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

CALCULATION TITLE PAGE

Total Number of Pages: 49

MP3- Fuel Handling Accident In the Fuel Building

TITLE

M3FHA-01792-R3	0	NA
CALCULATION No.	**Revision No.**	**System Name**

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

NA
VENDOR NAME

1

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

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

INCORPORATES:

CCN NO:	AGAINST REV.
NA	NA

Executive Summary

The MP3 Control Room, EAB and LPZ doses are summarized below along with the MP2 Control Room and TSC doses.

	Beta Dose, rem	Thyroid dose, rem	Whole Body Dose, rem
EAB	NA	6.87E+00	5.28E-01
LPZ	NA	4.65E-01	3.57E-02
MP3 Cont RM	1.04E+00	4.21E+00	1.10E-01
MP2 Cont RM	2.17E+01	2.27E+00	7.08E-01
TSC	2.43E+00	1.44E+00	5.70E-01

The doses associated with an MP3 FHA occurring in the Fuel Building with 100 hours decay from shutdown, are within GDC 19 requirements for the control room and "well within" 10 CFR 100 requirements. The dose consequences for the FHA with 60 day decay and no credit for filtration by the Fuel Building Ventilation system are bounded by the FHA at 100 hours decay time.

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

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:

PassPort DATABASE INPUTs

Page 2

Calculation Number: M3FHA-01792-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Superseded By: NA Supersedes Calc: NA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
			P(R)-697	0	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-148A	1	36
12179-EM-148C	1	19

Comments:
NA

NOTE: Avoid multiple item references on a line, e.g., LT 1210 A-D requires four separate lines. 1

TABLE OF CONTENTS

49 PAGES TOTAL

1. PURPOSE

The purpose of this calculation is to determine the dose consequences of a fuel handling accident (FHA) in the Fuel Building for 100 hours decay and for 60 days decay.

This calculation supports AR # 99014682-04.

2. SUMMARY OF RESULTS

The MP3 Control Room, EAB and LPZ doses are summarized below along with the MP2 Control Room and TSC doses.

	Beta Dose, rem	Thyroid dose, rem	Whole Body Dose, rem
EAB	NA	6.87E+00	5.28E-01
LPZ	NA	4.65E-01	3.57E-02
MP3 Control Room	1.04E+00	4.21E+00	6.44E-02
Plume shine component	NA	NA	1.38E-02
Filter shine component	NA	NA	3.17E -02
MP3 Control Room Totals	1.04E+00	4.21E+00	1.10E-01
MP2 Control Room	2.17E+01	2.27E+00	7.03E-01
Plume shine component	NA	NA	4.96E-03
Filter shine component	NA	NA	2.90E-04
MP2 Control Room Totals	2.17E+01	2.27E+00	7.08E-01
TSC	2.43E+00	1.44E+00	7.86E-02
Plume shine component	NA	NA	4.60E-01
Filter shine component	NA	NA	3.17E-02
TSC Totals	2.43E+00	1.44E+00	5.70E-01

The doses associated with an MP3 FHA occurring in the Fuel Building with 100 hours decay from shutdown, 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. Appendix A identifies that the dose consequences for the FHA in the Fuel Building with 60 day decay and no credit for filtration by the Fuel Building Ventilation system are bounded by the FHA in the Fuel Building at 100 hours decay time.

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 ä 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. Intentionally Blank
24. Calc. M2M3CR-01671R3, Rev 0, "MP2 Radiological consequences to the MP3 Control Room", dated 3/22/99
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. DWG 12179-EM-148A-36, Rev. 36, "P&ID Reactor Plant Ventilation"
28. DWG 12179-EM-148C-19, Rev. 19, "P&ID Reactor Plant Ventilation"
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 # P(R)-697, Rev. 0, "Spent Fuel Pool and Fuel Building Volumes", dated 12/1/80

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 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. (50% of 230 CFM, 230 CFM is from Assumption 9).	Consistent with Ref. 12 (Datum 44, pg 47). The 10 seconds is based on the time it takes for the control room to be isolated , which will be verified in Section 6 of this calculation.
8) Release Point: - Ventilation vent	Tech Spec 3.9.12 requires at least one Fuel Building Exhaust Filter System to be operating during fuel movement if fuel is decayed less than 60 days. This system exhausts to the ventilation vent (References 27 & 28).
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.

ASSUMPTIONS	BASIS
10) MP2 & MP3 Control Room Unfiltered inleakage after initiation of recirculation due to ingress/ egress = 10 cfm.	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). See Assumption 42 for additional information regarding the conservatism of this approach.
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 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.
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) Control Room 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	Ref. 13 (MP2) Ref. 14 (MP3) Ground release X/Qs are lower and therefore less conservative. They will not be used for the control room dose calculation.
17) Offsite X/Q's (sec/m3) vent release (0-2) hr EAB 4.30E-04 (0-8) hr LPZ 2.91E-05	Ref. 12
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

ASSUMPTIONS	BASIS
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 plus 50 rods is assumed to fail in a FHA in the Fuel Building.	See Attachment 4
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.	Ref. 11 - Tech. Spec 3.9.11
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. This is based on an air change rate of 7 / hour.	Ref. 5 - the exponential rate ensures esentially all activity is released over a 2 hour period. The 7 / hour is determined based on exhaust flow, 41,360 CFM (Assmptn 45) divided by Fuel building volume, 3.53.E+05 ft3 (Assmptn 43).
38) The Fuel Building Ventilation System filter efficiency for iodines is 95%.	Tech. Spec 3.9.12 requires the charcoal filtration have a methyl iodide penetration of less than 0.175%. This implies an iodine removal effectiveness of >99%. For conservatism, 95% effectiveness will be used.
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 inleakge 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) Fuel Building Free Air Volume = 3.53E+05 ft3	Ref. 32
44) MP2 Control Room Volume = 3.565E+04 ft3	Ref. 20
45) Exhaust Rate from Fuel Building - assume 2 trains running at 20,680 CFM each for a total of 41,360 CFM.	Ref. 27

5. METHOD OF ANALYSIS

This analysis will evaluate the dose consequences of a fuel handling accident (FHA) in the fuel building.

The scenario analyzed consists of a FHA in the Fuel Building where 1.19 fuel bundles (1 bundle plus 50 rods) are damaged. The radiation monitors provide no auto-initiation of equipment, they only provide indication. In addition, Tech specs require the Fuel Building ventilation to be aligned when moving fuel in the pool such that exhaust from the building passes through charcoal filters. Ventilation exhaust from the Fuel Building will release essentially all airborne activity over a 2 hour period.

The dose components evaluated for this accident scenario 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 the Fuel Building is initiated

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

@T = 1 minute: MP2 control room isolates based on MP2 control room inlet rad monitor and isolation damper response time (Reviewer Comment: 1 minute is extremely conservative when considering that MP2 control room isolates within 10 seconds)

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

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

@R = 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: the release is essentially complete with 99.99% of activity released

@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 release on control room inlet radiation monitors is evaluated based on 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 room 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 dose 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. 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 (1.19 damaged ass'y/ 193 ass'ys in a core)
DF - spent fuel 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:

iodines -	1.26E-05
noble gases (except KR-85) -	1.05E-03
KR-85 -	3.14E-03.

These release fractions will be used in 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)	Spent Fuel Pool DF	Release Fraction from pool	CRADLE Activity, Ci	MP3 to CRADLE Source Term Conversion Factor
I-131	9.11E+07	1.70	0.12	1.19	193	100	1.26E-05	9.12E+07	9.99E-01
I-132	1.30E+08	1.70	0.12	1.19	193	100	1.26E-05	1.38E+08	9.38E-01
I-133	2.04E+08	1.70	0.12	1.19	193	100	1.26E-05	2.04E+08	9.97E-01
I-134	2.38E+08	1.70	0.12	1.19	193	100	1.26E-05	2.39E+08	9.94E-01
I-135	1.88E+08	1.70	0.12	1.19	193	100	1.26E-05	1.86E+08	1.01E+00
Kr-83m	1.58E+07	1.70	0.10	1.19	193	1	1.05E-03	1.51E+07	1.05E+00
Kr-85	8.83E+05	1.70	0.30	1.19	193	1	3.14E-03	1.49E+06	5.92E-01
Kr-85m	3.96E+07	1.70	0.10	1.19	193	1	1.05E-03	4.72E+07	8.40E-01
Kr-87	7.71E+07	1.70	0.10	1.19	193	1	1.05E-03	8.49E+07	9.08E-01
Kr-88	1.08E+08	1.70	0.10	1.19	193	1	1.05E-03	1.16E+08	9.32E-01
Kr-89	1.40E+08	1.70	0.10	1.19	193	1	1.05E-03	1.45E+08	9.66E-01
Xe-131m	8.01E+04	1.70	0.10	1.19	193	1	1.05E-03	9.44E+05	8.49E-02
Xe-133m	4.89E+06	1.70	0.10	1.19	193	1	1.05E-03	5.03E+06	9.72E-01
Xe-133	2.03E+08	1.70	0.10	1.19	193	1	1.05E-03	2.04E+08	9.94E-01
Xe-135m	5.50E+07	1.70	0.10	1.19	193	1	1.05E-03	5.66E+07	9.72E-01
Xe-135	5.38E+07	1.70	0.10	1.19	193	1	1.05E-03	1.95E+08	2.76E-01

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)	Spent Fuel Pool DF	Release Fraction from pool	CRADLE Activity, Ci	MP3 to CRADLE Source Term Conversion Factor
Xe-137	1.83E+08	1.70	0.10	1.19	193	1	1.05E-03	1.86E+08	9.85E-01
Xe-138	1.80E+08	1.70	0.10	1.19	193	1	1.05E-03	1.74E+08	1.04E+00

6.2. Radiation monitor impact

There are 2 radiation monitoring systems that must be addressed because they may impact isolation of MP2/3 control rooms and the TSC. They are the MP3 Control Room Inlet Vent rad Monitor and the MP2 Control Room Ventilation Intake rad monitor. They will be addressed individually below.

6.2.1. 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 the Fuel Building, 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.

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

An air change rate of 7/hr was used for the release rate from the Fuel Building to the Ventilation Vent. This ensures that essentially all airborne activity is released from Fuel building to the environment within 2 hours. From CRADLE run # 08781, dated 5/22/00, it has been determined that the Xe-133 activity in the Fuel Building (CRADLE node 1) at T = 0 sec post-FHA is 1.242E+05 Ci. A determination at T = 0 second was made to identify the earliest possible time for release and detection by the RE16 rad monitors.

The release rate from the Fuel Bldg at T= 0 second is 1.242E+05 Ci * 7 / hour = 8.69E+05 Ci/ hour = 2.42E+02 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 9.08E-01 uCi/cc (= 2.42E+02 Ci/sec * 3.75E-03 sec/m^3). This will alarm the inlet rad monitor based on the alarm setpoint of 1.5E-05 uCi/cc and as a result, 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 9.08E-01 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 = 9.08E-01 uCi/cc
Step increase (Cf) = 9.08E-01 uCi/cc / 1.3E-08 uCi uCi/cc/cpm = 6.99E+07 cpm
Since the detector instantaneous count rate (6.99E+07 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:
$Cs = Cf\,(1-e^{-T/RC})$
$Cs / Cf = (1-e^{-T/RC})$
$1154 / 6.99E+07 = (1-e^{-T/1\,sec})$

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

T = 1.65E-05 sec << 1 sec

The response time is << 1 second. For conservatism, 5 seconds will be used. 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.

6.2.2. MP2 Control Room Ventilation Intake, RM9799A&B

The MP2 control room rad monitor response will be determined using the methods of Section 6.2.1 for the MP3 control room because most of it is still applicable. 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 4.54E-02 uCi/cc from Section 6.2.1 to arrive at the air concentration at the Unit 2 Control room. The resulting value is 1.25E-03/ 3.75E-03 x 4.54E-02 uCi/cc = 1.51E-02 uCi/cc. Therefore activity the MP2 control room rad monitor sees is 1.51E-02 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 1.51E-02 uCi/cc activity, the rad monitor will see approximately 1.7 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, 1.7 mr/hr

$1/ 1.7 = 1 - e^{-(T/1.98)}$

T = 1.8E+00 sec

Therefore rad monitor response time is 1.8E+00 seconds and will be assumed to be 5 seconds for conservatism. From Assumption 26, the MP2 control room isolation damper closing time is 5 seconds. This results in an isolation time (including detector response and damper closure) of 10 seconds.

6.3. *Offsite dose*

TACT III was used to evaluate offsite dose based on a puff release from the Fuel Building. The puff release was used over an exponential release for simplicity and conservatism in this offsite dose analysis. The following TACT data set was run based on the failure of 1 fuel bundle. Since the calculation assumes the failure of 1 bundle plus 50 rods (equivalent to 1.19 bundles) the dose results will be multiplied by 1.25 to compensate for the additional 50 rods, plus margin.

The ground release TACT input dataset is listed below.

```
MP3 FHA IN FUEL BUILDING- PUFF RELEASE                          00000100
1 3 1 21 5 18 00 0 0                                            00000200
3636. 0.0 1.26E-5 1.05E-3 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 1.00E1                                                     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  0 100.0 102.000                                              00000640
10 1  1 1.0E5                                                      00000700
12 1  1 95.0                                                       00000710
13 1  1 95.0                                                       00000720
14 1  1 95.0                                                       00000730
17 6  0 4.30E-4 2.91E-5 3.47E-4 0.0 0.0 0.0                        00000800
1  2  0 102.0 820.000                                              00000900
17 6  0 0.00E-0 0.00E-0 3.47E-4 0.0 0.0 0.0                        00001000
0/                                                                 00001500
```

TACT run# 11287, performed on 5/18/2000, provides the following whole body dose information for the vent releases.

	(TACT #11287)
EAB - whole body:	4.218E-01 rem
LPZ - whole body:	2.854E-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 #11287)
EAB - thyroid:	5.491E+00 rem
LPZ - thyroid:	3.716E-01 rem

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.

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*
Vent release	9.794E-01	0.000E+00	2.059E-02	0.000E+00	3.660E-06	*7.1905E-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*
Vent release		7.636E+00	5.168E-01	*5.491E+00*	*3.716E-01*

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

Applying the 1.25 factor to compensate for the additional 50 rods results in the following offsite doses :

	Whole body, rem	Thyroid, rem
EAB	5.273E-01	6.864E+00
LPZ	3.568E-02	4.645E-01

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	0.0	0.0	0.0	0.0			00002010
0.0	7.00000	7.00000	7.00000	7.00000	7.00000	7.00000	00002100
7.0	0.0	0.0	0.0	0.0			00002110
95.0	95.0	95.0					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

6.4.2. Plume shine to the MP3 control room

Vent release plume shine is determined by taking the EAB whole body dose from the TACT run # 11287 (provided in Attachment 2), ratioing the "vent to control room" X/Q to it and then adjusting for dose reduction as a result of MP3 control room shielding.

The source term corrected EAB whole body dose from Section 6.3 is 5.27E-01 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 = 5.27E-01 rem * (3.75E-03/ 4.30E-04) * 0.003
= 1.38E-02 rem plume shine from the vent release

6.4.3. Filter shine from MP3 Control Room 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 #08781, 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 results in a total activity of less than 3E-02 Ci and will be applied for a conservative determination at T = 0 for the entire 720 hours of the accident. This activity will be treated as a point source and dose/ dose rate determined as follows. 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

For 3E-02 Ci of iodine, the dose rate at 1 meter is 6.6E-03 R/hr

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 6.6E-03 R/hr @ 1 meter 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 4.4E-04 R/hr @ 12' 8 1/2".

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 room of 4.4E-05 R/hr.

Multiplying the dose rate by 30 days (720 hours) results in a dose of 3.17E-02 Rem.

6.5. MP 2 control room

6.5.1. Submersion and inhalation dose

The CRADLE input to support the MP2 control room dose determination from the MP3 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 # 12735, dated 5/24/2000 (provided with Attachment 2). (NOTE: the reviewer noted that in the following input dataset, the MP2 control room does not isolate until 1 minute post-FHA. This is extremely conservative when considering the control room will actually isolate in 10 seconds or less)

CRADLE Input for MP2 Control Room - MP3 Ventilation vent release path

```
                                                                                 100000100
MP-2 CR FROM FUEL BUILDING RELEASE                                                00000200
     3636.  3.565E+4         1.          0          12                            00000300
       0.0       100.  100.0014   100.0167   100.1833   100.1861   101.0194       00000400
  101.6278      102.0     108.0      124.0      196.0      820.0                  00000410
       0.0        0.0                                                             00000500
  1.26-05     1.05E-3                                                             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
       0.0        0.0                                                             00001000
      800.       800.     800.0       130.       10.0       10.0       10.0       00001010
       10.        10.       10.        10.        10.                             00001100
      000.        0.0       0.0         0.        0.0        0.0        0.0       00001110
       0.0        0.0       0.0         0.        0.0                             00001200
      800.       800.     800.0       130.       10.0       10.0       10.0       00001210
       10.        10.       10.        10.        10.                             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
     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
```

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	0.00000	0.00000	0.00000	0.00000			00002010
0.0	7.00000	7.00000	7.00000	7.00000	7.00000	7.00000	00002100
7.0	0.00000	0.00000	0.00000	0.00000			00002110
95.0	95.0	95.0					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

Vent release plume shine is determined by taking the EAB whole body dose from the TACT run # 11287 (provided in Attachment 2), ratioing the "vent to control room" X/Q to it and then adjusting for dose reduction as a result of MP3 control room shielding.

The source term corrected EAB whole body dose from Section 6.3 is 5.27E-01 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 = 5.27E-01 rem * (1.25E-03/ 4.30E-04) * 0.003
= 4.96E-03 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 35'. From Assumption 31, the MP2 control room has 18" of shielding. Using Cradle run #12735, dated 5/24/00, the iodine activity in the control room is provided. It will be assumed that 100% of the iodine activity identified at the beginning of each time step in the CRADLE run is trapped on the filter. The sum of all of this activity will be used as the soure term on the filter from T=0. This activity will be treated as a point source and dose/ dose rate determined as follows.

From CRADLE run # 12735, 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 T = 0 time step and treated as a point source sourrounded by 18" of concrete (Assumption 31). From the CRADLE run, the sum of iodine activity in the control room is estimated at less than 2E-02 Ci. 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 2E-02 Ci of iodine.

Applying 2E-02 Ci of iodine to 2E-05 R/hr - Ci results in a dose rate of 4E-07 R/hr. Multiplying this by 30 days (720 hours) results in a dose of 2.9E-04 R which is essentially negligible.

6.6. *Technical Support Center (TSC) dose*

6.6.1. 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 # 12749, dated 5/24/2000 (provided on CD with Attachment 2).

CRADLE Input for TSC

```
TSC   FHA FUEL BUILDING RELEASE OVER 2 HOURS                                    100000100
     3636.    3.32E+4       1.          0          5                             00000200
       0.0       100.  100.0028   100.5030       102.        820.0               00000300
       0.0        0.0                                                            00000410
   1.26-05    1.05E-3                                                            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
       0.0    7.00000   7.00000    7.00000    0.00000                            00002100
      95.0       95.0      95.0                                                  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
```

The TSC beta dose listed below has been source corrected (Table 15). The resultant dose value listed at the bottom of Table 15 is 2.43E+00 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	1.48E-08	1.06E-04	4.54E-05	2.63E-07	1.52E-04	1.51E-04
I-132 ELEM	0.9381	8.87E-21	5.89E-17	2.16E-17	8.07E-20	8.06E-17	7.57E-17
I-133 ELEM	0.9970	4.08E-09	2.90E-05	1.22E-05	6.77E-08	4.13E-05	4.12E-05
I-134 ELEM	0.9939	7.01E-42	4.12E-38	1.18E-38	2.10E-41	5.30E-38	5.27E-38
I-135 ELEM	1.0134	2.34E-12	1.63E-08	6.63E-09	3.31E-11	2.30E-08	2.33E-08
I-131 ORG.	0.9988	6.51E-10	4.66E-06	2.00E-06	1.16E-08	6.67E-06	6.66E-06
I-132 ORG.	0.9381	3.90E-22	2.59E-18	9.51E-19	3.55E-21	3.54E-18	3.33E-18
I-133 ORG.	0.9970	1.80E-10	1.27E-06	5.37E-07	2.98E-09	1.81E-06	1.81E-06
I-134 ORG.	0.9939	3.08E-43	1.81E-39	5.18E-40	9.21E-43	2.33E-39	2.32E-39
I-135 ORG.	1.0134	1.03E-13	7.18E-10	2.92E-10	1.46E-12	1.01E-09	1.02E-09
I-131 PART.	0.9988	8.14E-10	5.83E-06	2.49E-06	1.45E-08	8.33E-06	8.32E-06
I-132 PART.	0.9381	4.88E-22	3.24E-18	1.19E-18	4.43E-21	4.43E-18	4.16E-18
I-133 PART.	0.9970	2.24E-10	1.59E-06	6.71E-07	3.72E-09	2.27E-06	2.26E-06
I-134 PART.	0.9939	3.85E-43	2.26E-39	6.48E-40	1.15E-42	2.91E-39	2.90E-39
I-135 PART.	1.0134	1.29E-13	8.97E-10	3.65E-10	1.82E-12	1.26E-09	1.28E-09
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	6.14E-07	8.06E-03	2.91E-02	8.46E-02	1.22E-01	2.16E-01
KR-85M	0.8397	2.61E-12	3.27E-08	1.02E-07	1.45E-07	2.80E-07	2.35E-07
KR-87	0.9078	1.84E-27	2.07E-23	4.68E-23	2.38E-23	9.13E-23	8.28E-23
KR-88	0.9317	1.16E-15	1.41E-11	4.06E-11	4.28E-11	9.75E-11	9.08E-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	1.09E-07	1.42E-03	5.13E-03	1.47E-02	2.13E-02	1.80E-03
XE-133M	0.9717	4.36E-07	5.70E-03	2.04E-02	5.51E-02	8.12E-02	7.89E-02
XE-133	0.9941	1.11E-05	1.46E-01	5.24E-01	1.47E+00	2.14E+00	2.13E+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	5.60E-08	7.18E-04	2.42E-03	4.79E-03	7.93E-03	2.19E-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	2.38E+00	2.43E+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 7.86E-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	3.29E-08	2.35E-04	1.01E-04	5.84E-07	3.37E-04	3.36E-04
I-132 ELEM	0.9381	4.43E-20	2.94E-16	1.08E-16	4.02E-19	4.02E-16	3.77E-16
I-133 ELEM	0.9970	4.38E-09	3.11E-05	1.31E-05	7.26E-08	4.43E-05	4.41E-05
I-134 ELEM	0.9939	1.61E-41	9.48E-38	2.71E-38	4.82E-41	1.22E-37	1.21E-37
I-135 ELEM	1.0134	1.27E-11	8.87E-08	3.60E-08	1.80E-10	1.25E-07	1.27E-07
I-131 ORG.	0.9988	1.45E-09	1.03E-05	4.43E-06	2.57E-08	1.48E-05	1.48E-05
I-132 ORG.	0.9381	1.95E-21	1.29E-17	4.74E-18	1.77E-20	1.77E-17	1.66E-17
I-133 ORG.	0.9970	1.93E-10	1.37E-06	5.76E-07	3.19E-09	1.95E-06	1.94E-06
I-134 ORG.	0.9939	7.09E-43	4.17E-39	1.19E-39	2.12E-42	5.36E-39	5.33E-39
I-135 ORG.	1.0134	5.59E-13	3.90E-09	1.58E-09	7.91E-12	5.49E-09	5.56E-09
I-131 PART.	0.9988	1.81E-09	1.29E-05	5.54E-06	3.21E-08	1.85E-05	1.85E-05
I-132 PART.	0.9381	2.43E-21	1.62E-17	5.93E-18	2.21E-20	2.21E-17	2.07E-17
I-133 PART.	0.9970	2.41E-10	1.71E-06	7.20E-07	3.99E-09	2.43E-06	2.42E-06
I-134 PART.	0.9939	8.86E-43	5.21E-39	1.49E-39	2.65E-42	6.70E-39	6.66E-39
I-135 PART.	1.0134	6.99E-13	4.88E-09	1.98E-09	9.88E-12	6.87E-09	6.96E-09
KR-83M	1.0492	1.47E-23	1.73E-19	4.52E-19	3.46E-19	9.71E-19	1.02E-18
KR-85 **	0.5922	7.95E-09	1.04E-04	3.77E-04	1.10E-03	1.58E-03	2.80E-03
KR-85M	0.8397	2.24E-12	2.80E-08	8.76E-08	1.25E-07	2.40E-07	2.02E-07
KR-87	0.9078	1.39E-27	1.57E-23	3.54E-23	1.80E-23	6.90E-23	6.27E-23
KR-88	0.9317	8.37E-15	1.02E-10	2.94E-10	3.10E-10	7.06E-10	6.57E-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	3.62E-08	4.74E-04	1.71E-03	4.90E-03	7.08E-03	6.01E-04
XE-133M	0.9717	1.46E-07	1.91E-03	6.81E-03	1.84E-02	2.72E-02	2.64E-02
XE-133	0.9941	1.30E-05	1.71E-01	6.13E-01	1.73E+00	2.51E+00	2.49E+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	5.87E-08	7.53E-04	2.54E-03	5.02E-03	8.31E-03	2.29E-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		2.55E+00	2.53E+00
				Finite Cloud Dose		7.95E-02	$\boxed{7.86E-02}$

** - 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 1.24E+00 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	1.74E-04	1.25E+00	5.34E-01	3.09E-03	1.79E+00	1.78E+00
I-132 ELEM	0.9381	4.41E-19	2.93E-15	1.08E-15	4.01E-18	4.01E-15	3.76E-15
I-133 ELEM	0.9970	3.68E-06	2.61E-02	1.10E-02	6.11E-05	3.72E-02	3.71E-02
I-134 ELEM	0.9939	6.57E-41	3.86E-37	1.11E-37	1.97E-40	4.97E-37	4.94E-37
I-135 ELEM	1.0134	6.42E-10	4.48E-06	1.82E-06	9.08E-09	6.31E-06	6.39E-06
I-131 ORG.	0.9988	7.67E-06	5.48E-02	2.35E-02	1.36E-04	7.85E-02	7.84E-02
I-132 ORG.	0.9381	1.94E-20	1.29E-16	4.73E-17	1.76E-19	1.76E-16	1.65E-16
I-133 ORG.	0.9970	1.62E-07	1.15E-03	4.84E-04	2.68E-06	1.64E-03	1.63E-03
I-134 ORG.	0.9939	2.89E-42	1.70E-38	4.86E-39	8.64E-42	2.19E-38	2.17E-38
I-135 ORG.	1.0134	2.82E-11	1.97E-07	8.00E-08	3.99E-10	2.77E-07	2.81E-07
I-131 PART.	0.9988	9.58E-06	6.86E-02	2.94E-02	1.70E-04	9.81E-02	9.80E-02
I-132 PART.	0.9381	2.42E-20	1.61E-16	5.91E-17	2.20E-19	2.20E-16	2.07E-16
I-133 PART.	0.9970	2.02E-07	1.44E-03	6.06E-04	3.36E-06	2.05E-03	2.04E-03
I-134 PART.	0.9939	3.61E-42	2.12E-38	6.08E-39	1.08E-41	2.73E-38	2.72E-38
I-135 PART.	1.0134	3.53E-11	2.46E-07	1.00E-07	4.99E-10	3.47E-07	3.51E-07
						Uncorrected	Corrected
					Total	2.00E+00	2.00E+00

TABLE 18 - DCF CORRECTION TO CRADLE THYROID DOSE RESULTS

	Corrected Dose (rem)	R.G. 1.109 to ICRP 30 DCF Corr.	Total Corrected Dose (rem)
I-131 ELEM	1.78E+00	7.20E-01	1.28E+00
I-132 ELEM	3.76E-15	4.40E-01	1.65E-15
I-133 ELEM	3.71E-02	6.74E-01	2.50E-02
I-134 ELEM	4.94E-37	2.88E-01	1.42E-37
I-135 ELEM	6.39E-06	5.62E-01	3.59E-06
I-131 ORG.	7.84E-02	7.20E-01	5.64E-02
I-132 ORG.	1.65E-16	4.40E-01	7.27E-17
I-133 ORG.	1.63E-03	6.74E-01	1.10E-03
I-134 ORG.	2.17E-38	2.88E-01	6.26E-39
I-135 ORG.	2.81E-07	5.62E-01	1.58E-07
I-131 PART.	9.80E-02	7.20E-01	7.05E-02
I-132 PART.	2.07E-16	4.40E-01	9.09E-17
I-133 PART.	2.04E-03	6.74E-01	1.37E-03
I-134 PART.	2.72E-38	2.88E-01	7.82E-39
I-135 PART.	3.51E-07	5.62E-01	1.97E-07
		Total:	1.44E+00

Computer Output on Floppy Disks

6.6.2. Plume shine to the TSC

Since the X/Qs for the TSC are same as for the MP3 Control Room, the only difference from the MP3 control room determination is in the amount of 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 = 1.38E-02 rem * 0.1/ 0.003
= 0.46 rem

6.6.3. Filter shine from charcoal filter beds

From CRADLE run # 12749, 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 enrgies are similar, all activity will be assumed to be I-131. It will be assumed that 100% of the iodine activity is trapped on the filter at each time step in the CRADLE run. This results in a total activity of less than 2E-03 Ci based on CRADLE determination for activity in the TSC and will be applied for a conservative determination at T = 0 for the entire 720 hours of the accident. The dose rate 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

The dose rate based on 2E-03 Ci would be 4.4E-04 R/hr @ 1 meter (= 2E-03 Ci * 0.22 R/hr-Ci @ 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. Crediting 1 foot of concrete shielding (Assumption 30) provides an additional shielding reduction. The transmission factor of 0. 1 from Ref. 22, pg 149 will be used to address the impact of shielding. The resultant dose rate at 1 meter from the filter is 4.4E-05 R/hr (= 4.4E-04 Rr/hr * 0.1). Exposure for 720 hours @ at meter is 3.17E-02 rem. It should be noted that no credit is taken for occupancy factor in the TSC, therefore this evaluation is conservative.

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

Attachment 1 - Floppies with TACT and CRADLE outputs
Attachment 2 - Reviewer comments
Attachment 3 - Westinghouse Fuel Failure Analysis

APPENDIX A

FUEL HANDLING ACCIDENT IN THE FUEL BUILDING WITH 60 DAY (OR GREATER DECAY)

A dose evaluation will be performed in this appendix using the information from Section 6 and adjusting it for 60 day decay instead of 100 hours. In addition, no credit will be taken for filtration by the Fuel Building Ventilation System. For offsite dose analysis, a ground level release will be assumed because ground level X/Qs are higher than Ventilation Vent X/Qs, but for Control Room and TSC analyses, the Ventilation Vent X/Qs will be used because they are higher than ground release X/Qs.

The release fraction determined in Section 6.1 remains the same, but after 60 days, the released activity consists of the isotopes listed in Table A. All other isotopes are negligible in activity and are not included.

Table A - isotopic breakdown from FHA

Isotope	PR-194- Full Core Inventory, Rev. 0, Ci*@ T = 0	Release Fraction from pool	Total Activity Released (no decay correction), Ci	Decay constant, hr-1	100 hour Decayed activity, mCi	60 day Decayed activity, mCi
I-131	9.11E+07	1.26E-05	1.15E+03	3.58E-03	8.01E+05	6.63E+03
Kr-85	8.83E+05	3.14E-03	2.78E+03	7.68E-06	2.78E+06	2.75E+06
Xe-131m	8.01E+04	1.05E-03	8.40E+01	2.41E-03	6.60E+04	2.63E+03
Xe-133m	4.89E+06	1.05E-03	5.13E+03	1.28E-02	1.43E+06	5.24E-02
Xe-133	2.03E+08	1.05E-03	2.13E+05	5.48E-03	1.23E+08	7.98E+04

OFFSITE DOSE

From Table A, the iodine activity available for release after 60 day decay is 6.63E+03 mCi, I-131. The I-131 available for release after 100 hours decay is 8.01E+05 mCi (this value does not include other iodine isotopes). After adjusting for the 95% filtration effectiveness of the Fuel Building Ventilation System charcoal filters, there is a release to the environment of 4.01E+04 mCi (= 8.01E+05 Ci * (1 - 0.95)). The unfiltered, 60 day release sends out 6.63E+03 mCi. It is apparent that the filtered release occurring at 100 hours sends more iodine to the environment than the unfiltered release occurring at 60 days. Since the total iodine released from 60 day decay is less than the 100 hour decay, then offsite thyroid doses for a 60 day decay mix will be bounded by the 100 hour decayed mix.

In the case of noble gas effect on offsite dose, there is no filtration credited in the 100 hour decay analysis. The only real difference between the 100 hour decay and the 60 day decay is the time difference. During that time, due to radioactive decay, there is more activity released from 100 hour decay than from 60 day decay, therefore the 100 hour decay analysis is bounding for offsite whole body dose.

CONTROL ROOM DOSE

MP3 Control Room (and TSC) rad monitors will be evaluated similar to Section 6.2.1. The only difference in inputs used is the Xe-133 activity available to alarm the MP3 Control Building Inlet Vent Monitors, 3HVC*RE16A&B. Section 6.2.1 provided a 100 hour decayed Xe-133 activity at the control room inlet of 4.54E-02 uCi/cc based on a released Xe-133 activity of 1.242E+05 Ci.

From TABLE A, there are 7.98E+04 Ci of Xe-133 available for release after 60 days. Ratioing the activities (60 day : 100 hour) will provide the activity at the control room inlet after 60 days.

4.54E-02 uCi/cc * (7.98E+04 Ci-Xe-133 / 1.242E+05 Ci-Xe-133)

= 2.92E-02 uCi/cc

The rad monitor response time based on this activity is determined below (as in Section 6.2.1).

Alarm setpoint: 1.5E-05 uCi/cc Xe-133
Time constant: 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 = 2.92E-02 uCi/cc
Step increase (Cf) = 2.92E-02 uCi/cc / 1.3E-08 uCi uCi/cc/cpm = 2.12E+06 cpm
Since the detector instantaneous count rate (2.12E+06 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:
$Cs = Cf\ (1-e^{-T/RC})$
$Cs\ /\ Cf = (1-e^{-T/RC})$
$1154\ /\ 2.12E+06 = (1-e^{-T\ /\ 1\ sec})$
$T = 5.5E-04\ sec << 1\ sec$

The response time is << 1 second. For conservatism, 5 seconds will be used. 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.

This verifies that the control room will isolate within 10 seconds. Since control room isolation occurs at the same time as for the 100 hour decayed mix, and the noble gas and iodine activity entering the control room is less (due to decay), then the analysis in this calculation supporting a FHA in the Fuel Building for 100 hours decay will bound the MP3 control room and TSC dose consequences for 60 day decay.

MP2 Control Room rad monitors will be evaluated similar to Section 6.2.2. The only difference in inputs used is Xe-133 available to alarm the MP2 Control Room Ventilation Intake, RM9799A&B. Section 6.2.2 provided a Xe-133 activity at the control room inlet of 1.51E-02 uCi/cc based on a released Xe-133 activity of 1.242E+05 Ci. From the table above, there are 7.98E+04 Ci of Xe-133 after 60 days. Ratioing the activities will provide the activty at the control room inlet after 60 days. The resultant activity is 9.70E-03 uCi/cc (= 1.51E-02 uCi/cc * 7.98E+04 Ci / 1.242E+05 Ci). The detector has a response conversion factor of 1 mr/hr = 0.009 uCi/cc dose equivalent XE-133. For a 9.7E-03 uCi/cc activity, the rad monitor will see approximately 1.1 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 :

Cs = Cf * (1-e-T/RC)
where
Cs = monitor setpoint of 1 mr/hr
Cf = exposure rate at the detector, 8.7 mr/hr

1/ 1.1 = 1 - e -(T/1.98)

T = 4.75 sec

Therefore rad monitor response time is 4.75 seconds and will be assumed to be 5 seconds. From Assumption 26, the MP2 control room isolation damper closing time is 5 seconds. This results in an isolation time (including detector response and damper closure) of 10 seconds.

This verifies that the control room will isolate within 10 seconds. Since control room isolation occurs at the same time as for the 100 hour decayed mix, and the noble gas and iodine activity entering the control room is less (due to decay), then the analysis in this calculation supporting a FHA in the Fuel Building for 100 hours decay will bound the MP2 control room dose consequences for 60 day decay.

In summary, the dose analysis based on 100 hour decay is bounding over the 60 day decay. For offsite doses, this is true because more activity is released to the environment based on the 100 hour mix when factoring in charcoal filtration than that released from an unfiltered 60 day mix. In addition, the control rooms and TSC will still isolate within the 10 seconds credited for isolation time. With all other factors being equal, the dose analysis based on 100 hour decay will bound the dose consequences for 60 day decay.

Attachmt 2
Pg C1

Calculation Review Comment and Resolution Form

(Sheet 1 of 2)

Calculation Number: M3FHA-01792-R3 Revision: 0 CCN NA

Calculation Title: MP3 FHA in the Fuel building

Calc. Originator: S. M. Torf Reviewer (PRINT): W. J. Eakin

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) W J Eakin Date: 5/30/00

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

Item	Page/Section	Comments	Response
1	Sec 3	ensure that calc references list approval dates	done
2	Sec 4	Assumptions 5 and 7 need clarification	done
3	General	the MP2 control room is determined to isolate within 10 seconds of initiation of FHA, but in the calculation, 1 minute is used. This is extremely conservative.	The use of 1 minute is in error, but since it is conservative, it will not be corrected.
4	Sec 6.3	The TACT run to support offsite dose was calculated using 1 fuel assembly. It should use 1 assembly plus 50 rods.	This was an error and has been corrected.
5	General	an explanation is necessary as to the basis for the CRADLE source term adjustment factors	an explanation was added.
6	General	various editorial and grammatical corrections are necessary	done
7	General	MP3 control room CRADLE inputs are assigning an iodine removal rate during a period when the rate should be zero.	MP3 CRADLE runs were corrected and re-run.

Attachment 2
Pg. C2

Calculation Review Comment and Resolution Form (Continued)

Sheet 2 of 2 Number: M3FHA-01792-R3 Revision: 0 CCN NA

Item	Page/Section	Comments	Response

Calc M3FHA-01792-R3 Rev.0
Attachment 3
Pg D1

PAT-77-002

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

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.

Calc M3FHA-01792-R3 Rev C
Attachment 3
Pg D2

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.

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:

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

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.

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

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.

414 Fuel Assembly Extrapolation

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

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

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

$V_t = 12.9$ ft/sec $\qquad C_d' \quad V_t'$ · 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

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

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

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).

Calc. M3FHA-01792-R3 Rev. 0
Attachmt 3
Pg D6

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 on 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.

Calc. M3FHA-01792-R3, Rev. 0
Attachment 3
Pg D7

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.

Calc. M3FHA-01792-R3 Rev.0
Attachment 3
Pg D8

REFERENCES

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

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

Calc. M3FHA-01792-R3 Rev.0
Att. 3, Pg D13

SKETCH SHEET
FORM 28577

ATTACHMENT A

A-5

WESTINGHOUSE ELECTRIC CORPORATION

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.

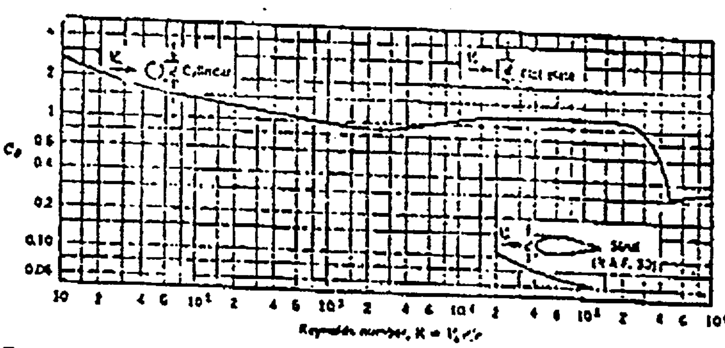

FIG. 260. Drag coefficients for circular cylinders, flat plates, and streamlined struts of infinite length.[12]

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.[13]

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-

[12] 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.

[13] 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.