ALTERNATIVE FUEL HANDLING ACCIDENT TRANSPORT METHODOLOGY

This Enclosure provides a general description of the alternative fuel handling accident transport methodology (herein referred to as the alternative model) within the spent fuel- or reactor pool 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 irradiated 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. A calculational tool for NRC staff use has been developed to compute various parameters to model the transport of iodine within the spent fuel- or reactor pool water based on plant-specific parameters and can be found under ADAMS Accession No. ML19248C683.

The alternative model is incompatible with past models[1] due to fundamental assumptions of the chemical form of iodine as follows:

> Current Model – Assumes the initial conditions of the damaged fuel bundle is at operating reactor temperature and pressure. The gap inventory iodine consists of 5 percent gaseous and 95 percent solid cesium iodine. The chemical form of the gaseous iodine is 4.85 percent elemental iodine, or I_2, and 0.15 percent organic iodide, such as methyl iodide, or CH_3I. The model assumes the 5 percent gaseous iodine is available for release to the pool water instantaneously. To model the scrubbing effects of iodine in the pool water, a single lumped parameter known as the iodine decontamination factor with a numerical value of about 200, has been assumed to represent not only the iodine immediately released following the postulated fuel rupture but also represented re-evolution of iodine. The re-evolution release was assigned to the immediate release for the purposes of determining the decontamination factor for simplicity.
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> Alternative 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 fuel handling pool water temperature conditions, the physical form of iodine is likely a solid as cesium iodide (CsI),

[1] The "past model" refers to those described by the: proprietary Westinghouse topical report, WCAP-7518-L (1970), "*Topical Report: Radiological Consequences of a Fuel Handling Accident*," and the non-proprietary version WCAP-7828 (1971), "*Radiological Consequences of a Fuel Handling Accident;*" Atomic Energy Commission report (1971), "*Evaluation of Fission Product Release and Transport*;" Atomic Energy Commission Safety Guide 25, "*Assumptions Use for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors;"* Nuclear Regulatory Commission Regulatory Guide 1.25 "*Assumptions Use for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors*;" Nuclear Regulatory Commission Regulatory Guide 1.183 (2000), *Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors*; and, Nuclear Regulatory Commission Regulatory Guide 1.195 (2003), M*ethods and Assumptions for Evaluating Radiological Consequences of Design Basis Accidents at Light-Water Nuclear Power Reactors*.

or I_2, and a liquid as methyl iodide (CH_3I) at the time of the postulated rupture and therefore not 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 I_2 (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 (0.95 percent) to completely dissociate into the pool water over a 2-hour period then slowly re-evolve into the building atmosphere as I_2 due to the low pool water pH for up to 30 days.

It is therefore non-conservative to adopt a portion of either model as the initial conditions to derive the chemical forms of iodine are fundamentally different.

Source Term Definition

The fission product release from the breached fuel is based on Regulatory Guide 1.183, Revision 0, Regulatory Position 3.2 and the estimate of the number of fuel rods breached. Radionuclides that should be considered include xenons, kryptons, halogens, cesiums, and rubidiums. The chemical form of radioiodine released from the fuel to the pool should be assumed to be 95 percent CsI, 4.85 percent I_2, and 0.15 percent organic iodide such as CH_3I.

All the gap activity in the damaged rods is assumed to be released over two phases:

Phase 1 - the instantaneous release from the rising bubbles. I_2 and organic iodine are conservatively assumed to be in vapor form and subsequently decontaminated by passage through the overlaying pool of water into the building atmosphere. The retention of noble gases in the water in the fuel pool or reactor cavity is negligible (i.e., decontamination factor of 1). Particulate radionuclides such as CsI released from the fuel are assumed to be retained by the water in the fuel pool or reactor cavity (i.e., infinite decontamination factor).

Phase 2 - the protected release of CsI re-evolving as I_2. CsI is conservatively assumed to completely dissociate into the pool water. Due to the low pH of the pool water, CsI (and Phase 1 absorbed I_2 and organic iodine) then slowly re-evolve as I_2 into the building atmosphere.

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 I_2 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:

$$DF_I = 81.046e^{0.305(t/d)} \quad \text{(Equation 1)}$$

where:

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

$$t(sec) = 9.2261e^{-6E-4*x} \quad \text{(Equation 2)}$$

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

$$d(cm) = -0.0002 * \mathrm{x} + 1.0009 \quad \text{(Equation 3)}$$

If the depth of water is not between 19- and 23 feet, the decontamination factor will have to be determined on a case-by-case method (see ADAMS Accession No. ML19248C647 for the description of technical basis for alternative fuel handling accident.)

Phase 2 Release – Re-evolution Release

The re-evolution calculation results in a simple exact transient solution. It has the flexibility to consider 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;
- S_{pool} – spent fuel pool surface area;
- Q_{recirc} – volumetric flow of recirculation system (to evaluate effects of filtration);
- F – Overall recirculation filter fractional efficiency for iodine – Expected to be ~ 1 (to evaluate the effects of filtration);
- $N_{I\text{-}131gap}$ – fuel pin radioactive iodine in gap (moles);
- $N_{I\text{-}129gap}$ – fuel pin non-radioactive iodine in gap (moles);
- K_L = mass transfer coefficient – 3.66E-6 m/s[2]; and,
- pH – acidity of pool.

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:

[2] See ADAMS Accession Number ML19248C647

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

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:

$$N_{I-131} = \left(\frac{m_{I-131}(g)}{M_{I-131}(^{g}/_{mol})}\right) \quad \text{(Equation 4)}$$

$$N_{I-129} = \left(\frac{m_{I-129}(g)}{M_{I-129}(^{g}/_{mol})}\right) \quad \text{(Equation 5)}$$

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

$$N_{I-131} = \left(\frac{A_{I-131}(^{dis}/_{s})}{\lambda_{I-131}(^{dis}/_{atom.s})}\right) \quad \text{(Equation 6)}$$

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

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

Step 2 - Calculate volatile iodine fraction in pool.

Next, determine the fraction of iodine atoms in the pool that are in I_2 (volatile) form by:

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

(Equation 7)

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

(Equation 8)

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

- Calculate the H+ concentration:
  - $C_h = [H^+] = 10^{-pH}$ (Equation 9)
- Calculate the $[I_2] / [I-]^2$ concentration ratio, R_i[3]:
  - $R_i = [I_2] / [I-]^2 = C_h^2 / (6.0603E\text{-}14 + 1.4708E\text{-}09\ C_h)$ (Equation 10)
- Calculate the fraction of I atoms in I_2 form:
  - First evaluate B_m (Negative B for quadratic equation below)
  - $B_m = 4\ C_t + 1 / R_i$ (Equation 11)
  - Then evaluate the volatile fraction, X_e (fraction of I atoms in I_2 form):
  - $X_e = (B_m - \sqrt{B_m^2 - 16\ C_t^2}\ ) / (4\ C_t)$ (Equation 12)

Step 3 - Calculate applicable removal coefficients.

The evolution removal coefficient, λ_e, is calculated using the mass transfer coefficient, the pool surface-to-volume ratio, and the fraction of I that is in I_2 form.

$$\lambda_e = K_L\ X_e\ S_{pool} / V_{pool} \quad \text{(Equation 13)}$$

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

$$\lambda_f = F\ Q_{recirc} / V_{pool} \quad \text{(Equation 14)}$$

[3] Combined Speciation Rate from Beahm, et. al. "Iodine Evolution and pH Control" (NUREG/CR-5950)

If no recirculation is considered, $\lambda_f = 0$ (or simply not included in the calculation). For this calculation Q_{recirc} and V_{pool} units must be consistent. The time units for all removal coefficients must be consistent.

Step 4 - Evaluate release as an overall release.

The removal coefficients can be used in RADTRAD by modeling a volume that represents the pool and flow rate that represents evolution to the refuel floor with a volumetric evolution rate such that flow is to the refuel floor is as follows:

$$Q_e = \lambda_e V_{pool} \quad \text{(Equation 15)}$$

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

REFERENCES

1. Memorandum RES RAR Alternative FHA Closeout Memo (2019), (ADAMS Accession No. ML19270E335)

2. USNRC (2019), “Re-Evaluation of the Fission Product Release and Transport for the Design-Basis Accident Fuel Handling Accident,” (ADAMS Accession No. ML19248C647)

3. USNRC (2019), “Computational Tool to Compute Site Specific Input Parameters for the Alternative FHA Model,” (ADAMS Accession No. ML19248C683)

4. Westinghouse. (1970). *WCAP-7518-L - Topical Report: Radiological Consequences of a Fuel Handling Accident, (attachment to accession 9804290400).* Monroeville: Westinghouse Electric Corporation.

5. Westinghouse. (1971). *WCAP-7828 - Topical Report: Radiological Consequences of a Fuel Handling Accident, (ADAMS Accession Number ML18025B589).* Monroeville: Westinghouse Electric Corperation.

6. Burley, G. (1971). *Evaluation of Fission Product Release and Transport (Accession ML16357A003).* Washington: Atomic Energy Commission.

7. USNRC. (1972). *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, Safety Guide 25.* Washington: US Nuclear Regulatory Commission.

8. USNRC. (1972). *Regulatory Guide 1.25, "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," Revision 0.* Washington: US Nuclear Regulatory Commission.

9. USNRC. (2000). *Regulatory Guide 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors".* Washingtion: US Nuclear Regulatory Commission.

10. USNRC. (2003). *Regulatory Guide 1.195, "Methods and Assumptions for Evaluating Radiological Consequences of Design Basis Accidents at Light-Water NUclear Power Reactors".* Washington: US NUclear Regulatory Commission.

11. ORNL. (1992). *NUREG/CR-5950 "Iodine Evolution and pH Control".* Oak Ridge: Oak Ridge National Laboratory.