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April 13, 2000

**Re: Indian Point Unit No. 2  
Docket No. 50-247**

**Document Control Desk  
US Nuclear Regulatory Commission  
Mail Station P1-137  
Washington, DC 20555-0001**

**Subject: NEI Pilot Program for Use of NUREG-1465**

As part of the NEI Pilot Program for the use of NUREG-1465, Consolidated Edison Company of New York, Inc., the owner and operator of Indian Point Unit No. 2, hereby submits the following document for the Nuclear Regulatory Commission review:

**Responses to Requests for Additional Information  
Received from the Regulatory Staff**

Please note that Attachments D and E are claimed by Polestar Applied Technology, Inc. (Polestar) as proprietary. Attachment C contains an Affidavit by David E. W. Leaver, a Principal of Polestar, seeking withholding of the documents (contained in Attachments D and E to this letter) in accordance with NRC regulations 10 CFR 9.17(a)(4), 2.790(a)(4), and 2.790(d)(1).

Should you or your staff have any questions regarding this letter, please contact Mr. John McCann, Manager, Nuclear Safety and Licensing.

Very truly yours,



AP01

Attachments

C: with Attachments A, B, and C

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**Responses to Requests for Additional Information**  
**Received from the Regulatory Staff**

**April, 2000**

**Question 1:**

Explain or provide the basis for the large value for the fraction of occurrence of A stability class in the meteorology data.

**Response:**

A re-review of the data revealed a discrepancy in the units for wind speed and temperature associated with the data logger source of the data provided to the analyst for the ARCON96  $\chi/Q$  calculations. This discrepancy has been corrected and the calculations redone. Revised  $\chi/Q$  values for the Control Room are provided below.

**95%  $\chi/Q$  from ARCON96 (sec/m<sup>3</sup>)**

Release Location	0 to 2 hours	2 to 8 hours	8 to 24 hours	1 to 4 days	4 to 30 days
Unit 2 Containment Surface - 6	3.82E-04	2.81E-04	1.05E-04	8.31E-05	7.04E-05
Unit 2 Aux Boiler Feed - Side	1.09E-03	1.02E-03	4.99E-04	3.86E-04	2.99E-04
Unit 2 Aux Boiler Feed - Stack	9.49E-04	8.65E-04	4.17E-04	3.30E-04	2.54E-04
Unit 2 Vent - 0 cfm	6.44E-04	4.69E-04	1.72E-04	1.37E-04	1.17E-04

As a result of revising the  $\chi/Q$  values for the Control Room, all of the design basis accident doses for the Control Room have been recalculated and are presented below. Based upon tracer gas testing performed in February 2000, a value of 700 cfm was used for the unfiltered inleakage into the Control Room in these calculations.

Accident	Dose (rem TEDE) (5 rem Limit)
Loss of Coolant Accident	3.5
Rod Ejection	1.5
Locked Rotor	1.6
Small Break Loss of Coolant Accident	2.6
Steam Generator Tube Rupture (pre accident spike)	2.1
Steam Generator Tube Rupture (accident initiated spike)	0.7
Main Steam Line Break (pre accident spike)	0.5
Main Steam Line Break (accident initiated spike)	2.3
Fuel Handling Accident (8% gap fraction)	1.8

**Question 2:**

Provide an analysis of the control room and offsite radiological doses for the design basis loss of coolant accident which includes the contribution from potential external ECCS leakage post accident.

**Response:**

The requested analysis has been performed and is presented below. Specific analysis assumptions are the same as those presented in our submittal of October 8, 1999 with the following modifications:

1. Based upon tracer gas testing conducted in February 2000, a value of 700 cfm was utilized for unfiltered inleakage into the Control Room.
2. X/Q values for the control room have been recalculated using ARCON 96. Values for a vent release with 0 CFM flow are utilized for the external ECCS leakage path.
3. Indian Point Unit 2 is equipped with an internal (to containment) recirculation system. Use of the internal system is directed by emergency operating procedure ES 1.3. No post accident fluid circulates outside of containment for the first 24 hours following a loss of coolant accident. At that time, partial flow is directed to the suction of the high head safety injection pumps to provide for injection to the reactor coolant system hot legs. Thus, external ECCS leakage dose calculations commence at 24 hours post accident.
4. Containment sump water temperatures have been recalculated to more accurately define the conditions at extended periods post accident. These replace the values currently in the UFSAR. These temperatures are provided in Figure 1.
5. Iodine release fractions have been specifically calculated for external leakage sources, rather than assuming a 10% default value. These calculations (summarized below) are presented in attachment A (non-proprietary) and B (non-proprietary). Attachment C contains an affidavit from POLESTAR asserting proprietary status and requesting the withholding of specified proprietary versions of the iodine release calculations which are contained in Attachments D and E.

**Fraction of Incoming Iodine Released With Internal Recirculation**

<b>Time Period</b>	<b>Without Boundary Layer Effect</b>	<b>With Boundary Layer Effect</b>
0 to 2 hours	0.00E+00	0.00E+00
2 to 8 hours	0.00E+00	0.00E+00
8 to 24 hours	0.00E+00	0.00E+00
24 hr to 24.5 hr	7.16E-05	7.16E-06
1 to 4 days	5.29E-02	5.29E-03
4 to 30 days	4.30E-02	4.30E-03

6. External ECCS leakage is assumed to begin at 24 hours at 4 gal/hr (twice the Technical Specification value of 2 gal/hr). No contribution from postulated passive failures is included. This is consistent with draft Regulatory Guide 1081, in that a safety grade filtered (charcoal and HEPA) ventilation system is provided for the primary auxiliary building which houses the portions of the ECCS located outside of containment. The system components are classified safety grade in accordance with the Indian Point Quality Assurance Program. The charcoal filter is a 2 inch bed type. Redundant fans are provided which can be supplied with emergency power post accident. Emergency Operating Procedure ES 1.3 (switchover to recirculation) directs re-establishment of building HVAC post accident. Testing of these charcoal filters will be performed in accordance with ASTM D3803-1989. Routine preventive maintenance is performed on system components every six months and yearly. Additional inspections and testing are performed every two years.
7. While safety grade filtration is available, no credit is taken for filtration in the dose calculations.

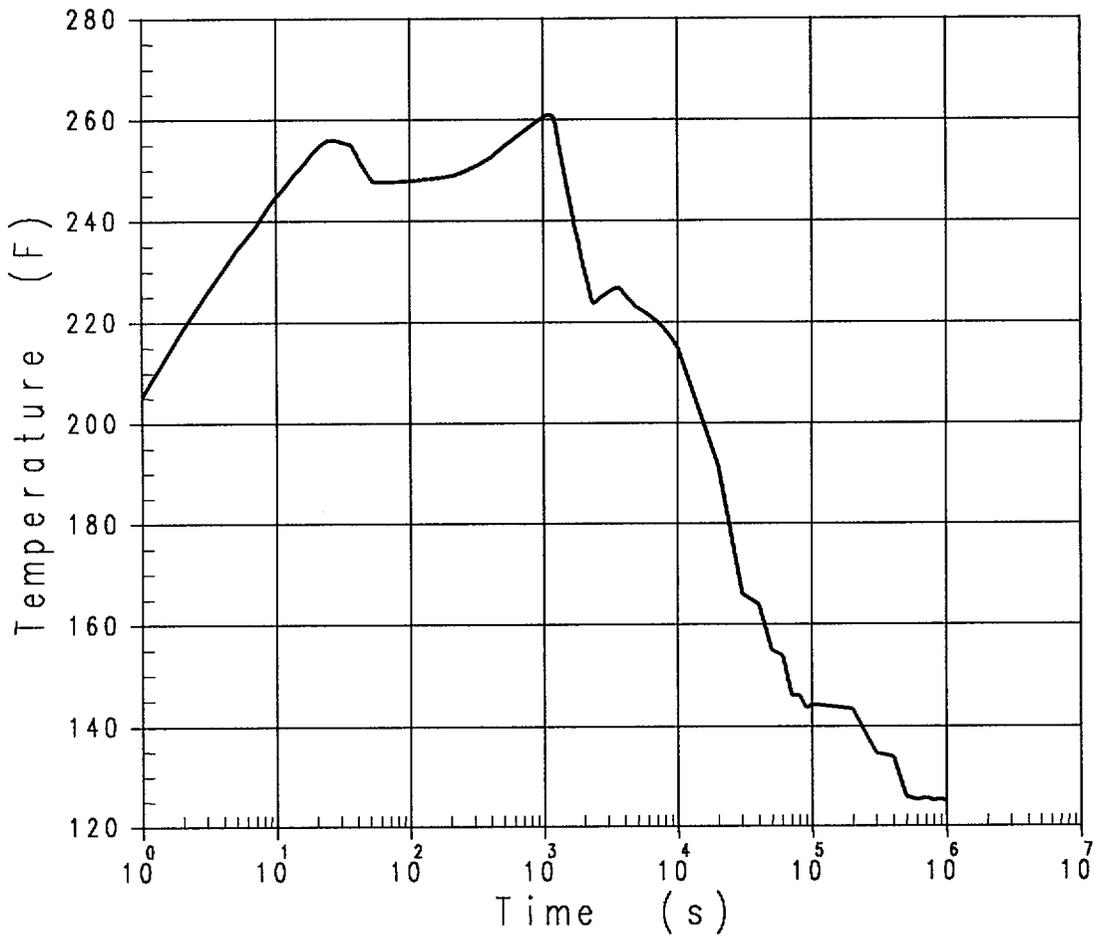
### Summary of Dose Calculations

#### ECCS External Recirculation Starts at 24 hours

		Combined Containment and ECCS Leakage Dose (without boundary layer effect)
Site Boundary Dose (2 hr)	N/A	16.6 rem TEDE
Low Population Zone Dose	0.6 rem TEDE	$11.3 + 0.6 = 11.9$ rem TEDE
Control Room Dose	0.9 rem TEDE	$3.5 + 0.9 = 4.4$ rem TEDE
		(with boundary layer effect)
Site Boundary Dose (2 hr)	N/A	16.6 rem TEDE
Low Population Zone Dose	0.06 rem TEDE	$11.3 + 0.06 = 11.4$ rem TEDE
Control Room Dose	0.09 rem TEDE	$3.5 + 0.09 = 3.6$ rem TEDE

Figure 1

**Containment Sump Water Temperature vs. Time  
Indian Point Unit 2 Minimum Safeguards 3216 MWt**



**Question 3:**

Provide a replacement Technical Specification page 4.5-4 correcting the typographical error in item 4.c. by deleting the words "... neutral or ...".

**Response:**

The corrected page follows.

4. At least once every Refueling Interval(#) by:
  - a. verifying that the pressure drop across the combined HEPA filters and charcoal adsorber banks is less than 6 inches water gauge while operating the system at ambient conditions and at a flow rate of 2000 cfm  $\pm 10\%$ .
  - b. verifying that, on a Safety Injection Test Signal or a high radiation signal in the control room, the system automatically switches into a filtered intake mode of operation with flow through the HEPA filters and charcoal adsorber banks. <sup>1</sup>
  - c. verifying that the system maintains the control room at a positive pressure relative to the adjacent areas during system operation.
5. After each complete or partial replacement of an HEPA filter bank, by verifying that the HEPA filter banks remove greater than or equal to 99% of the DOP when they are tested in-place in accordance with ANSI N510-1975 while operating the system at ambient conditions and at a flow rate of 2000 cfm  $\pm 10\%$ .
6. After each complete or partial replacement of a charcoal adsorber bank, by verifying that the charcoal adsorbers remove greater than or equal to 99.95% of a halogenated hydrocarbon refrigerant test gas when they are tested in-place in accordance with ANSI N510-1975 while operating the system at ambient conditions and at a flow rate of 2000 cfm  $\pm 10\%$ .
7. Each toxic gas detection system shall be demonstrated operable by performance of a channel check at least once per day, a channel test at least once per 31 days and a channel calibration at least once each Refueling Interval(#).

F. FUEL STORAGE BUILDING AIR FILTRATION SYSTEM

The fuel storage building air filtration system specified in Specification 3.8 shall be demonstrated operable:

1. At least once per 31 days by initiating, from the control room, flow through the HEPA filters and charcoal adsorbers and verifying that the system operates for at least 15 minutes.

**Attachment A**

**CALCULATION TITLE PAGE**

CALCULATION NUMBER: PSAT 126.02CT.QA.04

CALCULATION TITLE: Calculation of Indian Point 2 Engineered Safety Feature  
Component Leakage Iodine Release (Non-Proprietary  
Version)

## Table of Contents

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Attachment 1: XL Spreadsheet for Indian Point 2 ESF Leakage Fraction Released to Environment, 2 pages (page 1 for external recirculation, page 2 for internal recirculation) – See Proprietary Version

### Purpose

In accordance with the requirements of Section 4.2, reference [1], the purpose of this calculation is to determine the iodine released to the environment due to Indian Point (IP2) engineered safety feature (ESF) component leakage into one or more ESF component rooms in the primary auxiliary building (PAB), subsequent evolution of the iodine from the leakage pool, and forced circulation of the air from the ESF component rooms to the environment.

### Methodology

The approach to this calculation is to apply the Reference [2] Standard Review Plan (SRP) guidance that if the calculated flash fraction is less than 10% or if the water is less than 212 F, then an amount of iodine smaller than 10% of the iodine in the leakage may be used if justified based upon actual sump pH history and ventilation rates. The steps in the calculation are as follows:

- Evaluate the elemental iodine concentration in the ESF liquid. This is a function of the core inventory of iodine, the iodine release from the core during the DBA LOCA (this iodine is assumed to go into solution in the RCS and containment sump liquid which is in turn recirculated through certain PAB rooms as ESF liquid), the total ESF liquid mass, liquid density, and the ESF liquid pH.
- Evaluate the iodine concentration in the ESF room gas phase. It is assumed that the liquid phase – gas phase partitioning of iodine is always at equilibrium condition which is a function of liquid temperature as discussed below under assumptions.
- Using the volumetric flow of gas from the ESF room gas space to the environment, calculate iodine release to the environment.

In addition to the approach described above, a boundary layer approach has been calculated in reference [3] in which credit is taken for the iodine concentration gradient across the boundary layer at the liquid – gas interface, thus lowering the equilibrium iodine concentration in the gas phase.

Two ESF leakage cases, which involve different timing and room geometry, will be addressed here: external recirculation and internal recirculation.

For external recirculation, the ESF liquid is circulated outside containment beginning at 20.7 minutes after the initiating event per reference [4], items 4.3 and 4.5. Per Assumption 4, it is assumed that leakage can occur in both the RHR cells and the piping penetration area, even though it is likely that the leakage will be confined to one set of rooms (the RHR cells) since all RHR pumps and valves are in these rooms except one valve (Valve 744) which is in the RHR line to containment in the piping penetration area. After 24 hours, circulation occurs in the High Head pump room per reference [4], item 4.4, with leakage assumed to occur in this room (in addition to the RHR cells and piping penetration area) per Assumption 4.

For internal recirculation, the ESF liquid is not circulated outside containment until after 24 hours per reference [4], items 4.2, 4.4, and 4.6. Per Assumption 4, it is assumed that leakage can occur in the RHR cells, the piping penetration area, and the High Head pump room.

### Assumptions

Assumption 1: The flashing fraction is always less than 10% and the flash release is negligible compared to the calculated release.

Justification: The peak ESF liquid temperature is 261 F. Using a constant enthalpy method per reference [2],

$$mh = m_g h_g + m_l h_l$$

where  $m$  is total mass (liquid),  $h$  is the initial liquid enthalpy,  $m_g$  is flashed mass,  $h_g$  is gas enthalpy,  $m_l$  is unflashed liquid mass, and  $h_l$  is unflashed

liquid enthalpy. Thus, the flashing fraction, which is the flashed mass divided by the total mass, is

$$ff = m_g / m = (mh - m_l h_l) / m h_g$$

Using initial liquid temperature of 261 F and final temperature of 212 F (corresponding to the saturation temperature at atmospheric pressure which is the final pressure of the flashed mixture), using the steam tables, and setting  $m = 1$  so that the flashing fraction is just  $m_g$ , we obtain

$$ff = (229 - (1 - ff)180) / 1150$$

$$ff(1150 - 180) = 229 - 180$$

$$ff = 0.051 = 5.5\%$$

Since the ESF liquid temperature continuously decreases from the initial temperature, the flashing fraction is always  $< 10\%$ .

The flash release is the iodine released to the gas phase during the flash. It can be estimated as the product of:

- The fraction of total iodine in the liquid which is elemental
- The fraction of this elemental iodine which partitions to the gas phase
- The ratio of flashed steam volume to liquid volume
- The fraction of liquid which flashed.

As is calculated below in the Attachment 1 spreadsheet, the fraction of total iodine in the liquid which is elemental is roughly  $1E-7$  (due to the high pH). The steam from the flashed liquid has a volume of the order of 1000 times the liquid. The partition coefficient is of the order of unity at the peak ESF liquid temperature, and of the order of 0.1 or lower after 24 hours. The flashing fraction is of the order of 0.1 at the beginning of the accident and quickly approaches zero after a few hours. The flashing release can then be approximated as

$$(1E-7)(1000)(1)(0.1) \approx 1E-5$$

at the beginning of the accident, and after a few hours is much lower. As will be seen from the calculation result, the release over 30 days is of the order of  $1E-2$ . Thus the flashing release is negligible.

**Assumption 2:** The iodine partitioning between the liquid and bulk gas is based on equilibrium conditions. That is, a fraction of the  $I_2$  in the liquid is assumed to partition instantaneously to the bulk gas phase. This fraction depends only on the temperature of the liquid and does not consider

transport of the  $I_2$  within the liquid to the liquid – gas interface, nor transport of the  $I_2$  across the gas boundary layer between the liquid surface and the bulk gas phase.

**Justification:** Elemental iodine will transport across the liquid – gas interface (i.e., partition) at a rate depending upon its actual vapor pressure in the gas vs. its saturation vapor pressure. For lower temperatures, the saturation vapor pressure will be lower and the partitioning will be lower. Similarly, as temperature increases, the saturation vapor pressure increases and the partitioning increases. At equilibrium, the actual vapor pressure equals the saturation vapor pressure. Equilibrium conditions have been assumed to simplify the calculation. This assumption is very conservative since it neglects any transient effects and it neglects the resistance to gas transport across the gas boundary layer. This boundary layer effect is considered in the reference [3] calculation.

**Assumption 3:** The ESF component leakage remains at the containment sump liquid temperature.

**Justification:** ESF liquid is containment sump liquid which is recirculating through systems in the various ESF component rooms in the PAB. ESF component leakage is ESF liquid which leaks (e.g., pump seal, valve stem) into the room in which the component is located. The ESF component leakage is assumed to remain at the containment sump liquid temperature. In fact there will be heat transfer due to flashing and due to a temperature difference between the unflashed liquid and the ESF component room wall surfaces and structures (and to the air). This will lower the liquid temperature significantly. Neglecting this heat transfer is conservative since the amount of iodine partitioned from the liquid to the gas phase increases with increasing temperature.

**Assumption 4:** The continuous ESF leakage (i.e., 4 gph) will be assumed to be distributed in all rooms in which ESF components are located.

**Justification:** Prior to 24 hours (and after the 20.7 minute delay), it is likely that the leakage will be confined to one set of rooms (the RHR cells) since all RHR pumps and valves are in these rooms except one valve (Valve 744) which is in the RHR line to containment in the piping penetration area. However, distributing the ESF leakage involves a greater gas phase volume and thus effectively increases the volumetric exchange rate with the environment. Since the iodine release fraction is directly proportional to volumetric exchange (per Assumption 2 the iodine in the gas phase is assumed to be in equilibrium with the aqueous phase iodine), distributing the ESF leakage will be conservative.

Assumption 5: The volumetric exchange with the environment will be assumed to be the sum of the exchange rates of all ESF rooms into which leakage can occur with the rooms being well-mixed.

Justification: It is conservative to assume that the flow from all ESF rooms into which leakage can occur is available since maximizing the exchange with the environment will maximize the iodine release. It is also conservative to assume well-mixed rooms since time for mixing would slow the exchange with the environment relative to the well-mixed case.

Assumption 6: The ESF leakage is assumed to pool on room surfaces. Any droplets formed as the leakage exits the ESF component are assumed to fall to a surface without evaporating.

Justification: The ESF leakage is most likely to occur through a capillary-like opening such as through packing or seal material. Due to surface tension, this would result in relatively large drops which fall to the floor. In the unlikely event that the ESF leakage is spray-like, given that the ESF system has the thermal-hydraulic characteristics of a containment spray system, it is reasonable to assume that the spray-like leakage has a droplet size distribution similar to a spray nozzle. Calculations using the Mason equation for condensation on and evaporation from a water droplet indicate that droplets with an initial size in this range (e.g., diameter of several hundred to several thousand  $\mu\text{m}$ ) will fall to the floor without evaporating. In fact, with consideration of hygroscopicity, an equilibrium (non-zero) droplet size will be reached for any initial droplet size, no matter how small.

Assumption 7: Evaporation from ESF leakage pools will be limited by the moisture-carrying capacity of the air flow and the pool surface area.

Justification: The water falling to the floor of the areas in which the ESF leakage may occur will rapidly reach ambient temperature by heat transfer to the floor and to the ventilation air and by evaporation. However, evaporation to dryness is extremely unlikely because of two limiting phenomena: the finite evaporation rate and the degree of saturation possible for ventilation air flowing through the ESF areas.

The evaporation rate may be characterized by the following expression [5]:

$$W_{\text{evap}} \text{ (lbm/hr)} = 0.47(\text{pool area in ft}^2)(P_{\text{vapor/liquid}} - P_{\text{vapor/gas in psia}})^{1.2}$$

A likely situation is that the leakage will collect in the sump, which is a 3ft x 3ft x 3ft cavity in the sump room. Spreading of the liquid to an area of 9

ft<sup>2</sup> will cool the liquid quickly to a temperature at or near the room temperature.. Thus, if the incoming air were at 90 F and 70% relative humidity, the evaporation rate would be of the order of 0.1 gph, well below the 4 gph entering the room.

The pool surface area required to evaporate all of the incoming water (at 4 gph) would be approximately 460 ft<sup>2</sup> assuming no increase in the room relative humidity. Even if the leakage were to spread over both RHR pump rooms (an area approaching 1000 ft<sup>2</sup>) the average relative humidity in the vicinity of the water pool could not exceed about 85% if the four gph were to be evaporated. Therefore, the leaving relative humidity of the ventilation air in the vicinity of the water pool would have to approach 100% (for the stated incoming conditions). The relative humidity of the air leaving the ESF area would, of course, be less (depending on the amount of "bypass"; i.e., the fraction of the ventilation flow which was not in the vicinity of the water pool).

For the ventilation supply conditions stated and the assumption that all of the supply air is completely saturated when leaving the ESF area, the change in moisture content would be approximately 0.01 lbm per lbm of dry air. Noting that the total ventilation flowrate in the RHR cells is 5150 cfm (or about 2.2E4 lbm dry air per hour), the theoretical evaporation rate could be as great as 220 lbm per hour or about 26.5 gph. However, this would require perfect mixing within all the cells. Even if perfect mixing in the room were achieved, the only effect would be to limit the exposed surface area, not to lead to a complete evaporation of the water. Indeed, as noted in the previous paragraph, one can assume that the minimum required surface area of the water pool would be about 460 ft<sup>2</sup> in order to have the evaporation rate equal the leak rate no matter how well-mixed the ventilation flow is. Under these conditions the four gph leak rate would limit the relative humidity increase to about four or five percent, but even with such a low relative humidity, at least 460 ft<sup>2</sup> would be necessary for a four gph evaporation rate.

The above assessment assumes that the energy needed to evaporate the water is simply available at the temperature stated. If the situation were adiabatic (i.e., as in an evaporative cooling model in which all energy must come from the air-water system as would be the case for evaporation of spray droplets), then the amount of water which could be evaporated would be only 15 to 20 percent of that given above (depending on the water temperature). Under these conditions complete mixing of the ventilation air would be absolutely required for complete evaporation (even if the droplets were sufficiently small and non-hygroscopic - see Assumption 6). Such complete mixing would be viewed as very unlikely.

Given the above thermodynamic and mass transfer limits, it would appear very unlikely that complete evaporation of the ESF leakage could occur for an assumed leak rate of four gph. Instead, it is expected that a pool of ESF leakage would collect on the floor of the ESF areas.

### References

- Reference 1: PSAT 126.02CT.QA.02, "Implementing Procedure for Design Control for Calculation of Indian Point 2 Engineered Safety Feature Component Leakage Iodine Release," Rev. 0.
- Reference 2: NUREG-0800, NRC Standard Review Plan, Section 15.6.5, Appendix B, "Radiological Consequences of a Design Basis Loss of Coolant Accident: Leakage from Engineered Safety Features Components Outside Containment"
- Reference 3: PSAT 126.02CT.QA.05, "Calculation of Indian Point 2 Engineered Safety Feature Component Leakage Iodine Release with Boundary Layer Effect," Rev. 0.
- Reference 4: PSAT 126.02CT.QA.03, "Plant-Specific Design Input for Calculation of Indian Point 2 ESF Component Leakage Iodine Release," Rev. 0.
- Reference 5: L.M.K. Boelter, Gordon, H.S.; and Griffin, J.R. "Free Evaporation into Air of Water from a Free, Horizontal, Quiet Surface", Industrial and Engineering Chemistry, Volume 38, No. 6, pp. 596-600 (June 1946)
- Reference 6: L. Soffer et al., "Accident Source Terms for Light-Water Nuclear Power Plants," NUREG-1465, February, 1995.
- Reference 7: R. Sher and J. Jokiniemi, "NAUAHYGROS 1.0: A Code for Calculating the Behavior of Aerosols in Nuclear Plant Containments Following a Severe Accident," EPRI Report TR-102775, July, 1993
- Reference 8: NUREG/CR-5950, "Iodine Evolution and pH Control", November 1992

### Calculation

Per reference [1], the calculational approach is to evaluate the iodine release based upon actual sump pH history and ventilation rates. This is consistent with the SRP [2] guidance, based upon Assumption 1 that flashing fraction is less than 10%.

#### I<sub>2</sub> Concentration in Liquid

This is the first of three calculational sections. This calculational section determines the concentration of elemental iodine in the ESF liquid.

The total iodine concentration in the ESF liquid is

$$[\Gamma] = (I_c)(frel)/V_{ESF}/130$$

where  $[\Gamma]$  = total iodine concentration in  $\text{kgmol}/\text{m}^3$  in the ESF liquid

$I_c$  = total core inventory of iodine in kg

frel = iodine release fraction from core to containment (= 0.4 per reference [6])

$V_{ESF}$  = the volume of liquid ( $\text{m}^3$ ) in which  $\Gamma$  is dissolved

From reference [4], items 2.1 and 3.1,  $I_c = 26.28$  kg which is  $26.28/130$   $\text{kgmol}$  and total liquid mass  $m = 3.3\text{E}6$  lbm. From reference [7] the density of liquid water may be expressed as

$$\rho_{water} = \frac{(4.6137)(0.018016)(1000)}{0.26214^{(1+(1-T/647.29)^{0.23072})}}$$

Noting that  $V_{ESF} = m / \rho_{water}$  we have

$$[\Gamma] = (26.28)(0.4) / 130 / (m / \rho_{water}) \text{ kgmol}/\text{m}^3 \quad \text{Equation 1}$$

The elemental iodine concentration in the liquid may be calculated as

$$\text{See Proprietary Version} \quad \text{Equation 1a}$$

Equations 1 and 1a are used to obtain  $[\Gamma]$  and  $[\text{I}_2]_{aq}$  as a function of temperature (see Attachment 1 spreadsheet, discussed further below). For external recirculation (page 1 of Attachment 1), an exception is for 0 to 20.7 minutes during which time recirculation has not yet been initiated, and  $[\Gamma]$  and  $[\text{I}_2]_{aq}$  are zero. For internal recirculation (page 2 of Attachment 1), an exception is for 0 to 24 hours during which time recirculation has not yet been initiated and  $[\Gamma]$  and  $[\text{I}_2]_{aq}$  are zero.

### $\text{I}_2$ Concentration in Bulk Gas

This is the second of three calculational sections. Per Assumption 2, the iodine partitioning between the liquid and bulk gas is based on equilibrium conditions. Thus, the  $\text{I}_2$  concentration in the bulk gas may be expressed as

$$\text{See Proprietary Version} \quad \text{Equation 2}$$

where PC is the partition coefficient for  $\text{I}_2$  between the liquid and gas.

To evaluate PC and [I<sub>2</sub>]g the ESF liquid (i.e., the leakage pool) temperature is required. ESF liquid is containment sump liquid which is recirculating through various systems in the ESF rooms of the PAB. The leakage is pooled on a surface in one or more ESF rooms per Assumptions 4 and 6. Per Assumption 3, the ESF component leakage is assumed to remain at the containment sump liquid temperature. Reference [4], item 3.2 includes containment sump liquid temperature vs. time. ESF leakage pool temperature has been estimated by mass averaging the ESF liquid added to the pool over time. The Attachment 1 spreadsheet contains the details. The containment sump liquid temperature vs. time data was divided into time intervals, with the length of the intervals chosen to correspond to the chi/Q intervals with several intervals added to limit the temperature decrease, to account for the fact that external recirculation does not begin for 20.7 minutes after the start of the accident, to account for the fact that internal recirculation does not begin for 24 hours after the start of the accident, and to account for the increased ESF leakage between 24 and 24.5 hours per reference [4], item 4.1. There are a total of 11 time intervals with iodine concentration being zero for the first 2 intervals for the external recirculation case and for the first 6 intervals for the internal recirculation case. For each interval, the average temperature of the incoming ESF liquid was volume averaged with the pool volume up to that point. Thus the temperature for the i<sup>th</sup> interval may be expressed as

$$T_i = (\text{vol}_{\text{pool},i-1}T_{\text{pool},i-1} + \text{vol}_{\text{inc},i}T_{\text{inc},i})/\text{vol}_{\text{pool},i} \quad \text{Equation 3a}$$

The time intervals in seconds are shown in columns 1 to 3 of Attachment 1. Columns 4 and 5 are the incoming ESF leakage temperature (K) at the beginning of the time interval and end of the time interval, respectively. Column 6 solves for the ESF leakage pool volume-average temperature (K) for that interval using equation 3a. For time intervals after 24 hours, the 30 minutes of 50 gal per minute leakage was taken into account in the volume averaging.

### I<sub>2</sub> Release from Gas Space

This is the third of three calculational sections. The I<sub>2</sub> release to the environment from the PAB is equal to the product of the volumetric gas flow from the affected ESF rooms to the environment in m<sup>3</sup> per hour and [I<sub>2</sub>]g. Accordingly, the iodine release in kgmol/hour to the environment during time interval i is

See Proprietary Version

where  $V$  is volume and  $\dot{V}/V$  is the exchange rate with the environment in  $\text{hr}^{-1}$ .

See Proprietary Version

The values for  $V$  and  $\dot{V}/V$  are obtained as follows. Per Assumption 4, for external recirculation leakage can occur into the RHR cells and the piping penetration area after 20.7 minutes (per reference [4], items 5.1, 5.2, and 5.4 , total volume =  $(10.5)(18.5)(16.5) + (18.5)(18)(13.7) + (8)(9)(15) + (4)(24)(15) + (8)(10)(15) + (5)(44)(15) + (43.4)(91.8)(18) = 86,501 \text{ ft}^3 = 2450 \text{ m}^3$ ) and into the RHR cells, the piping penetration area, and the High Head Pump room after 24 hours (per reference [4], items 5.1 and 5.3, total volume  $86,501 + (35.6)(35.6)(17.1) = 108,170 \text{ ft}^3 = 3064 \text{ m}^3$ ). For internal recirculation leakage can occur into the RHR cells, the piping penetration area, and the High Head pump room after 24 hours (volume  $3064 \text{ m}^3$ ).

Per Assumption 5 and reference [4], items 5.1, 5.2, and 5.4, for external recirculation between 20.7 minutes and 24 hours, volumetric gas flow to the environment is based on an exchange rate,  $\dot{V}/V$ , of  $(5150 + 6100)(60) = 6.75\text{E}5 \text{ cfh} = 6.75\text{E}5/35.3/2450 = 7.8$  volumes per hour For external recirculation after 24 hours,  $\dot{V}/V$  is  $(5150 + 6100 + 9000)(60) = 1.22\text{E}6 \text{ cfh} = 1.22\text{E}6/35.3/3064 = 11.2$  volumes per hour.

Per Assumption 5 and reference [4], items 5.1 and 5.3, for internal recirculation after 24 hours,  $\dot{V}/V$  is 11.2 volumes per hour.

## Results

The results of this calculation are presented in Tables 1 through 4. Tables 1 and 2 are taken from page 1 of 2 of the Attachment 1 spreadsheet. Table 1 is taken from column

12, and Table 2 is taken from the lower left hand sub-table of the spreadsheet. Tables 3 and 4 are taken from page 2 of 2 of the Attachment 1 spreadsheet. The 2 pages in Attachment 1 are for external and internal recirculation, respectively.

The results are in units of fraction of total iodine leaking into the ESF component room(s) (i.e., fraction of the total dissolved iodine in the 4 gal per hour). As is evident from Table 1, in the first 20.7 minutes (1242 seconds) the release is zero since recirculation has not yet started. For a short duration early in the accident, the release is between 10 and 20% of the total iodine in the leakage. The fraction decreases with time and is about 5% percent after a day. This decrease is due mainly to decreasing temperature as the ESF liquid is cooled (and thus the amount of iodine partitioning from the liquid decreases per equations 2 and 3).

For Con Edison use as input to the dose calculation, the  $Frac_i$  quantities in Table 1 (from equation 5) have been time-weighted to produce a fractional release of total incoming iodine for time intervals corresponding to the  $\chi/Q$  intervals. This is presented in Table 2.

As is evident from Table 3, in the first 24 hours (86,400 seconds) the release is zero since recirculation has not yet started. The fraction is in the range of 4 to 5% percent after 24 hours.

For Con Edison use as input to the dose calculation, the  $Frac_i$  quantities in Table 3 (from equation 5) have been time-weighted to produce a fractional release of total incoming iodine for time intervals corresponding to the  $\chi/Q$  intervals. This is presented in Table 4.

It is noted that the results reported here are quite conservative with respect to three effects: (1) the ESF leakage was assumed to be distributed over the maximum PAB room volume and to be transported from the PAB to the environment with the maximum volumetric flow; and (2) the ESF leakage temperature was estimated by assuming no heat transfer from the leaked liquid to the structures and surfaces in the area in which the leakage occurs, and (3) the flashing of ESF liquid and the associated reduction in unflashed liquid temperature to 212 F upon leakage to ESF rooms was neglected which overestimates the liquid temperature for the first 3.1 hours.

### **Conclusions**

The conclusion from this calculation for the external recirculation case is that the iodine release from ESF leakage for IP 2 is between 10 and 20% of the total incoming iodine in the leakage for the first 2 hours, decreasing to below 5% over the long term. For the internal recirculation case, the iodine release is zero up to 24 hours and 5% or below thereafter.

**Table 1 Fraction of Incoming Iodine Released for External Recirculation**

Time Interval (sec)			Frac <sub>i</sub> (Fraction of Incoming Iodine)
75	to	720	N/A
720	to	1242	N/A
1242	to	3300	1.90E-01
3300	to	7200	1.49E-01
7200	to	28800	8.63E-02
28800	to	86400	4.84E-02
86400	to	88200	7.16E-05
88200	to	172800	5.35E-02
172800	to	345600	5.26E-02
345600	to	500000	5.13E-02
500000	to	2.59E+06	4.24E-02

**Table 2 Fraction of Incoming Iodine Released During Chi/Q Periods for External Recirculation**

Time Period	Fraction of Incoming Iodine
0 to 2 hr	1.35E-01
2 to 8 hr	8.63E-02
8 to 24 hr	4.84E-02
24 hr to 24.5 hr	7.16E-05
1 to 4 days	5.29E-02
4 to 30 days	4.30E-02

**Table 3 Fraction of Incoming Iodine Released for Internal Recirculation**

Time Interval (sec)			Frac <sub>i</sub> (Fraction of Incoming Iodine)
75	to	720	N/A
720	to	1242	N/A
1242	to	3300	N/A
3300	to	7200	N/A
7200	to	28800	N/A
28800	to	86400	N/A
86400	to	88200	7.16E-05
88200	to	172800	5.35E-02
172800	to	345600	5.26E-02
345600	to	500000	5.13E-02
500000	to	2.59E+06	4.24E-02

**Table 4 Fraction of Incoming Iodine Released During Chi/Q Periods for Internal Recirculation**

Time Period	Fraction of Incoming Iodine
0 to 2 hr	0.00E+00
2 to 8 hr	0.00E+00
8 to 24 hr	0.00E+00
24 hr to 24.5 hr	7.16E-05
1 to 4 days	5.29E-02
4 to 30 days	4.30E-02

**Attachment B**

**CALCULATION TITLE PAGE**

CALCULATION NUMBER: PSAT 126.02CT.QA.05

CALCULATION TITLE: Calculation of Indian Point 2 Engineered Safety Feature  
Component Leakage Iodine Release with Boundary Layer  
Effect (Non-Proprietary Version)

## Table of Contents

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Attachment 1: XL Spreadsheet for Indian Point 2 ESF Leakage Fraction Released to Environment with Boundary Layer Effect – See Proprietary Version

Attachment 2: XL Spreadsheet Calculation of Iodine Concentration in Bulk Gas Phase with Boundary Layer Effect – See Proprietary Version

### Purpose

In accordance with the requirements of Section 4.2, reference [1], the purpose of this calculation is to determine the Indian Point 2 (IP2) engineered safety feature (ESF) component leakage iodine release to the environment with consideration of the effect of the gas boundary layer that exists at the interface between the ESF liquid leakage and the bulk gas in the room into which the ESF leakage occurs (i.e., liquid – gas interface).

### Methodology

The approach is to apply the Reference [2] Standard Review Plan (SRP) guidance that if the calculated flash fraction is less than 10% or if the water is less than 212 F, then an amount of iodine smaller than 10% of the iodine in the leakage may be used if justified based upon actual sump pH history and ventilation rates. In addition, the effect of the gas boundary layer existing at the liquid – gas interface on the bulk gas iodine concentration has been considered. The steps in the calculation are as follows:

- Evaluate the elemental iodine concentration in the ESF liquid. This is a function of the core inventory of iodine, the iodine release from the core during the DBA LOCA

(this iodine is assumed to go into solution in the RCS and containment sump liquid which is in turn recirculated through certain primary auxiliary building (PAB) rooms as ESF liquid), the total ESF liquid mass, liquid density, and the ESF liquid pH.

- Evaluate the gaseous iodine concentration at the liquid edge of the gas boundary layer that exists at the liquid - gas interface. This is accomplished by assuming that the liquid phase – gas phase partitioning of iodine is always at equilibrium condition which is a function of liquid temperature as discussed below under assumptions. This gaseous concentration at the liquid edge of the gas boundary layer becomes a boundary condition for the transport of iodine across the boundary layer.
- Evaluate the mass transport of iodine across the boundary layer. The iodine concentration gradient and the mass transfer coefficient must be considered here. This will allow determining the bulk gas iodine concentration, which is a function of the iodine mass flux across the boundary layer and a mass balance with the iodine removal due to the volumetric exchange of the bulk gas space with the environment.
- Using the volumetric flow of gas from the ESF gas space to the environment, calculate iodine release to the environment.

Two ESF leakage cases, which involve different timing and room geometry, will be addressed here: external recirculation and internal recirculation.

For external recirculation, the ESF liquid is circulated outside containment beginning at 20.7 minutes after the initiating event per reference [3], items 4.3 and 4.5. Per Assumption 4, it is assumed that leakage can occur in both the RHR cells and the piping penetration area, even though it is likely that the leakage will be confined to one set of rooms (the RHR cells) since all RHR pumps and valves are in these rooms except one valve (Valve 744) which is in the RHR line to containment in the piping penetration area. After 24 hours, circulation occurs in the High Head pump room per reference [3], item 4.4, with leakage assumed to occur in this room (in addition to the RHR cells and piping penetration area) per Assumption 4.

For internal recirculation, the ESF liquid is not circulated outside containment until after 24 hours per reference [3], items 4.2, 4.4, and 4.6. Per Assumption 4, it is assumed that leakage can occur in the RHR cells, the piping penetration area, and the High Head pump room.

### Assumptions

Assumption 1: The flashing fraction is always less than 10% and the flash release is negligible compared to the calculated release.

Justification: The peak ESF liquid temperature is 261 F. Using a constant enthalpy method per reference [2],

$$mh = m_g h_g + m_l h_l$$

where  $m$  is total mass (liquid),  $h$  is the initial liquid enthalpy,  $m_g$  is flashed mass,  $h_g$  is gas enthalpy,  $m_l$  is unflashed liquid mass, and  $h_l$  is unflashed liquid enthalpy. Thus, the flashing fraction, which is the flashed mass divided by the total mass, is

$$ff = m_g / m = (mh - m_l h_l) / m h_g$$

Using initial liquid temperature of 261 F and final temperature of 212 F (corresponding to the saturation temperature at atmospheric pressure which is the final pressure of the flashed mixture), using the steam tables, and setting  $m = 1$  so that the flashing fraction is just  $m_g$ , we obtain

$$ff = (229 - (1 - ff)180) / 1150$$

$$ff(1150 - 180) = 229 - 180$$

$$ff = 0.051 = 5.5\%$$

Since the ESF liquid temperature continuously decreases from the initial temperature, the flashing fraction is always  $< 10\%$ .

The flash release is the iodine released to the gas phase during the flash. It can be estimated as the product of:

- The fraction of total iodine in the liquid which is elemental
- The fraction of this elemental iodine which partitions to the gas phase
- The ratio of flashed steam volume to liquid volume
- The fraction of liquid which flashed.

As is calculated below in the Attachment 1 spreadsheet, the fraction of total iodine in the liquid which is elemental is roughly  $1E-7$  (due to the high pH). The steam from the flashed liquid has a volume of the order of 1000 times the liquid. The partition coefficient is of the order of unity at the peak ESF liquid temperature, and of the order of 0.1 or lower after 24 hours. The flashing fraction is of the order of 0.1 at the beginning of the accident and quickly approaches zero after a few hours. The flashing release can then be approximated as

$$(1E-7)(1000)(1)(0.1) \approx 1E-5$$

at the beginning of the accident, and after a few hours is much lower. As will be seen from the calculation result, the release over 30 days is of the order of  $1E-2$ . Thus the flashing release is negligible.

Assumption 2: The iodine partitioning between the liquid and the gas at the liquid edge of the boundary layer is based on equilibrium conditions. That is, a fraction

of the  $I_2$  in the liquid is assumed to partition instantaneously to the gas at the liquid edge of the boundary layer. This fraction depends only on the temperature of the liquid and does not consider transport of the  $I_2$  within the liquid to the liquid – gas interface. (Transport of the  $I_2$  across the gas boundary layer between the liquid surface and the bulk gas phase is considered below.)

**Justification:** Elemental iodine will transport to the gas at the liquid edge of the gas boundary layer (i.e., partition) at a rate depending upon its actual vapor pressure in the gas vs. its saturation vapor pressure. For lower temperatures, the saturation vapor pressure will be lower and the partitioning will be lower. Similarly, as temperature increases, the saturation vapor pressure increases and the partitioning increases. At equilibrium, the actual vapor pressure equals the saturation vapor pressure. Equilibrium conditions have been assumed to simplify the calculation. This is conservative in that it neglects transient effects from transport of iodine through the liquid to and across the liquid – gas interface.

**Assumption 3:** The ESF component leakage remains at the containment sump liquid temperature.

**Justification:** ESF liquid is containment sump liquid which is recirculating through systems in the various ESF component rooms in the PAB. ESF component leakage is ESF liquid which leaks (e.g., pump seal, valve stem) into the room in which the component is located. The ESF component leakage is assumed to remain at the containment sump liquid temperature. In fact there will be heat transfer due to flashing and due to a temperature difference between the unflashed liquid and the ESF component room wall surfaces and structures (and to the air). This will lower the liquid temperature significantly. Neglecting this heat transfer is conservative since the amount of iodine partitioned from the liquid to the gas phase increases with increasing temperature.

**Assumption 4:** The continuous ESF leakage (i.e., 4 gph) will be assumed to be distributed in all rooms in which ESF components are located.

**Justification:** Prior to 24 hours (and after the 20.7 minute delay), it is likely that the leakage will be confined to one set of rooms (the RHR cells) since all RHR pumps and valves are in these rooms except one valve (Valve 744) which is in the RHR line to containment in the piping penetration area. However, distributing the ESF leakage involves a greater gas phase volume and thus effectively increases the volumetric exchange rate with the environment. Since the iodine release fraction will increase with the volumetric exchange (per Assumption 2, the iodine concentration at the liquid edge of the boundary layer is assumed to be in equilibrium with the aqueous phase iodine, and the iodine concentration in the bulk gas phase

will increase with the iodine concentration at the liquid edge of the boundary layer), distributing the ESF leakage will be conservative.

**Assumption 5:** The volumetric exchange with the environment will be assumed to be the sum of the exchange rates of all ESF rooms into which leakage can occur with the rooms being well-mixed.

**Justification:** It is conservative to assume that the flow from all ESF rooms into which leakage can occur is available since maximizing the exchange with the environment will maximize the iodine release. It is also conservative to assume well-mixed rooms since time for mixing would slow the exchange with the environment relative to the well-mixed case.

**Assumption 6:** Per Assumption 8 below, the ESF liquid leakage is expected to pool on the floor of the area into which the leakage occurs. However, for purposes of quantifying the effect of the boundary layer, the ESF leakage is assumed to be in the form of a liquid film on the floor, walls, and structural surfaces of the ESF area into which the leakage occurs.

**Justification:** In considering the effect of the boundary layer, it is conservative to maximize the area of the liquid surface which will in turn increase the mass of iodine transported across the boundary layer. Thus, while it is expected that the liquid will be pooled on the floor, this assumption provides significant conservatism.

**Assumption 7:** The iodine gas concentration in the bulk gas region will be treated as a constant for a given temperature. That is, transient effects will be neglected.

**Justification:** In the boundary layer calculation, both the steady state and the transient equation for bulk gas region iodine concentration are solved and it is shown that equilibrium is reached quickly compared to the time intervals used to characterize temperature.

**Assumption 8:** The ESF leakage is assumed to pool on room surfaces. Any droplets formed as the leakage exits the ESF component are assumed to fall to a surface without evaporating.

**Justification:** The ESF leakage is most likely to occur through a capillary-like opening such as through packing or seal material. Due to surface tension, this would result in relatively large drops which fall to the floor. In the unlikely event that the ESF leakage is spray-like, given that the ESF system has the thermal-hydraulic characteristics of a containment spray system, it is reasonable to assume that the spray-like leakage has a droplet size distribution similar to a spray nozzle. Calculations using the Mason equation for condensation on and evaporation from a water droplet

indicate that droplets with an initial size in this range (e.g., diameter of several hundred to several thousand  $\mu\text{m}$ ) will fall to the floor without evaporating. In fact, with consideration of hygroscopicity, an equilibrium droplet size will be reached for any initial droplet size, no matter how small.

Assumption 9: Evaporation from ESF leakage pools will be limited by the moisture-carrying capacity of the air flow and the pool surface area.

Justification: The water falling to the floor of the areas in which the ESF leakage may occur will rapidly reach ambient temperature by heat transfer to the floor and to the ventilation air and by evaporation. However, evaporation to dryness is extremely unlikely because of two limiting phenomena: the finite evaporation rate and the degree of saturation possible for ventilation air flowing through the ESF areas.

The evaporation rate may be characterized by the following expression [4]:

$$W_{\text{evap}} (\text{lbm/hr}) = 0.47(\text{pool area in ft}^2)(P_{\text{vapor/liquid}} - P_{\text{vapor/gas}} \text{ in psia})^{1.2}$$

A likely situation is that the leakage will collect in the sump, which is a 3ft x 3ft x 3ft cavity in the sump room. Spreading of the liquid to an area of 9  $\text{ft}^2$  will cool the liquid quickly to a temperature at or near the room temperature.. Thus, if the incoming air were at 90 F and 70% relative humidity, the evaporation rate would be of the order of 0.1 gph, well below the 4 gph entering the room.

The pool surface area required to evaporate all of the incoming water (at 4 gph) would be approximately 460  $\text{ft}^2$  assuming no increase in the room relative humidity. Even if the leakage were to spread over both RHR pump rooms (an area approaching 1000  $\text{ft}^2$ ) the average relative humidity in the vicinity of the water pool could not exceed about 85% if the four gph were to be evaporated. Therefore, the leaving relative humidity of the ventilation air in the vicinity of the water pool would have to approach 100% (for the stated incoming conditions). The relative humidity of the air leaving the ESF area would, of course, be less (depending on the amount of "bypass"; i.e., the fraction of the ventilation flow which was not in the vicinity of the water pool).

For the ventilation supply conditions stated and the assumption that all of the supply air is completely saturated when leaving the ESF area, the change in moisture content would be approximately 0.01 lbm per lbm of dry air. Noting that the total ventilation flowrate in the RHR cells is 5150 cfm (or about 2.2E4 lbm dry air per hour), the theoretical evaporation rate

could be as great as 220 lbm per hour or about 26.5 gph. However, this would require perfect mixing within all the cells. Even if perfect mixing in the room were achieved, the only effect would be to limit the exposed surface area, not to lead to a complete evaporation of the water. Indeed, as noted in the previous paragraph, one can assume that the minimum required surface area of the water pool would be about 460 ft<sup>2</sup> in order to have the evaporation rate equal the leak rate no matter how well-mixed the ventilation flow is. Under these conditions the four gph leak rate would limit the relative humidity increase to about four or five percent, but even with such a low relative humidity, at least 460 ft<sup>2</sup> would be necessary for a four gph evaporation rate.

The above assessment assumes that the energy needed to evaporate the water is simply available at the temperature stated. If the situation were adiabatic (i.e., as in an evaporative cooling model in which all energy must come from the air-water system as would be the case for evaporation of spray droplets), then the amount of water which could be evaporated would be only 15 to 20 percent of that given above (depending on the water temperature). Under these conditions complete mixing of the ventilation air would be absolutely required for complete evaporation (even if the droplets were sufficiently small and non-hygroscopic - see Assumption 8). Such complete mixing would be viewed as very unlikely.

Given the above thermodynamic and mass transfer limits, it would appear very unlikely that complete evaporation of the ESF leakage could occur for an assumed leak rate of four gph. Instead, it is expected that a pool of ESF leakage would collect on the floor of the ESF areas.

Assumption 10: The effect of ESF liquid leakage as jetted droplets is neglected.

Justification: See Proprietary Version.

## References

- Reference 1: PSAT 126.02CT.QA.02, "Implementing Procedure for Design Control for Calculation of Indian Point 2 Engineered Safety Feature Component Leakage Iodine Release," Rev. 0.
- Reference 2: NUREG-0800, NRC Standard Review Plan, Section 15.6.5, Appendix B, "Radiological Consequences of a Design Basis Loss of Coolant Accident: Leakage from Engineered Safety Features Components Outside Containment"
- Reference 3: PSAT 05656A.03, "Plant-Specific Design Input for Calculation of TMI-1 ESF Component Leakage Iodine Release", Revision 0
- Reference 4: L.M.K. Boelter, Gordon, H.S.; and Griffin, J.R. "Free Evaporation into Air of Water from a Free, Horizontal, Quiet Surface", Industrial and Engineering Chemistry, Volume 38, No. 6, pp. 596-600 (June 1946)
- Reference 5: D. Powers and S. Burson, "A Simplified Model of Aerosol Removal by Containment Sprays," NUREG/CR 5966, June, 1993.
- Reference 6: L. Soffer et al., "Accident Source Terms for Light-Water Nuclear Power Plants," NUREG-1465, February, 1995.
- Reference 7: R. Sher and J. Jokiniemi, "NAUAHYGROS 1.0: A Code for Calculating the Behavior of Aerosols in Nuclear Plant Containments Following a Severe Accident," EPRI Report TR-102775, July, 1993.
- Reference 8: NUREG/CR-5950, "Iodine Evolution and pH Control", November 1992

## Calculation

The calculational approach is to evaluate the iodine release based upon actual sump pH history and ventilation rates, consistent with the SRP [2] guidance, based upon Assumption 1 that flashing fraction is less than 10%. In addition, the effect of the gas

boundary layer, which exists at the liquid – gas interface, on the bulk gas iodine concentration has been considered.

### I<sub>2</sub> Concentration in Liquid

This is the first of four calculational sections. This calculational section determines the concentration of elemental iodine in the ESF liquid.

The total iodine concentration in the ESF liquid is

$$[I] = (I_c)(frel)/V_{ESF}/130$$

where  $[I]$  = total iodine concentration in kgmol/m<sup>3</sup> in the ESF liquid

$I_c$  = total core inventory of iodine in kg

frel = iodine release fraction from core to containment (= 0.4 per reference [6])

$V_{ESF}$  = the volume of liquid (m<sup>3</sup>) in which  $I$  is dissolved

From reference [3], items 2.1 and 3.1,  $I_c = 26.28$  kg which is 26.28/130 kgmol and total liquid mass  $m = 3.3E6$  lbm. From reference [7] the density of liquid water may be expressed as

$$\rho_{water} = \frac{(4.6137)(0.018016)(1000)}{0.26214^{(1+(1-T/647.29)^{0.23072})}}$$

Noting that  $V_{ESF} = m / \rho_{water}$  we have

$$[I] = (26.28)(0.4) / 130 / (m / \rho_{water}) \text{ kgmol/m}^3 \quad \text{Equation 1}$$

The elemental iodine concentration in the liquid may be calculated as

$$\text{See Proprietary Version} \quad \text{Equation 1a}$$

Equations 1 and 1a are used to obtain  $[I]$  and  $[I_2]_{aq}$  as a function of temperature (see Attachment 1 spreadsheet, discussed further below). For external recirculation (page 1 of Attachment 1), an exception is for 0 to 20.7 minutes during which time recirculation has not yet been initiated, and  $[I]$  and  $[I_2]_{aq}$  are zero. For internal recirculation (page 2 of Attachment 1), an exception is for 0 to 24 hours during which time recirculation has not yet been initiated and  $[I]$  and  $[I_2]_{aq}$  are zero.

### I<sub>2</sub> Concentration at Liquid Edge of Gas Boundary Layer

This is the second of four calculational sections. Per Assumption 2, the iodine partitioning between the liquid and the liquid edge of the boundary layer is based on equilibrium conditions. Thus, from equations 14 and 15 of reference [8], the I<sub>2</sub> concentration at the liquid edge of the boundary layer may be expressed as

See Proprietary Version

Equation 2

where PC is the partition coefficient for  $I_2$  between the liquid and gas.

To evaluate PC and  $[I_2]_{g_i}$  the ESF liquid leakage temperature is required. Per Assumption 3, the ESF component leakage is assumed to remain at the containment sump liquid temperature. Reference [3], item 3.2 includes containment sump liquid temperature vs. time. ESF leakage pool temperature has been estimated by mass averaging the ESF liquid added to the pool over time. The Attachment 1 spreadsheet contains the details. The containment sump liquid temperature vs. time data was divided into time intervals, with the length of the intervals chosen to correspond to the  $\chi/Q$  intervals with several intervals added to limit the temperature decrease, to account for the fact that external recirculation does not begin for 20.7 minutes after the start of the accident, to account for the fact that internal recirculation does not begin for 24 hours after the start of the accident, and to account for the increased ESF leakage between 24 and 24.5 hours per reference [3], item 4.1. There are a total of 11 time intervals with iodine concentration being zero for the first 2 intervals for the external recirculation case and for the first 6 intervals for the internal recirculation case. For each interval, the average temperature of the incoming ESF liquid was volume averaged with the pool volume up to that point. Thus the temperature for the  $i^{\text{th}}$  interval may be expressed as

$$T_i = (\text{vol}_{\text{pool},i-1} T_{\text{pool},i-1} + \text{vol}_{\text{inc},i} T_{\text{inc},i}) / \text{vol}_{\text{pool},i} \quad \text{Equation 3a}$$

The time intervals in seconds are shown in columns 1 to 3 of Attachment 1. Columns 4 and 5 are the incoming ESF leakage temperature (K) at the beginning of the time interval and end of the time interval, respectively. Column 6 solves for the ESF leakage pool volume-average temperature (K) for that interval using equation 3a. For time intervals after 24 hours, the 30 minutes of 50 gal per minute leakage was taken into account in the volume averaging.

### Gas Transport of Iodine Across Boundary Layer

This is the third of four calculational sections. The problem of iodine gas transport across the boundary layer at the liquid – gas interface is illustrated in Figure 1.  $[I_2]_{aq}$  and  $[I_2]_{g_i}$  are known from equations 1 through 3. The object of this gas transport calculation is to solve for  $[I_2]_{g_b}$ . The transport of gas is due to diffusion which is driven by the concentration gradient of gas from the liquid pool surface to the bulk gas region where

the gas is assumed to be well-mixed per Assumption 5. The elemental iodine concentration in the pool,  $[I_2]_{aq}$ , is assumed to be constant (i.e., a well-mixed pool) and is determined by  $[I]$  and pH. The well-mixed pool assumption is conservative since there will in fact be a boundary layer and concentration profile in the liquid which will reduce the  $[I_2]_{aq}$  concentration at the surface. The effect of this assumption is that there is an instantaneous source of  $I_2$  at the liquid edge of the boundary layer which is at concentration  $[I_2]_{g1}$  which is in turn determined by  $[I_2]_{aq}$  and the partition coefficient.

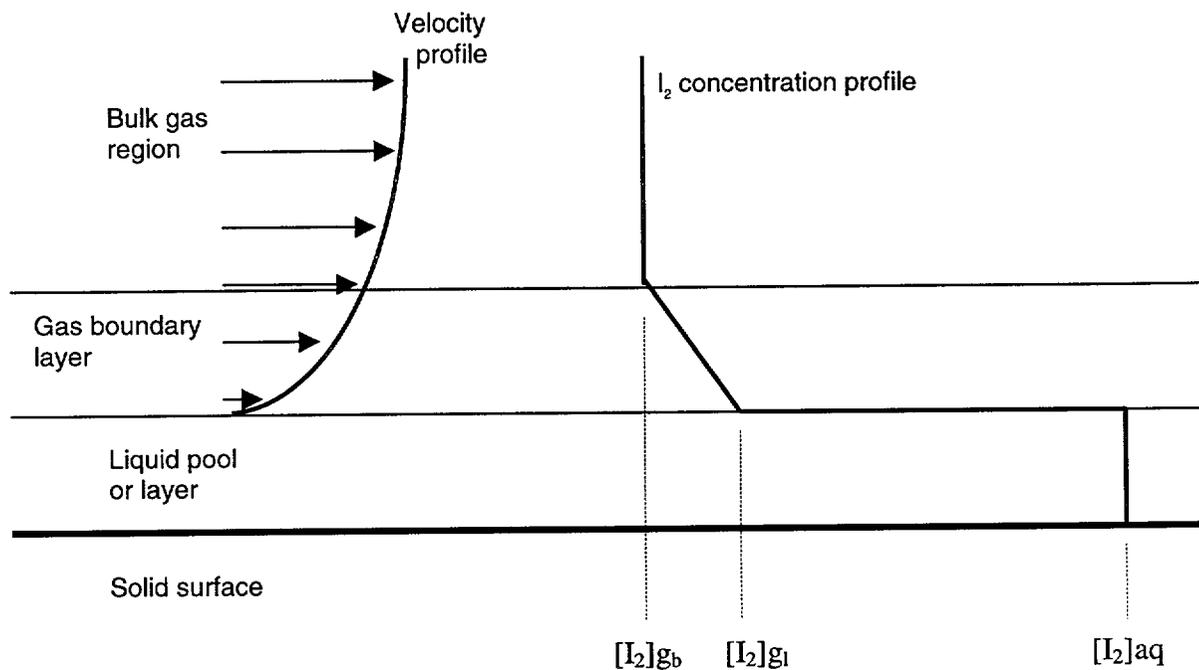


Figure 1 Illustration of Boundary Layer

The problem of mass transfer of the iodine gas across the gas boundary layer at the liquid-gas interface is treated by defining a mass transfer coefficient in a manner similar to that used for defining a heat transfer coefficient.

See Proprietary Version

See Proprietary Version

The pool average temperature, upon which several of the above parameters depend, varies from a peak of 397 K to a low of 330 K (see Attachment 1). Since the boundary layer effect decreases with increasing temperature, the peak temperature will be used in boundary layer quantification.

To obtain values for  $u$ ,  $A$ , and  $L$ , we need to establish the geometry of the bulk gas flow regime. Per reference [3], item 5.1, there are 8 rooms into which ESF leakage can occur and through which there is bulk gas flow. Table 1 lists the 8 rooms and their geometry and flow characteristics which are based on reference [3], items 5.2, 5.3 and 5.4, and are inputs to quantify the boundary layer effect in these rooms. The Hallway Outside will be used as an example calculation to illustrate the methodology.

We may determine  $u$ ,  $A$ , and  $L$  for the Hallway Outside as follows using the description and associated dimensions from reference [3], item 5.2. The direction of bulk gas flow is assumed to be in the long direction in order to maximize velocity over the pool, and thus maximize mass transfer across the boundary layer. The length scale,  $L$ , is taken as the length dimension in the direction of bulk gas flow (i.e., 44 ft = 13.4 m). Per Assumption 6, the area,  $A$ , is taken to be the sum of all Hallway Outside wall surfaces (not including the ends since the ends are open) plus an additional area equal to twice the floor area to conservatively account for equipment surfaces. Referring to item 5.2 of reference [3], the surface area may be approximated as

$$A = (5)(44)(2) + (15)(44)(2) + (5)(44)(2) \\ \approx 2200 \text{ ft}^2$$

which is about 205 m<sup>2</sup>.

The velocity may be conservatively estimated from

$$uA_c = \dot{V}$$

Table 1 Geometry, Flow Characteristics, and Boundary Layer DF of Rooms into which ESF Leakage Can Occur

Room	V (m <sup>3</sup> )	V-dot (m <sup>3</sup> /s)	V/V-dot (hr <sup>-1</sup> )	A (m <sup>2</sup> )	L (m)	A <sub>c</sub> (m <sup>2</sup> )	u (m/s)	DF	[I <sub>2</sub> ] <sub>gb</sub> mol/L
RHR Room 21	91	1.17	46	129	5.6	16.1	0.073	24	1.5E-13
RHR Room 22	129	1.17	33	109	4.4	16.1	0.073	27	1.3E-13
Sump Tank Room	31	0.094	11	52	2.7	11.1	0.009	24	1.5E-13
Sump Room	40	0.094	8.5	58	3	11.1	0.009	22	1.7E-13
Hallway to Sump Room	41	2.4	214	103	7.3	5.6	0.44	16	2.2E-13
Hallway Outside	123	2.4	71	205	13.4	7	0.35	11	3.5E-13
Penetration Area	2032	2.9	5.1	1933	28	73	0.04	10	4E-13
High Head Pump Room	614	4.3	25	697	11	56	0.08	18	2E-13

where the bulk gas flows with velocity  $u$  from one end of the Hallway Outside to the other,  $A_c$  is the Hallway Outside cross sectional area which per reference [3], item 5.2 is 75 ft<sup>2</sup>, and  $\dot{V}$  is volumetric flow (m<sup>3</sup>/s) exchange with the environment. Thus,

$$u = \dot{V} / 75 / 0.0929 \text{ m/s} \quad \text{Equation 12a}$$

In the case of the Hallway Outside, per reference [3]. Item 5.2,

$$\dot{V} = (5150 \text{ cfm})(1 / 60 \text{ s} / \text{min})(1 / 35.3 \text{ m}^3 / \text{ft}^3) = 2.43 \text{ hr}^{-1}$$

and

$$u = 2.43 / 75 / 0.0929 = 0.35 \text{ m/s}$$

We now have all of the parameter values and expressions necessary to solve for the steady state value of  $[I_2]_{gb}$ .

To confirm Assumptions 7 and 10, the transient behavior of  $[I_2]_{gb}$  was also calculated. This was accomplished by solving the following equation for  $[I_2]_{gb}$ :

$$\text{See Proprietary Version} \quad \text{Equation 13}$$

where  $V$  is the volume of the bulk gas region.

The solutions to equation 9 for steady state  $[I_2]_{g_b}$  and to equation 13 for transient  $[I_2]_{g_b}$  are provided in the Attachment 2 spreadsheet. Attachment 2 consists of 4 pages. Page 1 provides the steady state result at the top and the transient calculation carried out to 340 seconds at the bottom. It is seen that after about 150 seconds,  $[I_2]_{g_b}$  is about 90% of the steady state value. Thus the approach to steady state is fast enough relative to the duration of the 11 time intervals in Attachment 1 that neglecting transient effects will have negligible effect on the release. It may further be observed that in the approximately 5 second duration of droplet fall for the jetted leakage discussed in Assumption 10, the transient gas concentration will be negligible.

Page 2 includes case-specific and non-case specific inputs to the mass transfer calculation. Page 3 is the calculation of the Sherwood Number. Page 4 is a calculation of  $[I_2]_{g_l}$ .

It is noted that the boundary layer model in the Attachment 2 spreadsheet is configured for a 2 volume bulk gas region, although the problem addressed here assumes a single, well-mixed volume per Assumption 5.

The values of the steady state, turbulent boundary layer decontamination factors (DF) for each of the 8 rooms in Table 1 are recorded in Table 1. Boundary layer DF is defined as the elemental iodine concentration in the bulk gas without the boundary layer effect divided by the elemental iodine concentration with this effect. The turbulent value has been used since this gives a higher iodine diffusion. It is noted that the DF ranges from 27 down to 10. The Hallway Outside DF is 11. For conservatism, a DF of 10 will be used for all rooms.

Column 11 of Attachment 1 shows the DF of 10, and  $[I_2]_{g_b}$  is calculated in column 12 by dividing  $[I_2]_{g_l}$  (column 10) by boundary layer DF (column 11).

### $I_2$ Release from Gas Space

This is the fourth of four calculational sections. The  $I_2$  release to the environment from the PAB is equal to the product of the volumetric gas flow from the affected ESF rooms to the environment in  $m^3$  per hour and  $[I_2]_{g_b}$  in  $kgmol/m^3$ .

Accordingly, the iodine release in  $kgmol/hour$  to the environment during time interval  $i$  is

See Proprietary Version

Equation 14

where  $V$  is volume and  $\dot{V}/V$  is the exchange rate with the environment in  $hr^{-1}$ .

The values for  $V$  and  $\dot{V}/V$  to be used in equation 14 are obtained as follows. Per Assumption 4, for external recirculation leakage can occur into the RHR cells and the piping penetration area after 20.7 minutes (per reference [3], items 5.1, 5.2, and 5.4 , total volume =  $(10.5)(18.5)(16.5) + (18.5)(18)(13.7) + (8)(9)(15) + (4)(24)(15) + (8)(10)(15) + (5)(44)(15) + (43.4)(91.8)(18) = 85,501 \text{ ft}^3 = 2450 \text{ m}^3$ ) and into the RHR cells, the piping penetration area, and the High Head Pump room after 24 hours (per reference [3], items 5.1 and 5.3, total volume  $86,501 + (35.6)(35.6)(17.1) = 108,170 \text{ ft}^3 = 3064 \text{ m}^3$ ). For internal recirculation leakage can occur into the RHR cells, the piping penetration area, and the High Head pump room after 24 hours (volume  $3064 \text{ m}^3$ ).

Per Assumption 5 and reference [3], items 5.1, 5.2, and 5.4, for external recirculation between 20.7 minutes and 24 hours, volumetric gas flow to the environment is based on an exchange rate,  $\dot{V}/V$ , of  $(5150 + 6100)(60) = 6.75\text{E}5 \text{ cfh} = 6.75\text{E}5/35.3/2450 = 7.8$  volumes per hour For external recirculation after 24 hours,  $\dot{V}/V$  is  $(5150 + 6100 + 9000)(60) = 1.22\text{E}6 \text{ cfh} = 1.22\text{E}6/35.3/3064 = 11.2$  volumes per hour.

Per Assumption 5 and reference [3], items 5.1 and 5.3, for internal recirculation after 24 hours,  $\dot{V}/V$  is 11.2 volumes per hour.

## Results

The results of this calculation are presented in Tables 2 through 5. Tables 2 and 3 are taken from page 1 of 2 of the Attachment 1 spreadsheet. Table 2 is taken from column 14, and Table 3 is taken from the lower left hand sub-table of the spreadsheet. Tables 4 and 5 are taken from page 2 of 2 of the Attachment 1 spreadsheet. The 2 pages in Attachment 1 are for external and internal recirculation, respectively.

The results are in units of fraction of total iodine leaking into the ESF component room(s) (i.e., fraction of the total dissolved iodine in the 4 gal per hour). As is evident from Table 2, in the first 20.7 minutes (1242 seconds) the release is zero since recirculation has not yet started. For a short duration early in the accident, the release is between 1 and 2% of the total iodine in the leakage. The fraction decreases with time and is about 0.5% percent after a day. This decrease is due mainly to decreasing temperature as the ESF liquid is cooled (and thus the amount of iodine partitioning from the liquid decreases per equations 2 and 3).

For Con Edison use in the dose calculation, the  $\text{Frac}_i$  quantities in Table 2 (from equation 15) have been time-weighted to produce a fractional release of total incoming iodine for time intervals corresponding to the  $\chi/Q$  intervals. This is presented in Table 3.

As is evident from Table 4, in the first 24 hours (86,400 seconds) the release is zero since recirculation has not yet started. After 24 hours, the release fraction is approximately 0.5%.

For Con Edison use in the dose calculation, the  $Frac_i$  quantities in Table 4 have been time-weighted to produce a fractional release of total incoming iodine for time intervals corresponding to the  $\chi/Q$  intervals. This is presented in Table 5.

It is noted that the results reported here are quite conservative with respect to several effects: (1) the ESF leakage was assumed to be distributed over the maximum PAB room volume and to be transported from the PAB to the environment with the maximum volumetric flow; (2) the ESF leakage temperature was estimated by assuming no heat transfer from the leaked liquid to the structures and surfaces in the area in which the leakage occurs; (3) the flashing of ESF liquid and the associated reduction in unflashed liquid temperature to 212 F upon leakage to ESF rooms was neglected which overestimates the liquid temperature for the first 3.1 hours; (4) for purposes of the boundary layer calculation, the area of the ESF leakage pool was overestimated by assuming that a liquid layer is maintained on all walls and equipment surfaces in the area in which the leakage occurs which significantly increases the mass transport across the boundary layer; and (5) the minimum boundary layer DF was applied for all ESF leakage and associated bulk gas flow. These effects were treated in this manner for simplicity, and could be reevaluated if necessary to provide a more realistic estimate of the boundary layer.

### Conclusions

The conclusions from this calculation are as follows:

- For external recirculation, the iodine release from ESF leakage for IP2 varies over the range of 1% to 2% over the first few hours, decreasing to about 0.5% at 30 days.
- For internal recirculation, the iodine release is zero for the first 24 hours and about 0.5% thereafter.

**Table 2 Fraction of Incoming Iodine Released for External Recirculation**

Time Interval (sec)		$Frac_i$ (Fraction of Incoming Iodine)
75	to 720	N/A
720	to 1242	N/A
1242	to 3300	1.90E-02
3300	to 7200	1.49E-02
7200	to 28800	8.63E-03
28800	to 86400	4.84E-03
86400	to 88200	7.16E-06
88200	to 172800	5.35E-03
172800	to 345600	5.26E-03
345600	to 500000	5.13E-03
500000	to 2.59E+06	4.24E-03

**Table 3 Fraction of Incoming Iodine Released During Chi/Q Periods for External Recirculation**

Time Period	Fraction of Incoming Iodine
0 to 2 hr	1.35E-02
2 to 8 hr	8.63E-03
8 to 24 hr	4.84E-03
24 hr to 24.5 hr	7.16E-06
1 to 4 days	5.29E-03
4 to 30 days	4.30E-03

**Table 4 Fraction of Incoming Iodine Released for Internal Recirculation**

Time Interval (sec)	Frac <sub>i</sub> (Fraction of Incoming Iodine)
75 to 720	N/A
720 to 1242	N/A
1242 to 3300	N/A
3300 to 7200	N/A
7200 to 28800	N/A
28800 to 86400	N/A
86400 to 88200	7.16E-06
88200 to 172800	5.35E-03
172800 to 345600	5.26E-03
345600 to 500000	5.13E-03
500000 to 2.59E+06	4.24E-03

**Table 5 Fraction of Incoming Iodine Released During Chi/Q Periods for Internal Recirculation**

Time Period	Fraction of Incoming Iodine
0 to 2 hr	0.00E+00
2 to 8 hr	0.00E+00
8 to 24 hr	0.00E+00
24 hr to 24.5 hr	7.16E-06
1 to 4 days	5.29E-03
4 to 30 days	4.30E-03

**Attachment C**

**Polestar Applied Technology, Inc.**

**AFFIDAVIT**

I, David E.W. Leaver, being duly sworn, depose and state as follows:

- (1) I am a Principal and an Officer of Polestar Applied Technology, Inc. ("Polestar") and am responsible for the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.
- (2) The information sought to be withheld is contained in portions of the following proprietary Polestar reports prepared for Consolidated Edison in support of the Indian Point 2 Nuclear Plant calculation of the iodine release from ESF leakage:  
  
PSAT 126.02CT.QA.04 Calculation of Indian Point 2 Engineered Safety Feature Component Leakage Iodine Release  
PSAT 126.02CT.QA.05 Calculation of Indian Point 2 Engineered Safety Feature Component Leakage Iodine Release with Boundary Layer Effect
- (3) In making this application for withholding of proprietary information of which it is the owner, Polestar relies upon the exemption from disclosure set forth in the NRC regulations 10 CFR 9.17(a)(4), 2.790(a)(4), and 2.790(d)(1) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 2.790(a)(4)). The material for which exemption from disclosure is here sought is all "confidential commercial information".
- (4) Some examples of categories of information which fit into the definition of proprietary information are:
  - a. Information that discloses a process or method, including supporting data and analyses, where prevention of its use by Polestar's competitors without license from Polestar constitutes a competitive economic advantage over other companies.
  - b. Information which, if used by a competitor, would significantly reduce his expenditure of resources or improve his competitive position in the analysis, design, assurance of quality, or licensing of a similar product;
  - c. Information which reveals cost or price information, production capacities, budget levels, or commercial strategies of Polestar, its customers, or its suppliers;

- d. Information which reveals aspects of past, present, or future Polestar customer-funded development plans and programs, of potential commercial value to Polestar;
- e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in both paragraphs (4)a and (4)b, above.

- (5) The information sought to be withheld is being submitted to Consolidated Edison (and, we trust, to NRC) in confidence. The information is of a sort customarily held in confidence by Polestar, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by Polestar, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.
- (6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Distribution of such documents within Polestar is limited to those with a need to know.
- (7) The approval of external release of such a document typically requires review by the project manager, and the Polestar Principal closest to the work, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside Polestar are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.
- (8) The information identified in paragraph (2), above, is classified as proprietary because it contains detailed information on models in current software which were developed by Polestar and are justified from benchmark exercises and applications, detailed results of these models and analytical methods, and computer codes which Polestar has developed, documented, and is maintaining under the Polestar 10 CFR 50, Appendix B Quality Assurance Program. The model results are from applications of methods related to the alternate DBA

source term to the Indian Point 2 Nuclear Plant in support of Consolidated Edison.

The development and documentation of the methods, models, and associated Polestar computer codes used in these analyses was achieved at a significant cost to Polestar, on the order of \$25,000, which is a significant fraction of internal research and development resources available to a company the size of Polestar.

The development of the models and methods, along with the interpretation and application of the results, is derived from the extensive experience database that constitutes a major Polestar asset.

- (9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to Polestar's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of Polestar's comprehensive technology base on application of the alternate source term to operating plants and advanced light water reactors, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with methods which have been developed and are being maintained in accordance with 10 CFR 50, Appendix B requirements.

The research, development, engineering, analytical and review costs comprise a substantial investment of time and money by Polestar.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

Polestar's competitive advantage will be lost if its competitors are able to use the results of the Polestar experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to Polestar would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive Polestar of the opportunity to exercise its competitive advantage to seek an adequate return on its relatively large investment in developing these very valuable analytical tools.

STATE OF CALIFORNIA            )  
  )  
COUNTY OF SANTA CLARA        )        ss:

David E.W. Leaver, is being duly sworn, deposes and says:

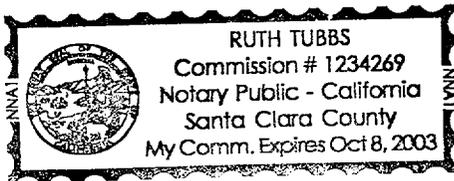
That he has read the foregoing affidavit and the matters stated therein are true and correct to the best of his knowledge, information, and belief.

Executed at Los Altos, California, this 6<sup>th</sup> day of April 2000.

*David E.W. Leaver*

David E.W. Leaver  
Polestar Applied Technology, Inc.

Subscribed and sworn before me this 6<sup>th</sup> day of April 2000.



*Ruth Tubbs*  
Notary Public, State of California