UNITED STATES
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MEMORANDUM TO: Kevin Hsueh, Chief
Radiation Protection and Consequence Branch
Division of Risk Assessment
Office of Nuclear Reactor Regulation

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SUBJECT: EXAMPLE CALCULATION OF RE-EVALUATED FUEL HANDLING ACCIDENT FISSION PRODUCT TRANSPORT MODEL FOR DRAFT RG 1.183 REVISION 1 (2021)

The purpose of this memorandum is to provide an example calculation of the re-evaluated fuel handling accident (FHA) fission product transport model for Regulatory Guide 1.183, *Alternative Radiological source terms for Evaluating Design Basis Accidents at Nuclear Power Plants,* Revision 1. This example calculation is based on efforts discussed in a memo from Michael Case, Office of Nuclear Reactor Research, Director of the Division of Safety Analysis Director, to Michael Franovich, Office of Nuclear Reactor Regulations, Director of the Division of Risk Assessment, *Closeout to Research Assistance Request for Independent Review of Regulatory and Technical Basis for Revising the Design-basis Accident Fuel Handlings Accident.*, dated November 23, 2019. (ADAMS Accession Number ML19270E335). Specifically, it restructures the previous calculation tool presented in Enclosure 3 of the memo, *A report providing a calculational tool to compute various input parameters for the alternative DBA FHA Model,* to have a better quality of image than the one currently in the agency's Agencywide Documents Access and Management System (ADAMS). (ADAMS Accession Number ML19248C683)

The following attachment is included with this memo:

Enclosure:
Example Calculation of Re-Evaluation Fuel Handling Accidents
Fission Product Transport Model for Draft Regulatory Guise 1.183.

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SUBJECT: EXAMPLE CALCULATION OF RE-EVALUATED FUEL HANDLING ACCIDENT FISSION PRODUCT TRANSPORT MODEL FOR DRAFT RG 1.183 REVISION 1 (2021) DATED: 8/30/2021

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EXAMPLE CALCULATION OF RE-EVALUATION FUEL HANDLING ACCIDENTS FISSION PRODUCT TRANSPORT MODEL FOR DRAFT REGULATORY GUISE 1.183.

This example calculation derives input parameters for the FHA transport model of iodine. It does so by providing a step-by-step calculation to compute the Phase 1 initial gas release decontamination factor and the Phase 2 iodine re-evolution rate from a pool of water. This methodology can only be applied when the chemical form of iodine within the fuel pin gap is derived from the initial conditions under which operations are taking place. These initial conditions consider, among others: a time period between power operation and the movement of recently irradiate fuel to account for both radioactive decay and less decay power; the use of spent fuel- or reactor pool water temperature to determine internal gas temperature and pressure; and, the availability of iodine to re-evolve.

The model assumes the entire fuel pin gap inventory of iodine (100 percent) is available for release between two separate release phases; the first from the initial gaseous release, the second from re-evolution. Under pool water temperature conditions, the physical form of iodine is likely as solid CsI, I2 is solid, and methyl iodide as a liquid at the time of the postulated rupture and therefore necessarily available for instantaneous release. It is readily absorbed in the pool water and slowly re-evolved over a long period of time. The first phase conservatively assumes I2 (4.85 percent) and methyl iodine (0.15 percent) to be gaseous and subsequently decontaminated by passage through the overlying pool of water. The second phase conservatively assumes CsI (95 percent) to completely dissociate into the pool water then slowly re-evolve into the building atmosphere as I2 due to the low pool water pH.

Phase 1 Release – Initial Gaseous Release and Water Depth

An overall iodine DF is a function of bubble size and rise time through the water column, both of which are functions of fuel pin pressure. If the water depth is 19 feet or greater, an overall effective iodine DF for I2 and organic iodine can be computed based on a best-estimate rod pin pressure for the limiting fuel rods in the reactor core at the most limiting time in life. The time period between reactor shutdown and the movement of fuel may be used to compute radioactive decay and less decay power. The use of pool water temperature based on a full-core offload may be used to determine internal gas temperature and thus pin pressure.

For water depths between 19- and 23 feet, an overall iodine DF based on pin pressure is computed as follows:

$$DF_I = 81.046e^{0.305(t/d)}$$

where:

t = bubble rise time (sec), computed as a function of pin pressure, x (psig), as:

$$t(sec) = 9.2261e^{-6E-4*x}$$

d = bubble diameter (cm), computed as a function of pin pressure, x (psig), as:

$$d(cm) = -0.0002 * x + 1.0009$$

Enclosure

Calculational Tool: Phase 1 Iodine DF			Note:	Input
				Output
pin pressure =	760	(psig)		
Overall Iodine DF_I =	**662**			

Phase 2 Release – Re-evolution Release

The re-evolution calculation results in a simple exact transient solution. It has the flexibility to considers the effect of potential filtration and other removal mechanisms.

The following information is needed:

Site-specific and general parameters:

• V_{pool} – spent fuel pool volume;		1152	(m^3)
• S_{pool} – spent fuel pool surface area;		108	(m^2)
• Q_{recirc} – volumetric flow of recirculation system;		0	(m^3/min)
• F – Overall recirculation filter efficiency for iodine;		0	(0 - 1)
• $N_{I\text{-}131gap}$ – bundle radioactive iodine in gap (moles);		1.79E-01	(moles)
• $N_{I\text{-}129gap}$ – bundle non-radioactive iodine in gap (moles);		7.03E-04	(moles)
• K_L = mass transfer coefficient – 3.66E-6 m/s; and,		3.66E-06	(m/s)
• pH – acidity of pool.		4	
Void Space, V		0.0047	(m^3) (A)
T_pool		338.706	(K)
T_gas space		349.817	(K)
I inventory			
	I-129	102	(g)
	I-131	4.49	(g)
gap fraction			
	I-129	0.23	(-)
	I-131	0.0155	(-)
Decay time (time after shutdown before FHA event)		24	(hrs.)

Note: V_{pool}, S_{pool}, K_L, and Q_{recirc} must use consistent units. (for the purpose of calculating concentrations in M (moles/liter) V_{pool} must be converted to liters).

Calculation Sequence:

1. Calculate amount of iodine (radioactive and non-radioactive) and cesium in the fuel pin gap;
2. Calculate volatile iodine fraction in pool;
3. Calculate removal coefficients; and,
4. Evaluate release as either an:
    a. overall release (neglecting time), or
    b. time-dependent release.

Step 1 - Calculate amount of iodine (radioactive and non-radioactive) in the fuel pin gap:

Gas inventory:			
P_{gas} space		760	(psig)
		5.341E+06	(Pa)
Initial gap inventory			
	I-129	23.1540	(g)
	I-131	0.0696	(g)
I-131 Decay factor = EXP(-24hrs.*3600*1E-6) =		0.9172	
Decayed I131 gap inventory (g) = 0.0696*0.9172 =		0.0638	
	I-131 factor to account for other isotopes = $\frac{Total\ Iodine\ Activity}{I-131\ Activity}$	1.4434	
Adjusted I131 gap inventory = 0.0638*1.4434 =		0.0921	(g)
I inventory in gap for calculation			
mass (g)	I-129	23.1540	(g)
	I-131 = Initial gap (0.0696) * I-131 factor (1.4434) =	0.0921	(g)

Step 2 – Calculate volatile iodine fraction in pool:

Both the radioactive and non-radioactive iodine in the pool affect the radioactive iodine evolution. The calculations operate on moles so iodine isotope quantities must be converted to moles. For a given mass of iodine, the number of moles of iodine can be calculated from the mass, m, in grams and its atomic weight, M, as:

$$N_{I-131} = \left(\frac{m_{I-131}(g)}{M_{I-131}\left(g/mol\right)} \right)$$

mol (I) N_{I-131} =	1.79E-01	(I)

$$N_{I-129} = \left(\frac{m_{I-129}(g)}{M_{I-129}\left(g/_{mol}\right)} \right)$$

mol (I) $N_{I\text{-}129}$ =	7.03E-4	(I)

mol (I) N_{total} =	1.80E-1	(I)

Alternatively, for radioactive materials the number of moles can be calculated from the activity in Becquerels (Bq):

$$N_{I-131} = \left(\frac{A_{I-131}\left(dis/_{s}\right)}{M_{I-131}\left(dis/_{atom.s}\right)} \right)$$

Activities in Curies must be converted to Becquerel (1 Ci = 3.7 x 10^{10} Bq).

The radioactive iodine concentration can be decayed accounting for time before fuel movement. If this is done, the activity of other iodine isotopes at this time should be added to the I-131 activity. In the calculation above the other isotopes contributed an additional 4 percent.

Next, determine the fraction of I atoms in the pool that are in I2 (volatile) form by:

- Calculating radioactive and total concentrations in pool by:
  - C_r = concentration (M) (moles I atoms /L) of radioactive I atoms = $NI\text{-}131_{gap}$ / V_{pool}

C_r =	1.55E-07	(M)

  - C_t = total I concentration (M) (moles I atoms /L) = ($NI\text{-}129_{gap}$ + $NI\text{-}131_{gap}$) / V_{pool}

C_t =	1.56E-07	(M)

Note: V_{pool} must be converted to liters to calculate concentrations in moles / liter.

- Calculate the H+ concentration:
  - $C_h = [H+] = 10^{-pH}$

C_h =	1.00E-04

- Calculate the $[I_2] / [I-]^2$ concentration ratio, R_i:
  - $R_i = [I_2] / [I-]^2 = C_h^2 / (6.0603E\text{-}14 + 1.4708E\text{-}09\ C_h)$

R_i =	4.82E-04

Note: Combined Speciation Rate from Beahm, et. al. Iodine Evolution and pH Control

- Calculate the fraction of I atoms in I2 form:
  - First evaluate B_m (Negative B for quadratic equation)
    - $B_m = 4\ Ct + 1 / R_i$

B_m =	2.14E-05

  - Then evaluate the volatile fraction, Xe (fraction of I atoms in I2 form):
    - $X_e = (B_m - SQRT(B_m^2 - 16\ C_t^2)) / (4\ C_t)$

X_e =	1.46E-02

Step 3 - Calculate applicable removal coefficients:

- Radioactive decay removal coefficient:

  The radioactive decay removal coefficient, λ_r, is the common one used in the radioactive decay equation:

$\lambda_r = \lambda_{I\text{-}131}$ =	1.00E-6	s^{-1}

- Evolution removal coefficient:

  The evolution removal coefficient, λe, is calculated using the mass transfer coefficient, the pool surface-to-volume ratio, and the fraction of I that is in I2 form.

  - $\lambda_e = K_L\ X_e\ S_{pool} / V_{pool}$

λ_e =	5.02E-9	(s^{-1})
	3.01E-7	(min^{-1})
	4.34E-4	(d^{-1})

  The removal rate is reduced to account for the fraction of iodine that is volatile and thus available to evolve to the gas space.

  This evolution rate applies to both non-radioactive and radioactive iodine.

- The filtration removal coefficient:

  The filtration removal coefficient, λ_f, is calculated using the recirculation system volumetric flow, Q_{recirc}, the volume of the pool, and filtration efficiency, F:

  - $\lambda_f = F\ Q_{recirc} / V_{pool}$

  If no recirculation is considered, F = 0 (or simply not included in the calculation).

Step 4 - Evaluate Release:

- The removal coefficients can be used as follows:

  Using a volume that represents the pool and flow rate that represents evolution to the building volume with a volumetric evolution rate as follows:

  - $Q_e = \lambda_e V_{pool}$

Q_e=	**5.78E-6**	(m^3/s)
	3.47E-4	(m^3/min)
	1.22E-2	(ft^3/min)
	4.99E-1	(m^3/d)

- **Note: λ_f is used if recirculation filtration is credited.**
  - Alternatively, a loop and filter can be modeled instead of using λ_f. It will return the same result either way.
  - In this calculation, a computer code like RADTRAD calculates the transient depletion of iodine in the pool.