.00                                          00002800
     0.00      0.00      0.00                                          00002900
     0.00      0.00      0.00                                          00003000
     0.00      0.00      0.00                                          00003100
     0.00      0.00      0.00                                          00003200
     0.00      0.00      0.00                                          00003300
     0.00      0.00      0.00                                          00003400
     0.00      0.00      0.00                                          00003500
     0.00      0.00      0.00                                          00003600
     0.00      0.00      0.00                                          00003700
     0.00      0.00      0.00                                          00003800
     0.00      0.00      0.00                                          00003900
     0.00      0.00      0.00                                          00004000
     0.00      0.00      0.00                                          00004100
     0.00      0.00      0.00                                          00004200
```

6.6.2. Plume shine to the control room

Ground release plume shine is determined by taking the EAB dose from the ground release TACT run # 15205 (provided in Attachment 2), ratioing the worst case X/Q (which happens to be the ground to Control Room X/Q) to it and then adjusting for dose reduction as a result of MP2 control room shielding.

The EAB whole body dose from the TACT run is 0.2238 rem based on a X/Q of 5.42E-04 sec/ m^3.

The ground to MP2 control room X/Q is 9.19E-04 sec/ m^3. (Assumption 16)

The control room shielding provides 2 feet of concrete (Assumption 28) which provides a radiation reduction factor of approximately 0.003. (Ref. 22 pg 149)

Plume dose to control room, rem =EAB dose * (vent to control rm X/Q) / (EAB X/Q) * shielding reduction factor.

Plume dose to control room, rem = 0.2238 rem * (9.19E-04 / 5.42E-04) * 0.003
= 0.001 rem plume shine from the ground release

Vent release plume shine is determined by taking the EAB dose from the vent release TACT run # 15881 (provided in Attachment 2), ratioing the worst case X/Q (which happens to be the Vent to Control Room X/Q) to it and then adjusting for dose reduction as a result of MP2 control room shielding.

The EAB whole body dose from the TACT run is 0.2195 rem based on a X/Q of 4.3E-04 sec/ m^3.

The Vent to MP2 control room X/Q is 1.25E-03 sec/ m^3. (Assumption 16)

The control room shielding provides 2 feet of concrete (Assumption 28) which provides a radiation reduction factor of approximately 0.003. (Ref. 22 pg 149)

Plume dose to control room, rem =EAB dose * (vent to control rm X/Q) / (EAB X/Q) * shielding reduction factor.

Plume dose to control room, rem = 0.2195 rem * (1.25E-03/ 4.30E-04) * 0.003
= 0.002 rem plume shine from the vent release

Since the worst case plume shine to the MP2 control room from ground or vent release is 0.002 rem, this value will be used to bound the plume shine dose.

6.6.3. Filter shine from charcoal filter beds

Reference 20, pg A9, lists the distance from the filter to the control room as 35'. From Assumption 31, the MP2 control room has 18" of shielding. Using Cradle run #5490, the iodine activity in the control room is provided. It will be assumed that 100% of the iodine activity is trapped on the filter at each time step in the CRADLE run. This activity will be added to the decay corrected activity of the previous time step to determine iodine activity on the filter at the beginning of each time step. This activity will be treated as a point source and dose/ dose rate determined as follows.

From CRADLE run # 5490, the amount of iodine in the control room has been determined. I-131 and I-133 are the dominant iodines in the control room (with average gamma energies of 0.39 Mev and 0.444 Mev, respectively). It will be conservatively assumed that all of the iodine activity in each time step is deposited on the filter at the beginnning of the time step and treated as a point source sourrounded by 18" of concrete (Assumption 31). Each time step will have the decay corrected activity from the previous step added to it. From the CRADLE run, the time dependent iodine activity in the control room is listed below. Also listed is the time dependent iodine buildup (and decay) on the filter. Since the gamma energies of I-131 and I-133 are so similar, the I 133 will be treated as I-131 for simplicity. Dose rate is calculated using the gamma constant, Γ, for I-131 from Ref 22, pg 131 of 2.2 . Per Ref 22:

Γ / 10 = R/hr at 1 meter/ Ci

2.2 / 10 = 0.22 R/hr at 1 meter/ Ci

In order to account for distance and shielding, the inverse square law will be used to correct the above equation to a 35' distance. 35' is equivalent to 10.7 meters. Dividing 0.22 R/hr @ 1 meter/Ci by 110 ($110 = 10.7^2$) provides an approximate inverse square correction to the 35' distance. The corrected equation is now 2E-03 R/hr @ 35 ft/ Ci.

In order to account for the shielding effectivenesss of the 18" of concrete, the transmission factor of 0.01 from Ref. 22, pg 149 will be used. This results in a dose rate to the control of 2E-05 R/hr - Ci. Total iodine activity in the control room is estimated from CRADLE at less than 4E-02 Ci of iodine.

Applying 4E-02 Ci of iodine to 2E-05 R/hr - Ci results in a dose rate of 8E-07 R/hr. Multiplying this by 30 days (720 hours) results in a dose of 6E-04 R which is essentially negligible.

6.7. *Technical Support Center (TSC) dose*

6.7.1. Inhalation and submersion dose within the TSC

The CRADLE input to support the TSC dose determination from the Aux Bldg/ vent release pathway is listed below. Following it are the source term corrected (and DCF corrected for thyroid) CRADLE outputs. These are based on CRADLE run # 15634, dated 5/2/2000 (provided on floppy with Attachment 2).

CRADLE Input for TSC

```
TSC       FROM CTMT RELEASE:2 HOUR RELEASE TO AUX. BLDG                   200000100
     3636.   3.32E+4       1.          0           5                       00000200
       0.0      100.   100.0028   100.5030       102.       820.0          00000300
       0.0       0.0                                                       00000410
   1.06-05   8.81E-4                                                       00000500
       0.0       0.0                                                       00000600
       0.0       0.0                                                       00000700
       0.0       0.0                                                       00000800
       50.       50.       50.0        10.       10.0                      00001000
     0.000       0.0        0.0       100.      100.0                      00001100
       50.       50.       50.0       110.      110.0                      00001200
      95.0      95.0       95.0                                            00001300
      0.00      0.00       0.00                                            00001400
      0.00      0.00       0.00                                            00001500
     3.434     3.434      3.434                                            00001600
     3.262     3.262      3.262                                            00001700
     3.262     3.262      3.262                                            00001701
       0.0   3.75E-3    3.75E-3    3.75E-3    3.75E-3                      00002000
       4.0   4.00000    4.00000    4.00000    4.00000                      00002100
```

6.0	6.00000	6.00000	6.00000	6.00000	00002120
0.00	0.00	0.00			00002200
0.00	0.00	0.00			00002300
0.00	0.00	0.00			00002310
0.00	0.00	0.00			00002400
0.00	0.00	0.00			00002410
0.00	0.00	0.00			00002500
0.00	0.00	0.00			00002501
0.00	0.00	0.00			00002502
0.00	0.00	0.00			00002510
0.00	0.00	0.00			00002600
0.00	0.00	0.00			00002700
0.00	0.00	0.00			00002800

The TSC beta dose listed below has been source corrected (Table 15). The resultant dose value listed at the bottom of Table 15 is 2.62 rem - beta.

TABLE 15 - SOURCE TERM CORRECTION TO CRADLE BETA DOSE RESULTS -TSC

	Source Term Correction	100 h - 100.003	100.0028 - 100.503	100.503 102	102 820	Integrated Dose rem	Total Corrected Dose (rem)
I-131 ELEM	0.9988	7.98E-10	9.62E-04	1.09E-03	1.19E-05	2.06E-03	2.06E-03
I-132 ELEM	0.9381	4.77E-22	5.24E-16	5.11E-16	3.63E-18	1.04E-15	9.73E-16
I-133 ELEM	0.9970	2.20E-10	2.63E-04	2.92E-04	3.06E-06	5.57E-04	5.56E-04
I-134 ELEM	0.9939	3.77E-43	3.53E-37	2.73E-37	9.36E-40	6.27E-37	6.23E-37
I-135 ELEM	1.0134	1.26E-13	1.47E-07	1.58E-07	1.49E-09	3.06E-07	3.11E-07
I-131 ORG.	0.9988	3.51E-11	4.23E-05	4.77E-05	5.22E-07	9.05E-05	9.04E-05
I-132 ORG.	0.9381	2.10E-23	2.30E-17	2.24E-17	1.59E-19	4.56E-17	4.28E-17
I-133 ORG.	0.9970	9.66E-12	1.15E-05	1.28E-05	1.34E-07	2.45E-05	2.44E-05
I-134 ORG.	0.9939	1.66E-44	1.55E-38	1.20E-38	4.11E-41	2.76E-38	2.74E-38
I-135 ORG.	1.0134	5.54E-15	6.47E-09	6.94E-09	6.56E-11	1.35E-08	1.37E-08
I-131 PART.	0.9988	4.38E-11	5.29E-05	5.97E-05	6.52E-07	1.13E-04	1.13E-04
I-132 PART.	0.9381	2.62E-23	2.88E-17	2.81E-17	1.99E-19	5.70E-17	5.35E-17
I-133 PART.	0.9970	1.21E-11	1.44E-05	1.60E-05	1.68E-07	3.06E-05	3.05E-05
I-134 PART.	0.9939	2.07E-44	1.94E-38	1.50E-38	5.14E-41	3.44E-38	3.42E-38
I-135 PART.	1.0134	6.92E-15	8.09E-09	8.68E-09	8.20E-11	1.68E-08	1.71E-08
KR-83M	0.0000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85 **	0.5922	1.65E-09	3.18E-03	3.03E-02	9.80E-02	1.31E-01	2.34E-01
KR-85M	0.8397	7.01E-15	1.28E-08	1.06E-07	1.68E-07	2.87E-07	2.41E-07
KR-87	0.9078	4.94E-30	7.93E-24	4.74E-23	2.75E-23	8.28E-23	7.52E-23
KR-88	0.9317	3.10E-18	5.48E-12	4.17E-11	4.95E-11	9.67E-11	9.01E-11
KR-89	0.9663	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE-131M	0.0849	2.91E-10	5.61E-04	5.34E-03	1.70E-02	2.29E-02	1.95E-03
XE-133M	0.9717	1.17E-09	2.25E-03	2.12E-02	6.38E-02	8.73E-02	8.48E-02
XE-133	0.9941	2.98E-08	5.74E-02	5.45E-01	1.71E+00	2.31E+00	2.30E+00
XE-135M	0.9717	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE-135	0.2760	1.50E-10	2.82E-04	2.51E-03	5.55E-03	8.34E-03	2.30E-03
XE-137	0.9852	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE-138	1.0350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
						Uncorrected	Corrected
					Total	2.56E+00	2.62E+00

** - KR-85 dose is multiplied by 3 to reflect a 30% release instead of 10%

The TSC whole body dose listed below has been source corrected (Table 16). The resultant dose value listed at the bottom of Table 16 is 8.49E-02 rem - whole body.

TABLE 16 - SOURCE TERM CORRECTION TO CRADLE WB DOSE RESULTS-TSC

	Source Term Correction	100 h - 100.003	100.0028 - 100.503	100.503 102	102 820	Integrated Dose rem	Total Corrected Dose (rem)
I-131 ELEM	0.9988	1.77E-09	2.14E-03	2.41E-03	2.64E-05	4.57E-03	4.57E-03
I-132 ELEM	0.9381	2.38E-21	2.61E-15	2.55E-15	1.81E-17	5.18E-15	4.86E-15
I-133 ELEM	0.9970	2.36E-10	2.82E-04	3.13E-04	3.28E-06	5.98E-04	5.96E-04
I-134 ELEM	0.9939	8.67E-43	8.13E-37	6.27E-37	2.15E-39	1.44E-36	1.43E-36
I-135 ELEM	1.0134	6.85E-13	7.99E-07	8.58E-07	8.11E-09	1.67E-06	1.69E-06
I-131 ORG.	0.9988	7.78E-11	9.39E-05	1.06E-04	1.16E-06	2.01E-04	2.01E-04
I-132 ORG.	0.9381	1.05E-22	1.15E-16	1.12E-16	7.95E-19	2.27E-16	2.13E-16
I-133 ORG.	0.9970	1.04E-11	1.24E-05	1.38E-05	1.44E-07	2.63E-05	2.62E-05
I-134 ORG.	0.9939	3.81E-44	3.57E-38	2.76E-38	9.47E-41	6.34E-38	6.30E-38
I-135 ORG.	1.0134	3.01E-14	3.51E-08	3.77E-08	3.56E-10	7.32E-08	7.42E-08
I-131 PART.	0.9988	9.73E-11	1.17E-04	1.32E-04	1.45E-06	2.51E-04	2.51E-04
I-132 PART.	0.9381	1.31E-22	1.44E-16	1.40E-16	9.94E-19	2.85E-16	2.67E-16
I-133 PART.	0.9970	1.30E-11	1.55E-05	1.72E-05	1.80E-07	3.29E-05	3.28E-05
I-134 PART.	0.9939	4.77E-44	4.47E-38	3.45E-38	1.18E-40	7.92E-38	7.88E-38
I-135 PART.	1.0134	3.76E-14	4.39E-08	4.72E-08	4.46E-10	9.15E-08	9.28E-08
KR-83M	1.0492	3.94E-26	6.70E-20	4.62E-19	4.00E-19	9.29E-19	9.75E-19
KR-85 **	0.5922	2.13E-11	4.11E-05	3.92E-04	1.27E-03	1.70E-03	3.02E-03
KR-85M	0.8397	6.01E-15	1.10E-08	9.04E-08	1.44E-07	2.46E-07	2.06E-07
KR-87	0.9078	3.74E-30	6.00E-24	3.58E-23	2.08E-23	6.26E-23	5.69E-23
KR-88	0.9317	2.25E-17	3.97E-11	3.02E-10	3.59E-10	7.00E-10	6.53E-10
KR-89	0.9663	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE-131M	0.0849	9.70E-11	1.87E-04	1.78E-03	5.67E-03	7.64E-03	6.49E-04
XE-133M	0.9717	3.92E-10	7.51E-04	7.08E-03	2.14E-02	2.92E-02	2.84E-02
XE-133	0.9941	3.49E-08	6.72E-02	6.38E-01	2.00E+00	2.70E+00	2.69E+00
XE-135M	0.9717	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE-135	0.2760	1.58E-10	2.96E-04	2.63E-03	5.82E-03	8.74E-03	2.41E-03
XE-137	0.9852	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
XE-138	1.0350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
						Uncorrected	Corrected
					Infinite Cloud dose	2.76E+00	2.73E+00
					Finite Cloud Dose	8.58E-02	8.49E-02

** - KR-85 dose is multiplied by 3 to reflect a 30% release instead of 10%

The TSC thyroid dose listed below has been source and DCF corrected (Tables 17 & 18). The resultant dose value listed at the bottom of Table 18 is 1.95E+01 rem - thyroid.

TABLE 17 - SOURCE TERM CORRECTION TO CRADLE THYROID DOSE RESULTS-TSC

	Source Term Correction	100 h - 100.0028	100.0028 - 100.503	100.503 102	102 820	Integrated Dose rem	Corrected Dose (rem)
I-131 ELEM	0.9988	9.39E-06	1.13E+01	1.28E+01	1.40E-01	2.42E+01	2.42E+01
I-132 ELEM	0.9381	2.37E-20	2.60E-14	2.54E-14	1.80E-16	5.16E-14	4.84E-14
I-133 ELEM	0.9970	1.98E-07	2.37E-01	2.63E-01	2.76E-03	5.03E-01	5.01E-01
I-134 ELEM	0.9939	3.54E-42	3.31E-36	2.56E-36	8.78E-39	5.88E-36	5.84E-36
I-135 ELEM	1.0134	3.46E-11	4.04E-05	4.33E-05	4.09E-07	8.41E-05	8.52E-05
I-131 ORG.	0.9988	4.13E-07	4.98E-01	5.62E-01	6.14E-03	1.07E+00	1.06E+00
I-132 ORG.	0.9381	1.04E-21	1.14E-15	1.12E-15	7.92E-18	2.27E-15	2.13E-15
I-133 ORG.	0.9970	8.71E-09	1.04E-02	1.16E-02	1.21E-04	2.21E-02	2.20E-02
I-134 ORG.	0.9939	1.55E-43	1.46E-37	1.12E-37	3.86E-40	2.58E-37	2.57E-37
I-135 ORG.	1.0134	1.52E-12	1.77E-06	1.90E-06	1.80E-08	3.70E-06	3.75E-06
I-131 PART.	0.9988	5.16E-07	6.22E-01	7.02E-01	7.68E-03	1.33E+00	1.33E+00
I-132 PART.	0.9381	1.30E-21	1.43E-15	1.40E-15	9.90E-18	2.83E-15	2.66E-15
I-133 PART.	0.9970	1.09E-08	1.30E-02	1.45E-02	1.51E-04	2.76E-02	2.75E-02
I-134 PART.	0.9939	1.94E-43	1.82E-37	1.41E-37	4.82E-40	3.23E-37	3.21E-37
I-135 PART.	1.0134	1.90E-12	2.22E-06	2.38E-06	2.25E-08	4.62E-06	4.68E-06
						Uncorrected	Corrected
					Total	2.72E+01	2.72E+01

TABLE 18 - DCF CORRECTION TO CRADLE THYROID DOSE RESULTS-TSC

	Corrected Dose (rem)	R.G. 1.109 to ICRP 30 DCF Corr.	Total Corrected Dose (rem)
I-131 ELEM	2.42E+01	7.20E-01	1.74E+01
I-132 ELEM	4.84E-14	4.40E-01	2.13E-14
I-133 ELEM	5.01E-01	6.74E-01	3.38E-01
I-134 ELEM	5.84E-36	2.88E-01	1.68E-36
I-135 ELEM	8.52E-05	5.62E-01	4.79E-05
I-131 ORG.	1.06E+00	7.20E-01	7.66E-01
I-132 ORG.	2.13E-15	4.40E-01	9.36E-16
I-133 ORG.	2.20E-02	6.74E-01	1.49E-02
I-134 ORG.	2.57E-37	2.88E-01	7.40E-38
I-135 ORG.	3.75E-06	5.62E-01	2.10E-06
I-131 PART.	1.33E+00	7.20E-01	9.58E-01
I-132 PART.	2.66E-15	4.40E-01	1.17E-15
I-133 PART.	2.75E-02	6.74E-01	1.86E-02
I-134 PART.	3.21E-37	2.88E-01	9.25E-38
I-135 PART.	4.68E-06	5.62E-01	2.63E-06
		Total:	1.95E+01

6.7.2. Plume shine to the TSC

Since the X/Qs for the TSC are same as for the MP3 Control Room, the worst case plume shine would be from the vent release (Section 6.5.2). Since the only difference is in the amount of shielding, the MP3 control room plume from a vent release (0.006 rem) will be adjusted for shielding.

The TSC shielding provides 1 feet of concrete (Assumption 29) which provides a radiation reduction factor of approximately 0.1 (Ref. 22 pg 149). Ratioing the MP3 control room shielding factor of 0.003 to the 0.1 results in:

Plume dose to control room, rem =MP3 control room plume shine * TSC shielding reduction / MP3 Control room shielding factor.

Plume dose to control room, rem = 0.006 rem * 0.1/ 0.003
= 0.20 rem

6.7.3. Filter shine from charcoal filter beds

From CRADLE run # 15634, the amount of iodine in the TSC has been determined. I-131 and I-133 are the dominant iodines in the TSC (with average gamma enrgies of 0.39 Mev and 0.444 Mev, respectively). For simplicity, since the I-131 and I-133 energies are similar, all activity will be assumed to be I-131. The iodine activity in the TSC at the end of each time step in CRADLE will be assumed to be completely filtered by the charcoal filter and applied for dose evaluation over the duration of that time step. The activity in the TSC for each subsequent time step will be added to the inventory on the filter and the activity existing on the filter prior to the time step will be decayed. After the first 2 hours post FHA, no more iodine enters the TSC therefore the filter inventory will be decayed for the remainder of the 30 days, with decay correction being performed at approximately 8 day intervals from T = 102 to T = 820 hours post FHA. From the CRADLE run, the iodine activity in the TSC at the beginning of each time step is listed below in Tabl e 19. The dose for each time step would be calculated using the gamma constant, Γ, for I-131 from Ref 22, pg 131 of 2.2 . Per Ref 22:

Γ / 10 = R/hr at 1 meter/ Ci

2.2 / 10 = 0.22 R/hr at 1 meter/ Ci

Table 19 - TSC filter dose evaluation

T, hours	CRADLE Iodine Activity in TSC, Ci	Cumulative iodine on filter	Dose rate @ 1 meter from filter, R/hr	Dose over period, R
100		6.22E-06	1.37E-06	
100.0028	6.22E-06	1.24E-05	2.74E-06	3.83E-09
100.53	2.17E-02	2.17E-02	4.78E-03	1.44E-06
102	2.79E-04	2.19E-02	4.81E-03	7.02E-03
294		1.10E-02	2.42E-03	9.24E-01
486		5.52E-03	1.21E-03	4.64E-01
678		2.77E-03	6.10E-04	2.33E-01
820				8.66E-02
		Total 30 day dose from filter shine:		1.71E+00

The unshielded shine dose from the filter is 1.71 rem @ 1 meter. From Reference 12, page D3, it is identified that there are multiple distance/ shielding configurations. For conservatism, the assumption of 1 foot of concrete and 1 meter distance is used. From Assumption 30, 1 foot of concrete shielding can be credited, with an associated transmission factor of 0.1 (Section 6.5.3). The resultant dose at 1 meter is 1.71E-01 rem. It should be noted that no credit is taken for occupancy factor in the TSC, therefore this evaluation is conservative.

6.8. *Impact of Additional Fuel Failure*

Attachment 4 provides information identifying the amount of fuel damage associated with 1 bundle dropping on another bundle. This results in a potential failure of 1 full bundle plus an additional 50 rods from the other bundle. Since there are 264 rods in a fuel assembly (per Attachment 4 (pg 52 of this calculation) there are 264 rods in 1 fuel assembly), the additional 50 rods would increase the release fraction determined in Section 6.2 by 19% (50/264). Multiplying the release fractions by 1.19 would result in the appropriate amount of activity released to containment but the proportionality of dose to activity allows the doses to be determined based on multiplying the doses based on 1 bundle by 1.19 and would result in the dose associated with failure of 1 bundle plus 50 rods. For additional conservatism, a multiplier of 1.25 will be used instead of 1.19. This multiplier will be applied to the doses in Table A of Section 2 and reflected in Table B of Section 2.

7. DESIGN VERIFICATION

A design review was performed in accordance with DCM-04 "Design Inputs and Design Verification". All design inputs were verified and assumptions were validated.

8. ATTACHMENTS

Microsoft Excel Worksheet

NOTE: The block to the left represents an electronic link to the supporting spreadsheet and is not functional in hardcopy.

Attachment 1 - Response Time Testing of RE-41
Attachment 2 - Floppies with TACT and CRADLE outputs
Attachment 3 - Reviewer comments
Attachment 4 - Westinghouse Fuel Failure Analysis

Calc. M3FHA-01791-R3, Rev. 0
"MP3 Fuel Handling Accident in Containment - 10 minute closure time"

Attachment 2 - page 46

Attachment 3

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Calculation Review Comment and Resolution Form

(Sheet 1 of 1)

Calculation Number: M3FHA-01791-R3 Revision: 0 CCN NA

Calculation Title: MP3 Fuel Handling Accident In Containment - 10 Minute Closure Time

Calc. Originator: S. M. Torf Reviewer (PRINT): K. Ju

This form is intended to document significant comments and their resolutions. Typographical errors and other editorial recommendations may be marked up in the calculation text and presented to the originator

Review Type ☞ ☐ **Interdiscipline** ☒ **Independent**

Reviewer (SIGN) K. Ju / [signature] Date: 5/17/00 5/30/00

(signature signifies all comments have been resolved to your satisfaction)

Item	Page/Section	Comments	Response
1	3	General: Reference details are incomplete - need dates, titles, etc.	done
2	General	General: References to assumptions in body of calc need to be correct	all references to assumptionschecked and corrected
3	General	numerous editorial corrections	done
4	6.4	the TACT run supporting offsite dose is not representative of release nor conservative	new TACT runs were made to support both release paths
5	6.5.1.1	there is no basis for MP3 control room flow rates used	bases added to Section 4
6	6	General: the uncorrected dose values should be listed in the tables that provide corrected dose values	done
7	6.6.1	there is no basis for MP2 control room flow rates used	bases added to Section 4
8	6.7.1	the TSC CRADLE output is not consistent with dose tables in this section	tables were corrected to reflect CRADLE output`
9	6.7.1	Table 16 is listing the incorrect, uncorrected, finite cloud, whole body dose	the correct value was entered and table results were revised.

Attachment 4

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PAT-77-002

from NFD - Product Engineering
via 249-4415
date August 25, 1977
subject RESAR 41, Fuel Handling Accident

to M. Beaumont*

cc: S. Nakazato*
M. G. Arlotti
D. F. Dudek
J. Petrow
F. Thompson*
PE Managers (6)
B. H. Carroll

*w/attachments

An analysis to determine the maximum number of fuel rods that could be ruptured as a result of a dropped fuel assembly handling accident was performed. An assembly with 14 ft. fuel was considered in the analysis per your request to provide information and support for RESAR 41. The results of the analysis which included the viscous effects of the water indicated that a maximum of 314 fuel rods could be ruptured. A detailed description of the analysis and results are presented in the attachment.

L. T. Gesinski

L. T. Gesinski
Product Analysis & Testing

W. D. Rabenstein

Attachment reviewed by: W. D. Rabenstein
Product Analysis & Testing

/b
att.

DROPPED FUEL ASSEMBLY ANALYSIS

Introduction

In the process of refueling a reactor, it is necessary to transport the irradiated fuel assemblies to a spent fuel storage area. During the transfer operation, the fuel assemblies are handled remotely and are subject to potential damage. The purpose of this analysis is to determine the number of fuel rods that could be ruptured as a result of a fuel assembly being accidently dropped onto the core or spent fuel racks.

A previous analysis which addressed the subject was reported by the NRC (Ref. 1); however, the effects of the hydraulic drag on a falling fuel assembly were conservatively neglected. Information obtained from fuel assembly flow tests indicated that drag coefficients associated with a fuel assembly falling in water were significant. The fuel assembly test data was used to determine the impact velocity and resulting fuel damage.

Analytical Procedure

The analytical procedure for assessing the fuel damage was to assume that the total kinetic energy of the dropped assembly was converted into either fuel clad elastic strain energy or impact fracture energy. In the handling process, it is possible that the fuel assembly could be dropped a maximum distance of 13.5 feet over the core and 3.5 feet in spent fuel building plus an addition 15.5 ft. for locations which do not contain fuel.

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The initial consideration was to assume that the fuel assembly was dropped vertically (minimum drag cross-section). Test data indicated that a flow velocity of 13.7 ft/sec (at 70°F) was sufficient to produce a lift force equal to the weight of the fuel assembly minus the bouyant force. This information was obtained for a 17x17 fuel assembly with 12 foot fuel and seven grids (ref. 2). However, the data was extrapolated to assess the fuel damage to a 414 fuel assembly design.

The fuel assembly drag coefficient can be determined using the 13.7 ft/sec flow velocity and considering it a terminal velocity since the fuel assembly is in equilibrium. The equation of motion for the dropped assembly is given by

$$m\ddot{x} = W - F_b - F_d \qquad \text{eq. (1)}$$

where F_b = bouyant force

F_d = viscous drag force

Equation (1) can be written in terms of the drag coefficient as follows:

$$m\, dv/dt = W - F_b - \frac{C_d \rho V^2}{2\, g} \qquad \text{eq(2)}$$

For the case in which the fuel assembly attains a terminal velocity (i.e. V = constant, dv/dt = 0), equation (2) can be solved for drag coefficient.

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$$C_d = (W-F_b)\ 2g/\rho V^2 \qquad \text{eq. (3)}$$

where: V_t = terminal velocity

The drag coefficient for the 13.7 ft/sec velocity was found to be 28.0. The fuel assembly velocity as a function of drop can be obtained by integration of eq (2).

Let $a = W-F_b$ and $b = C_d\rho/2g$, thru equation (2) can be written as

$$\int \frac{1}{m}\,dt = \int \frac{1}{a-bV^2}\,dv$$

$$\text{or} \int \frac{1}{m}\,dx = \int \frac{V}{a-bV^2}\,dv \qquad \text{eq. (4)}$$

Integrating eq. (4), we obtain the following relations for the drop distance as a function of velocity.

$$S = m/2b\ \left(\log(-a/b) - \log(V^2 - a/b)\right) \qquad \text{eq. (5)}$$

since $V_t = \sqrt{a/b}$, equation (5) can be written the form

$$S = \frac{m}{2b}\ \log\left[\left(\frac{V_t}{V_t - V}\right)\right] = \frac{m}{2b}\ \log\left[\left(\frac{1}{1-V/V_t}\right)\right] \qquad \text{eq. (6)}$$

Examination of eq. (6) indicated that as the variable (V) approaches the terminal velocity, the drop distance, S, tends to infinity. However, eq. (6) may be evaluated for specific values of velocity to show that the fuel assembly attains 98 per cent of the terminal velocity ($.98\ V_t$) within a 12 ft. drop.

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414 Fuel Assembly Extrapolation

Based on hydraulic calculations, the drag coefficient for the 414 fuel assembly design is given by $C_d = \frac{18.7}{14.0} \times (28.0) = 37.4$

The terminal velocity corresponding to this drag coeffient was found to be

$$V_t^2 = \frac{W'}{W} \cdot \frac{C_d'}{C_d} (V_t')^2 = \frac{1600}{1350} \frac{28.}{37.4} (13.7)^2 = 166.5$$

$V_t = 12.9$ ft/sec $\qquad C_d'$ V_t' · values for D-loop test assembly

The 414 fuel assembly design reaches 98 per cent of the terminal velocity within a drop distance of 10.9 ft.

Fuel Assembly Kinetic Energy

During the process of reloading, a fuel assembly can be lifted to a maximum height of 13-1/2 ft. above the top of the core. If we assume the fuel assembly is dropped and then strikes either the top of another assembly or the lower core plate, the fuel assembly velocity at impact would be slightly less than the terminal velocity of 12.9 ft/sec.

The fuel assembly kinetic energy based on the terminal velocity is given by

$$KE = 1/2\ mV^2$$

$$KE = 1/2 \ \frac{1725}{32.2} \ (12.9)^2 = 4460 \text{ ft-lbs}$$

For a drop accident in which the fuel assembly (vertically) impacts a rigid surface, a significant amount of energy is required to buckle the bottom nozzle. The energy dissipated by nozzle plastic deformation was estimated 2500 ft-lbs (see Appendix B).

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No. of Fuel Rods Fractured

The energy required to break a fuel rod in compression and bending was estimated (Ref. 1) to be 90 ft-lbs and 1 ft-lbs respectively. If it is assumed that the total kinetic energy is absorbed by fracturing the rods, a total of 50 fuel rods would be broken. This value would be reduced to 22 rods if the energy dissipated by the bottom nozzle is taken into account.

Spent Fuel Storage Accident

The maximum drop height would be 19 ft. if the fuel assembly fell into an empty rack location. If the energy absorbed by the rack is neglected, the same number of rods will be fractured for this accident as predicted for an accidental drop over the core. If a fuel assembly is dropped an the rack structure, the structure is designed to preclude penetration at points between two assemblies. The impact velocity would be 9.2 ft/sec with a resulting kinetic energy of 2267 ft-lbs. A total of 25 fuel rods would be broken at the initial impact with additional rod fractures caused by the fallover.

Fallover Accident

After impacting with a rigid surface, the fuel assembly can tip over and fall to a horizontal position. The fuel assembly velocity profile for a fallover accident taking into account the viscous drag effects of the water is presented in Appendix A. The fuel assembly kinetic energy for the calculated velocity at impact is 412 ft-lbs. This energy could cause the breakage of 264 rods in bending.

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Conclusion

It can be concluded that the maximum number of fuel rods that can be damaged as a result of a dropped fuel assembly are as follows:

a) 50 fuel rods in the impacted assembly plus 264 rods for the assembly fallover or the equivalent of 1.19 assemblies in the core.

b) 50 fuel rods for an assembly dropped at a vacant location in the spent fuel storage area or 264 rods (1.0 equivalent assembly) for a fallover accident in the same area.

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REFERENCES

1) NRC Report, Docket No. STN 50-516, 50-517

2) WCAP 8254; "17x17 Hydraulic Flow Test".

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SKETCH SHEET
FORM 28577

ATTACHMENT 'A'

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The change from laminar to turbulent boundary layer on a flat plate has been seen (Art. 117) to occur at a critical Reynolds number dependent upon the turbulence of the approaching flow. It also occurs with a sphere, and with increased turbulence in the approaching flow the sudden drop in the drag coefficient curve occurs at lower Reynolds number. Thus a sphere may be used as a relative measure of turbulence by noting the Reynolds number at which a drag coefficient of 0.30 (see Fig. 259) is obtained. Before the development of the hot-wire anemometer (Art. 93), this method was used to compare the turbulence characteristics of different wind tunnels.

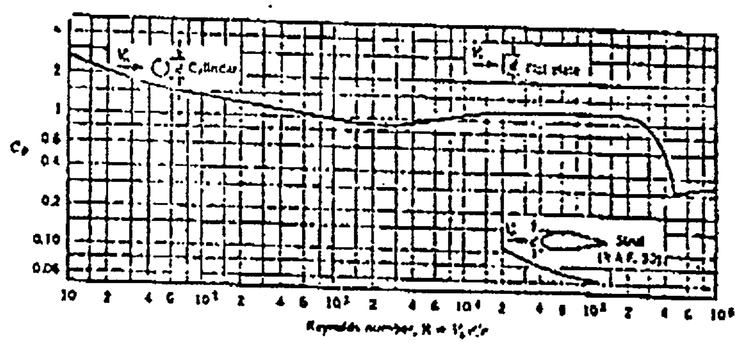

FIG. 260. Drag coefficients for circular cylinders, flat plates, and streamlined struts of infinite length.[34]

The drag coefficient of a thin circular disk placed normal to the flow shows practically no variation with the Reynolds number, since the separation point is fixed at the edge of the disk and cannot shift from this point, regardless of the condition of the boundary layer. Thus the width of the wake remains essentially constant, as does the drag coefficient. This idea may be usefully generalized and applied to all brusque or very rough objects in a fluid flow; experiment indicates that such objects have drag coefficients which are essentially constant in the range of high Reynolds numbers.[35]

The drag coefficients of circular cylinders placed normal to the flow show characteristics similar to those of spheres. The coefficients shown in Fig. 260 are for infinitely long cylinders. The drag coef-

[34] Data from L. Prandtl, *Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen*, Vol. II, p. 24, R. Oldenbourg, 1923; and B. A. Bakhmeteff, *Mechanics of Fluids*, Part II, p. 44, Columbia University Press, 1933.

[35] Compare this with the relation of the friction factor *f*, and Reynolds number, R, for rough pipes, Figs. 119 and 121, and also the fact that the minor loss coefficients of pipe flow show little variation with the Reynolds number.

REF. FLUID MECHANIC – VENNARD – WILEY PUB.