

## ArevaEPRDCPEm Resource

---

**From:** BRYAN Martin (EXTERNAL AREVA) [Martin.Bryan.ext@areva.com]  
**Sent:** Friday, August 06, 2010 9:41 AM  
**To:** Tesfaye, Getachew  
**Cc:** Lee, Heather  
**Subject:** RE: RAI 17, Supplement 1 response  
**Attachments:** RAI 17 Supplement 1 Response US EPR DC NonProprietary.pdf

Getachew,

This was in our files and appears to be the document you were looking for.

Martin (Marty) C. Bryan  
U.S. EPR Design Certification Licensing Manager  
AREVA NP Inc.  
Tel: (434) 832-3016  
702 561-3528 cell  
[Martin.Bryan.ext@areva.com](mailto:Martin.Bryan.ext@areva.com)

---

**From:** Tesfaye, Getachew [mailto:Getachew.Tesfaye@nrc.gov]  
**Sent:** Wednesday, August 04, 2010 2:03 PM  
**To:** BRYAN Martin (EXT)  
**Cc:** Lee, Heather  
**Subject:** FW: RAI 17, Supplement 1 response

Marty,  
The non-prop version of the subject response could not be found ADAMS. Please email me the document so that we can be enter in ADAMS. See detail below.  
Thanks,  
Getachew

---

**From:** Lee, Heather  
**Sent:** Wednesday, August 04, 2010 9:20 AM  
**To:** Tesfaye, Getachew  
**Cc:** McLellan, Judith  
**Subject:** RAI 17, Supplement 1 response

Getachew,

I know this is awhile back but I am looking for the 09/19/08 response to RAI 17, Supplement 1. I only show having the email & affidavit (ML082680054) and the Proprietary response (ML090340694). The email states that a non-proprietary response was sent as well.

I have searched in ADAMS but no luck! Unless NRC users can't see it.

Thanks.

**Heather Lee**  
(301) 415-4146

**Hearing Identifier:** AREVA\_EPR\_DC\_RAIs  
**Email Number:** 1865

**Mail Envelope Properties** (BC417D9255991046A37DD56CF597DB71071F72B4)

**Subject:** RE: RAI 17, Supplement 1 response  
**Sent Date:** 8/6/2010 9:40:39 AM  
**Received Date:** 8/6/2010 9:40:44 AM  
**From:** BRYAN Martin (EXTERNAL AREVA)

**Created By:** Martin.Bryan.ext@areva.com

**Recipients:**

"Lee, Heather" <Heather.Lee@nrc.gov>  
Tracking Status: None  
"Teschew, Getachew" <Getachew.Teschew@nrc.gov>  
Tracking Status: None

**Post Office:** AUSLYNCMX02.adom.ad.corp

<b>Files</b>	<b>Size</b>	<b>Date &amp; Time</b>	
MESSAGE	1275	8/6/2010 9:40:44 AM	
RAI 17 Supplement 1 Response US EPR DC NonProprietary.pdf			224667

**Options**

**Priority:** Standard  
**Return Notification:** No  
**Reply Requested:** No  
**Sensitivity:** Normal  
**Expiration Date:**  
**Recipients Received:**

**Response to**

**Request for Additional Information No. 17 Supplement 1, Revision 0**

**6/18/2008**

**U.S. EPR Standard Design Certification**

**AREVA NP Inc.**

**Docket No. 52-020**

**SRP Section: 15.00.03 - Design Basis Accidents Radiological Consequence**

**Analyses for Advanced Light Water Reactors**

**Application Section: FSAR 11.1 and 15.0.3**

**RSAC Branch**

**Question 15.00.03-19:**

The text in FSAR 15.0.3.9 for the REA dose analysis does not discuss elemental iodine removal. FSAR Table 15.0-40 states that the elemental iodine removal coefficients are the same as for aerosols, except limited to a decontamination factor (DF) of 100. Please justify use of models and assumptions on iodine elemental iodine removal. Provide the mechanism on which the elemental iodine removal is based. Document that this mechanism has been previously approved in reactor licensing. Identify the cases for which elemental iodine removal was assumed. Provide the time after the onset of the REA that the DF equals 100.

**Response to Question 15.00.03-19:**

The response to Question 15.00.03-27 provides justification and additional information on the models and assumptions used for elemental iodine removal, including the mechanism on which the elemental iodine removal is based, documentation that this mechanism has been previously approved in reactor licensing, and identification of cases for which elemental iodine removal is assumed.

The post-rod ejection accident time at which the DF of 100 is attained is 81.2 hours.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Question 15.00.03-23:**

Provide assurance that you have performed a dose analysis of the FHA for fuel that has less than 34 hours of decay time, using the containment or fuel building closure requirements in the Technical Specifications. If not, provide the means of preventing fuel movement prior to 34 hours decay time.

**Response to Question 15.00.03-23:**

The fuel handling accident assumes a decay time of 34 hours following reactor shutdown. The 34 hour decay time is selected to result in less than 90 percent of the dose acceptance criterion at the critical receptor as explained in U.S. EPR FSAR, Tier 2, Section 15.0.3.10.3.

The time interval between the time the reactor is last critical and the initial movement of a recently irradiated fuel assembly is based on the many shutdown and refueling operations necessary to support fuel movement. The means for preventing fuel movement prior to 34 hours decay time is a function of the reactor design. A representative short outage schedule for the U.S. EPR has fuel movement in the vessel commencing at about [ ] hours from reactor shutdown.

The minimum decay time of 34 hours, which must elapse following reactor shutdown, will be met for refueling outages because of the operations (e.g., containment entry, removal of reactor slab, removal of vessel head, removal of instrumentation lances) required prior to moving recently irradiated fuel. In addition, the inclusion of the 34 hour decay time in the U.S. EPR FSAR for the analysis of the fuel drop accident provides administrative controls for preventing fuel movement prior to 34 hours decay time.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Question 15.00.03-24:**

In the LOCA and REA dose analyses, the Powers natural deposition model and the “Henry model” for aerosol removal in containment were combined to model aerosol deposition in the containment. The Henry model has not previously been reviewed or found acceptable for use in reactor licensing. Please justify the use of the Henry model for aerosol natural deposition in the EPR containment.

**Response to Question 15.00.03-24:**

The Powers model correlations in the RADTRAD code (NUREG/CR-6604, “RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation,” Sec. 2.2.2.1) for aerosol removal as a result of natural deposition are functions of reactor type and power level for different time periods and probability percentiles. For pressurized water reactors (PWRs), the correlation coefficients are specified for the first 22.2 hours of a loss of coolant accident (LOCA), with no guidance for application of natural deposition credit beyond that time. For the U.S. EPR, the Henry model has been used to extend natural aerosol removal beyond 22.2 hours.

In most PWR applications, containment sprays augment and even dominate the aerosol removal process, so a time limitation for use of the Powers correlation coefficients in those cases is not a significant drawback. However, for a plant relying on natural deposition (such as the U.S. EPR), the time span is too short (22.2 hours using Powers) to produce a meaningful decontamination of the containment atmosphere.

For the advanced PWR correlations in RADTRAD for plants relying solely on natural removal because of its passive safety systems, the sedimentation component of aerosol removal (reflected in the standard boiling water reactor (BWR) and PWR correlations) is augmented by crediting substantial phoretic deposition (the removal associated with condensation and sensible heat transfer). By crediting substantial phoretic deposition, the removal rates become significantly greater than the same power level would produce for the standard PWR Powers correlation.

Figure 15.00.03-24-1—Normalized Iodine Aerosol Release Airborne presents the normalized aerosol airborne activity for the U.S. EPR with and without phoretic deposition, at 4612 MWt as represented by the APWRx2.56 (4612/1800) line, based on the methodology described in Section 2.2.2.1 of NUREG/CR-6604.

The sedimentation-only rates of the 10<sup>th</sup> percentile Powers PWR correlation (as implemented in RADTRAD) are much lower than either the RADTRAD-implemented 10<sup>th</sup> percentile Powers BWR or APWR correlation values, so therefore the time frame over which the Powers PWR correlation has been defined should be much longer than 22.2 hours. The PWR sedimentation rates are conservative (if not overly conservative by virtue of having been established at the 10<sup>th</sup> percentile and the fact that they basically ignore phoretic deposition), but what substantially limits the usefulness of the correlation is the cessation of removal at 22.2 hours. It is this fundamental limitation of the Powers correlation that the time extension using the RADTRAD Henry model is intended to remedy.

To extend the Powers PWR correlation in an acceptable manner using the Henry model, a comparable degree of conservatism is introduced. The Henry model has two inputs that must

be supplied by the user to establish the natural deposition removal coefficient ( $\lambda$ ): the sedimentation height ( $h$ ) of the volume of interest, and the aerosol density ( $\rho_P$ ). These inputs are both expressed as ratios to reference values from experimental data ( $h_{ref} = 5.0$  m and  $\rho_{Pref} = 2270$  kg/m<sup>3</sup>). The relationship of the removal rate to these ratios is illustrated by Equation 1, which is from NUREG/CR-6604 (Sec. 2.2.2.1.1):

$$\lambda = C_1 \left( \frac{h_{ref}}{h} \right) \left( \frac{\rho_P}{\rho_{Pref}} \right) \rho_A^K \quad [\text{Eq. 1}]$$

where  $C_1$  and  $K$  are constants and  $\rho_A$  is the aerosol “cloud” density or mass concentration in the volume (kg/m<sup>3</sup>). By assuming  $\rho_A$  to be approximately the same as that corresponding to the Powers 10<sup>th</sup> percentile lambda values (i.e., removal coefficient) up to 22.2 hours, along with a particle density ratio of unity, a sedimentation height ( $h$ ) is calculated that produces the same lambda at 22.2 hours as the 10<sup>th</sup> percentile Powers correlation for the PWR. This calculation yields a sedimentation height of 22.1 meters.

Equation 1 is then used beyond 22.2 hours. Because the Henry model lambdas are a function of aerosol mass remaining airborne ( $\rho_A$ ) whereas the Powers model is not, the lambdas for the Henry model decrease with time relative to the Powers 10<sup>th</sup> percentile lambdas as mass is removed. On this basis, using the Henry model to extend the Powers 10<sup>th</sup> percentile correlation beyond 22.2 hours is both reasonable and conservative. The smooth transition from the Powers to the Henry model is evident in the plot of the iodine-131 airborne activity in containment shown in Figure 15.00.03-30-1—Iodine-131 Activity Distribution in the response to Question 15.00.03-30.

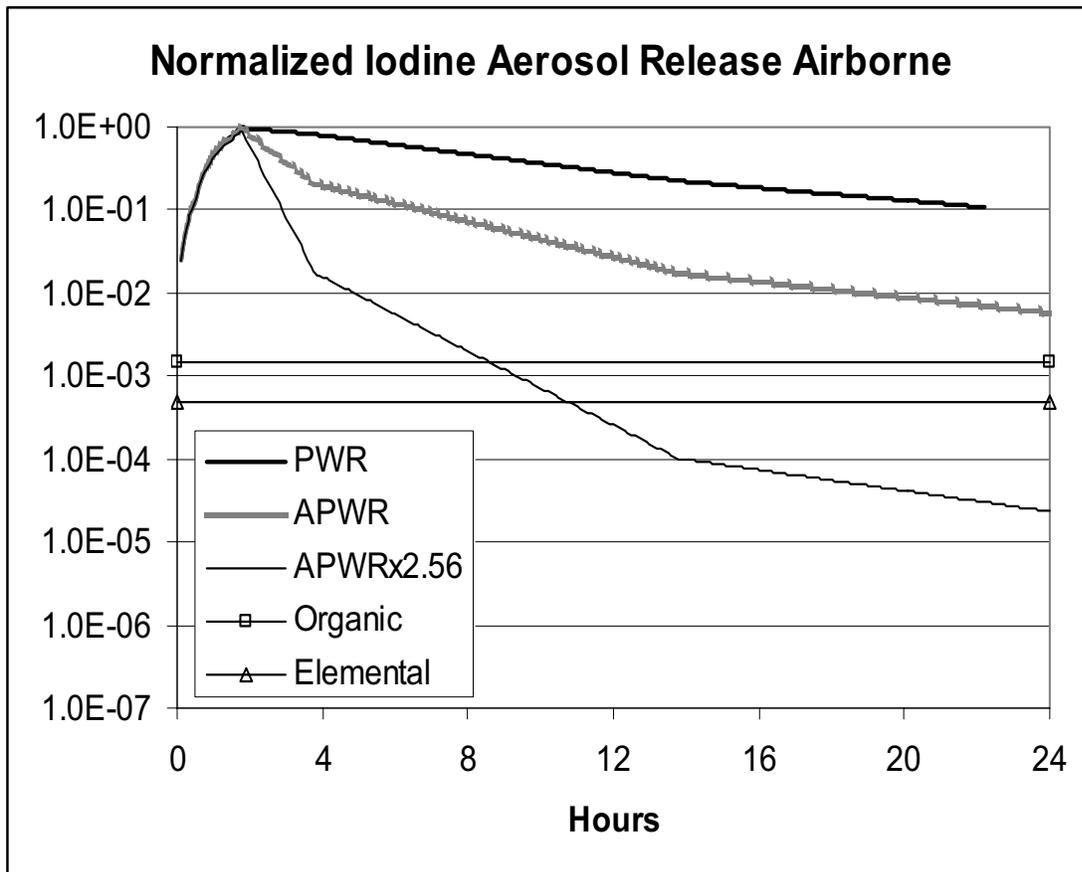
To summarize, the conservatism of the Powers-Henry methodology for natural aerosol removal in the U.S. EPR primary containment includes:

- The 10<sup>th</sup> percentile Powers PWR correlation with essentially no credit for phoretic deposition is used up to 22.2 hours.
- The Henry model inputs are established to produce the same conservative lambda as the Powers 10<sup>th</sup> percentile correlation at 22.2 hours.
- Because of the dependency of the Henry model lambdas on the mass of aerosol remaining airborne, the Powers 10<sup>th</sup> percentile correlation, when extended beyond 22.2 hours, produces lambdas comparable to or even greater than the lambdas produced by the Henry model extension as applied to the U.S. EPR.

#### **FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Figure 15.00.03-24-1—Normalized Iodine Aerosol Release Airborne**



**Question 15.00.03-25:**

In the LOCA and REA dose analyses, aerosol deposition in containment is modeled in part by using the 10<sup>th</sup> percentile Powers natural deposition correlation in RADTRAD. Considering that the Powers natural deposition correlation was developed using operating pressurized water reactor (PWR) and boiling water reactor (BWR) information on containment geometry and power, justify the applicability of the Powers natural deposition correlation to the EPR containment.

**Response to Question 15.00.03-25:**

In the case of the standard PWR application, the Powers natural deposition correlation in RADTRAD considers essentially only sedimentation (the advanced PWR application includes substantial phoretic deposition as well). The important parameters determining the aerosol deposition rate by sedimentation include the following:

- Initial size, shape, and density of the aerosol particles.
- The mass concentration of the aerosol particles, which affects the rate of agglomeration (a reduction in particle number and a corresponding increase in the particle size of the combined particles).
- The sedimentation height (volume of the compartment divided by the total horizontal area).

Because the Powers natural deposition correlation is solely a function of reactor power in the standard PWR application (with the deposition rate increasing slightly with power), there is an implied relationship that the aerosol loading will increase more rapidly with power than the containment volume and the sedimentation height will not increase to the extent that the greater mass concentration would be offset. In other words, the total aerosol mass released is expected to increase roughly linearly with power. If the containment volume increases proportionately so that the mass concentration remains unchanged and if the sedimentation height remains the same (i.e., a sedimentation area increase proportionate to the increase in containment volume), there will essentially be no effect on sedimentation rate. However, the correlation suggests that the ratio of reactor power to containment volume (and, therefore, airborne mass concentration) does increase with increasing reactor power, and the sedimentation height does not increase to the extent that the greater mass concentration effect is offset.

The PWRs studied in NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants" are principal sources of accident progression data considered in the development of the Powers correlation. The reactor power-to-volume ratios for those plants are as follows (based on BMI-2104, "Radionuclide Release Under Specific LWR Accident Conditions" values contemporary with NUREG-1150):

- Surry:  $2441 \text{ MWt}/1.8\text{E}6 \text{ ft}^3 = 1.4\text{E}-3 \text{ MWt}/\text{ft}^3$ .
- Zion:  $3238 \text{ MWt}/2.7\text{E}6 \text{ ft}^3 = 1.2\text{E}-3 \text{ MWt}/\text{ft}^3$ .
- Sequoyah:  $3570 \text{ MWt}/1.3\text{E}6 \text{ ft}^3 = 2.7\text{E}-3 \text{ MWt}/\text{ft}^3$ .

The corresponding value for the U.S. EPR is  $4590 \text{ MWt}/2.8\text{E}6 \text{ ft}^3 = 1.6\text{E}-3 \text{ MWt}/\text{ft}^3$ . Surry is designed as a subatmospheric containment which explains why, with a lower power than Zion,

the reactor power per unit containment volume is actually higher. Also, Zion employs a relatively large containment given its power level. As an ice condenser (vapor suppression) containment, the Sequoyah reactor power per unit containment volume is almost twice that of Surry.

The U.S. EPR reactor power-to-volume ratio is greater than that of Surry by about 14 percent. The comparison of Zion to the U.S. EPR shows the expected trend (implied in the Powers correlation) that a 42 percent increase in reactor power brings about a 4 percent increase in containment volume. This is why higher power reactors are generally expected to exhibit more favorable sedimentation rates (with Surry being an exception because of the relatively small, subatmospheric containment design).

The statistical treatment of the relationship between reactor power and containment volume used to develop the Powers model is based on a larger number of plants than just the plants represented in NUREG-1150. However, the plants evaluated in NUREG-1150 cover a wide range of power level per unit containment volume.

Figure 15.00.03-25-1— Relationship of PWR Power to Containment Volume is a markup of Figure 18 in NUREG/CR-6189, “A Simplified Model of Aerosol Removal by Natural Processes in Reactor Containments,” the supporting document for the Powers natural removal correlations found in NUREG/CR-6604, “RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation.”

The original NUREG/CR-6189 Figure 18 shows the data considered in establishing the functional relationship between containment volume and the reactor power level. Figure 18 considers reactor power as high as 4000 MWt. The solid line is the correlation line for the 32 data points considered. It has the formula  $V(m^3) = 16700(\pm 5500) + 16.16(\pm 1.94) \bullet P(MWt)$ , where V is the volume and P is the power level, and has been extended beyond 4000 MWt to include the power level of the U.S. EPR.

The actual volume of the U.S. EPR containment ( $7.9E4 m^3$ ) is within the stated uncertainty ( $1.4E4 m^3$ ) when compared to the central estimate of the volume according to the formula ( $9.1E4 m^3$ ). It is near the favorable limit of the uncertainty; i.e., the smaller the containment volume, the higher the mass concentration and the greater the sedimentation rate. The volume of the U.S. EPR is near the most favorable (smallest) end of range of PWR containment volumes (per unit reactor power) considered statistically possible with respect to the development of the Powers correlations. Even the median sedimentation rate based on a statistical treatment of the reactor power/containment volume relationship described by the formula above is conservative for the U.S. EPR.

Figure 15.00.03-25-1 shows plots of the three NUREG-1150 reactor power per unit containment volume values and the value for the U.S. EPR. For small power levels there are significant deviations; however, at reactor power levels above 1000 MWt, three of the four plotted slopes describe the range of the data reasonably well with Zion providing the upper bound of containment volume for a given reactor power level, Surry providing the central estimate, and the U.S. EPR providing the lower bound. The statistical outlier is Sequoyah, which is understandable given its ice condenser containment design.

As a benchmark, the Zion power is used to generate Powers 10<sup>th</sup> percentile PWR removal coefficients. This power is only 71 percent of that of the U.S. EPR, but the maximum decrease in removal rate calculated using the Powers 10<sup>th</sup> percentile PWR correlation (that occurring from 3.8 to 13.8 hours) is only 11 percent. This shows that the airborne mass concentration effect embedded in the Powers correlation is not overly significant in terms of its impact on aerosol deposition rate.

In summary:

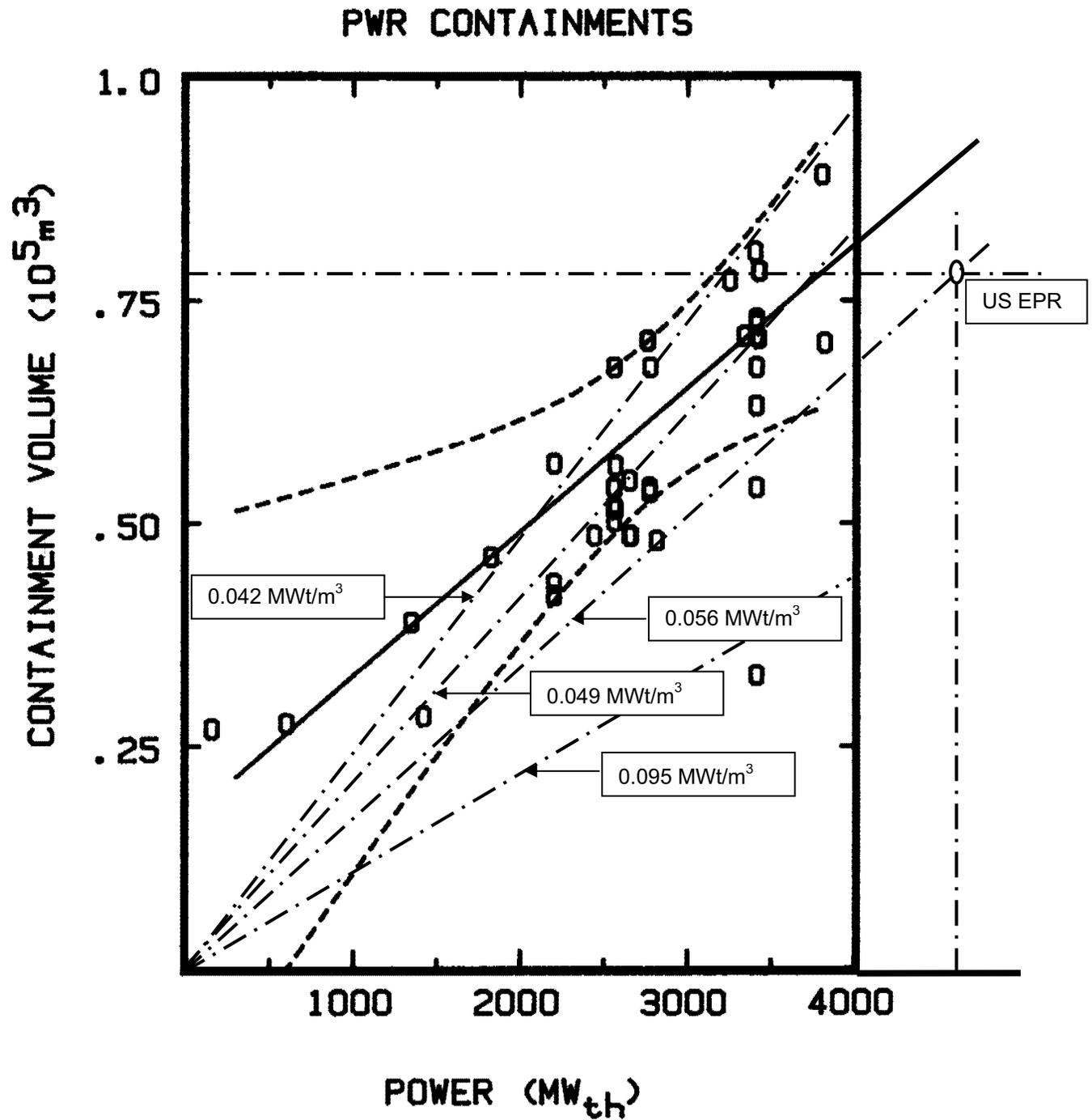
- For the important parameter of reactor power per unit containment volume, the U.S. EPR is comparable to the range of plants considered in the development of the Powers PWR correlation. The value for the U.S. EPR is near the most favorable bound of that range.
- The U.S. EPR is comparable in terms of containment size or type to typical U.S. PWRs. A directly comparable containment type of nearly the same size (Zion) is included in the NUREG/CR-6189 evaluation. The Zion power level is only 71 percent of the U.S. EPR's, but the increase in the 10<sup>th</sup> percentile aerosol deposition rate for the U.S. EPR (vs. Zion) is, at most, only 12 percent. A more typical value is 4 percent. The sensitivity of the aerosol deposition rate to the increased aerosol mass concentration corresponding to the more than 40 percent higher power level of the U.S. EPR is minimal.

Therefore, the Powers PWR natural aerosol deposition model (as incorporated into RADTRAD) is appropriate for application to the U.S. EPR. The U.S. EPR is within the range of reactor power-to-containment volume considered in the development of the Powers model, and the deposition rates are not particularly sensitive to changes in reactor power for a given size containment.

#### **FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

Figure 15.00.03-25-1—Relationship of PWR Power to Containment Volume



**Question 15.00.03-26:**

In regard to the LOCA and REA dose analyses, provide the methodology for combining the Powers model and the Henry model to give the effective aerosol removal coefficients in FSAR Tables 15.0-52 and 15.0-41. Include the justification for using these models in combination.

**Response to Question 15.00.03-26:**

The justification for using the models in combination is presented in the response to Question 15.00.03-24.

The Powers model effective aerosol removal coefficients (10<sup>th</sup> percentile pressurized water reactor (PWR) values) are calculated from the expressions given in Table 2.2.2.1-1 in NUREG/CR-6604, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation." The power level of the U.S. EPR used in the dose analysis is 4612 MWt. This value considers +0.48 percent uncertainty. If this uncertainty is removed, the removal coefficients will decrease at most by 0.17 percent with the core inventories decreasing 0.48 percent. Therefore, the use of the higher power level is conservative.

The only potential ambiguity in determining the lambdas (i.e., removal coefficients) from the expressions in Table 2.2.2.1-1 of NUREG/CR-6604 is the fact that two lambdas are provided for the 0.5 to 1.8 hour time period. One is for the gap release and the other is for the early in-vessel release. In order to resolve this ambiguity external to RADTRAD (i.e., for use in STARDOSE), the early in-vessel release value of  $\lambda = 0.032$  per hour is applied from time (t) = 0 to t = 1.8 hours. This is the lowest of the three potential values over that period.

In calculating the Henry values, it is necessary to first fix two input values (the aerosol density ratio and the sedimentation height ratio). The manner in which this is done (described in the response to Question 15.00.03-24) conservatively matches the removal coefficient for the Henry model to the last value of the Powers 10<sup>th</sup> percentile correlation at t = 22.2 hours.

The mass release corresponding to the activity release calculated by the RADTRAD code is 105 kg. In making the Henry model calculations external to RADTRAD, the assumed mass is 100 kg. Therefore, while RADTRAD predicts an airborne mass concentration of  $1.44\text{E-}4$  kg/m<sup>3</sup> at t = 22.2 hours, the "matching" Henry value is  $1.37\text{E-}4$  kg/m<sup>3</sup>. Because the Henry model mass concentration dependency for lambda is initially to the 0.6 power, this slight difference in the assumed aerosol mass at t = 22.2 hours amounts to only a three percent impact on the calculated aerosol removal coefficient.

Once the aerosol density ratio and the sedimentation height ratio are established, the Henry model extension is calculated in several time steps external to RADTRAD. For each time-step, a decontamination factor (DF) is assumed. This provides a final, end-of-time-step value of the airborne mass concentration beginning with the assumed value of  $1.37\text{E-}4$  kg/m<sup>3</sup>. For example, in the first time-step, the assumed DF is 2.25, leading to an end-of-time-step assumed value of  $6.1\text{E-}5$  kg/m<sup>3</sup>. This mass concentration is then used to calculate the Henry model removal coefficient for that time-step, and the duration of the time-step is determined from the assumed DF and the calculated removal coefficient. Therefore, the duration of each time-step to reach the assumed DF is conservatively maximized. The assumed DFs (in order) are 2.25, 2.2, 2.2, 2, 6, and 15.1. Combined with a DF of 9.2 for the Powers period (up to 22.2 hours), the overall

DF over 720 hours is approximately 18,000. At the end of the second time step with a DF of 2.2, the overall DF reaches 100; and it is here that the removal of elemental iodine stops.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Question 15.00.03-27:**

In regard to the LOCA dose analysis, FSAR Table 15.0-52 states that the elemental iodine removal coefficients are the same as for aerosols, except limited to a decontamination factor (DF) of 100. Please justify use of models and assumptions on iodine elemental iodine removal. Provide the methodology used for elemental iodine removal. Assure that this methodology been previously approved for reactor licensing. Identify the cases where elemental iodine removal is assumed. Provide the time after the onset of the LOCA that the DF equals 100.

**Response to Question 15.00.03-27:**

The elemental iodine will more readily adsorb onto the surface of the aerosol in lieu of the containment wetted surface, and thus is removed from the atmosphere along with the aerosol at the aerosol removal rate. Removal of the elemental iodine ceases in the model when a DF of 100 is reached, consistent with regulatory guidance.

Table 15.00.03-27-1—Deposition Models for the Removal of Elemental Iodine presents information pertinent to the two potential models for the removal of elemental iodines from the containment atmosphere: adsorption onto wetted containment surfaces, and adsorption onto post-loss of coolant accident (LOCA) airborne aerosols.

The adsorption of elemental iodine onto surfaces is well defined; for example, SRP 6.5.2 provides a deposition velocity for elemental iodine onto the wetted surfaces of the containment and its internal structures of 4.9 m/hour or 1.36E-3 m/sec. The wetted surface area of the U.S. EPR containment shell and containment internal structures is approximately 65,200 m<sup>2</sup> with approximately 9,200 m<sup>2</sup> associated with the containment shell alone. With a containment-free volume of approximately 79,800 m<sup>3</sup>, the lambda (i.e., removal coefficient) for wall removal of elemental iodine using the SRP 6.5.2 wall deposition model would be approximately four per hour for the full surface and 0.6 per hour for the containment shell only, one to two orders of magnitude greater than the aerosol sedimentation removal rates obtained from the Powers 10<sup>th</sup> percentile correlation for PWRs.

However, a characteristic length equal to the containment volume divided by the total wetted surface area is about 1.2 meters. The diffusion coefficient (D) of elemental iodine under containment conditions (two atmospheres and 100°C) is estimated to be ~0.07 cm<sup>2</sup>/sec. Using the definition of diffusion length,  $(4Dt)^{1/2}$  where t = time, the diffusion length will equal 1.2 m at ~14 hours. Since the diffusion length is a length scale for establishing uniform concentration gradients by diffusion only, bulk mixing must be augmenting diffusion if an iodine removal rate of four per hour (or even 0.6 per hour) is to be maintained.

For comparison, the spherical surface area of 100 kg of aerosol with a density of 2270 kg/m<sup>3</sup> (the reference density of aerosols for the Henry model application discussed in the response to Question 15.00.03-24) and an assumed representative diameter of one micron is 2.64E5 m<sup>2</sup> is about four times greater than the total wetted surface area of the containment including internal structures. The characteristic length equal to the containment volume divided by the aerosol surface area is only 0.3 meters. With a characteristic length ¼ that of the containment wetted surfaces (i.e., 0.3 m vs. 1.2 m), the diffusion length will be equal to the characteristic length in 0.9 hours, a significant calculation.

By using the Bixler model described in NUREG/CR-6604, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation," the deposition velocity of elemental iodine at 100°C is estimated to be approximately 7E-3 cm/sec, which is less than the 0.136 cm/sec value given in SRP 6.5.2. However, even at this lower deposition velocity, the deposition lambda for elemental iodine onto aerosol will exceed 0.8 per hour (deposition velocity of 7E-3 cm/sec divided by the characteristic length of 30 cm = 2.3E-4 per sec or 0.83 per hour), greater than the sedimentation rate of the aerosol (e.g., 0.032 per hour during the release phase). The diffusion length is equal to the characteristic length for deposition onto the dispersed aerosol in 0.9 hours; at that point, just over 50 percent of the elemental iodine adsorption onto the dispersed aerosol would have been calculated to occur (i.e.,  $e^{-(0.8 \text{ per hour} \cdot 0.9 \text{ hours})} = 0.49$ ). Therefore, simple diffusion of iodine through even a quiescent air/steam atmosphere will be able to support that rate of deposition. The expectation is that the elemental iodine will adsorb onto the surface of the aerosol during the release phase (and shortly after) and be removed from the atmosphere at the aerosol rate. However, the removal of the elemental iodine ceases in the model when a DF of 100 is reached, consistent with regulatory guidance. The time at which DF = 100 is 82 hours. Removal of elemental iodine at the same rate as the aerosol is used for all cases where natural removal in the containment by sedimentation is credited.

Therefore, it is conservative to assume the elemental iodine is removed at the aerosol removal rate. Given the greater surface area of the dispersed aerosol, this is the more likely outcome (as documented in the comments pertaining to Appendix A of Regulatory Guide 1.183, Section 3.3 in Attachment 2 of the September 30, 2004 license amendment request (ADAMS Accession No. ML042930374) for an alternative source term (AST) for the Columbia Generating Station). The March 16, 2005, response (ADAMS Accession No. ML050900256) to an NRC RAI regarding the Columbia AST application provided further explanation. In this licensing application, which was accepted by the NRC staff (ADAMS Accession No. ML062610440), the removal rate for elemental iodine was assumed to be the same as that for particulates. The licensing case for the Columbia Generating Station also identified experimental evidence confirming the expectation that elemental iodine will adsorb onto the surface of the dispersed aerosol.

Although the Columbia Generating Station application credited drywell sprays rather than natural removal by sedimentation, the key observations are that elemental iodine is more likely to be removed at the rate of the dispersed aerosol on which it is likely to adsorb than to be removed independently and that the assumption of removal as aerosol is conservative. In fact, the U.S. EPR application is more conservative in this regard than that of the Columbia Generating Station. For the Columbia Generating Station, no DF limitation was applied to the removal of elemental iodine when it is treated as particulate. The DF of 121 mentioned in the Columbia Safety Evaluation is applied only for the comparison case where the elemental iodine removal is treated as independent of the dispersed particulate (aerosol). For the U.S. EPR, not only is the elemental iodine assumed to be removed at the same rate as the aerosol, the elemental iodine removal is limited to a DF of 100.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Table 15.00.03-27-1—Deposition Models for the Removal of Elemental Iodine**

Description Phenomena	Deposition Velocity $K_w$ (m/hr)	Surface Area A ( $m^2$ )	Containment Volume V ( $m^3$ )	Characteristic Length L ( $L = V/A$ ) (m)	Diffusion Coefficient D ( $m^2/hr$ )	Time t at which Diffusion Length = $L^{(a)}$ (hr)	Removal Constant $\lambda_s^{(b)}$ ( $hr^{-1}$ )
<b>Deposition Model for Elemental Iodines</b>							
Adsorption onto containment wetted surfaces	4.9 (SRP 6.5.2, Sec. III.4.C.i)	6.52E+04	7.98E+04	1.22	0.025(c)	14.3	4.0
Adsorption onto airborne aerosol	0.25 m/hr (Bixler model in NUREG/CR-6604)	2.64E+05 (d)	7.98E+04	0.30	0.025	0.9	0.83
<b>Deposition Model for Aerosols - Maximum Removal Rate (from U.S. EPR FSAR, Tier 2 Table 15.0-41)</b>							
Natural deposition	N/A	N/A	N/A	N/A	N/A	N/A	0.128 <sup>(e)</sup>

Notes:

- a) Diffusion length,  $L = (4tD)^{0.5}$ ; time to diffuse to distance L:  $t = L^2 / (4D)$
- b)  $\lambda_s = K_w A / V$
- c) Based on a containment temperature of 100 °C and a pressure of 2.0 atmospheres
- d) The aerosol surface area is based on 100 kg of aerosol at a density of 2270 kg/m<sup>3</sup> (NUREG/CR-6604, Sec. 2.2.2.1.1, the reference density of aerosols for the Henry model application discussed in the response to Question 15.00.03-24) and an assumed representative diameter of 1 micron:  
  

$$\text{Area} = \{100 \text{ kg} / [2270 \text{ kg/m}^3 * (\pi/6) * (1.0E-06)^3 \text{ m}^3]\} * [\pi * (1.0E-06)^2 \text{ m}^2] = 2.64E+05 \text{ m}^2$$
- e) The removal constant of 0.128 per hr for the aerosols corresponds to the Powers 10<sup>th</sup> percentile correlation for PWRs in NUREG/CR-6604 (Table 2.2.2.2-1, worst-case interval, 3.8 to 13.8 hr). It is provided here solely for comparison.

**Question 15.00.03-30:**

In regard to the LOCA engineered safeguard features (ESF) component leakage dose analysis, provide the ESF component leakage source term and the basis for the assumed values.

**Response to Question 15.00.03-30:**

The analytical model for the loss of cooling accident (LOCA) event combines the release pathways (due to primary containment leakage and ESF component leakage) into a single scenario. The ESF component leakage source term is time-dependent and consists of whatever iodines end up in the post-LOCA liquids, in the inside containment refueling water storage tank (IRWST), as a result of natural deposition. No hold-up is considered other than in the containment atmosphere (with leakage). Therefore, iodine deposits from the containment atmosphere as fast as it is added to the IRWST inventory. Such a mechanistic treatment is permitted by Regulatory Guide 1.183 if it is established that the overall treatment is conservative. This conservatism has been established in the U.S. EPR FSAR, Tier 2, Chapter 15 LOCA analysis.

The iodine-131 (I-131) activity distribution resulting from the treatment as described is presented in Figure 15.00.03-30-1—Iodine-131 Activity Distribution for the IRWST, primary containment (PC), and as a total.

Table 15.00.03-30-1—Post-LOCA Iodine Activity presents the corresponding tabular distribution.

The fractional iodine release rates from the core directly to the IRWST that will mimic removal from the primary containment atmosphere (due to natural deposition) are shown in Figure 15.00.03-30-2—Fractional Core Release Rate for Iodine to IRWST and tabulated in Table 15.00.03-30-1.

The area under the curve in Figure 15.00.03-30-2 is 0.4, representing 40 percent of the total iodine release. As presented in Figure 15.00.03-30-2, most of the iodine enters the IRWST from 1.5 to ten hours. These rates assume that decay in the core is accounted for separately.

Once the iodine in the IRWST is calculated, the source term for release to the environment is calculated. The volumetric flow out of the IRWST is assumed to be 4 gpm (twice the expected upper bound of 0.5 gpm per train multiplied by four trains). Ten percent of the iodine in the 4 gpm is assumed to be released without hold-up to the environment as 97 percent elemental and three percent organic iodine after being filtered (99 percent filtration efficiency for both forms).

**FSAR impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Table 15.00.03-30-1—Post-LOCA Iodine Activity  
(2 Sheets)**

Post-LOCA Time (hr)	Post-LOCA I-131 Activity (Ci) (Based on 40% core release fraction and natural deposition, corrected for decay)			Undecayed I-131 Equivalent Core Release Rate Directly to the IRWST <sup>(a)</sup> (fraction/hr)
	Airborne in PC	Waterborne in IRWST	Total	
0	7.71E+03	6.86E-02	7.71E+03	0.00003
0.017	2.32E+05	6.19E+01	2.32E+05	0.00015
0.076	1.05E+06	1.28E+03	1.05E+06	0.00072
0.376	5.18E+06	3.12E+04	5.21E+06	0.00139
0.5	6.87E+06	5.51E+04	6.93E+06	0.00329
0.9	2.16E+07	2.37E+05	2.18E+07	0.00626
1.2	3.25E+07	4.97E+05	3.30E+07	0.00877
1.5	4.32E+07	8.59E+05	4.41E+07	0.01126
1.8	5.39E+07	1.32E+06	5.52E+07	0.03544
2.1	5.23E+07	2.79E+06	5.51E+07	0.03447
2.4	5.09E+07	4.21E+06	5.51E+07	0.03353
2.7	4.94E+07	5.59E+06	5.50E+07	0.03261
3	4.80E+07	6.92E+06	5.50E+07	0.03172
3.3	4.67E+07	8.22E+06	5.49E+07	0.031
3.5	4.58E+07	9.07E+06	5.49E+07	0.03029
3.8	4.45E+07	1.03E+07	5.48E+07	0.04077
4.1	4.28E+07	1.20E+07	5.47E+07	0.03925
4.4	4.11E+07	1.36E+07	5.47E+07	0.03777
4.7	3.95E+07	1.51E+07	5.46E+07	0.03631
5	3.80E+07	1.66E+07	5.46E+07	0.03497
5.3	3.65E+07	1.80E+07	5.45E+07	0.03362
5.6	3.51E+07	1.93E+07	5.44E+07	0.03237
5.9	3.38E+07	2.06E+07	5.44E+07	0.03114
6.2	3.25E+07	2.19E+07	5.43E+07	0.02998
6.5	3.12E+07	2.31E+07	5.43E+07	0.02881
6.8	3.00E+07	2.42E+07	5.42E+07	0.02774
7.1	2.88E+07	2.53E+07	5.41E+07	0.02671
7.4	2.77E+07	2.64E+07	5.41E+07	0.02566
7.7	2.66E+07	2.74E+07	5.40E+07	0.02472
8	2.56E+07	2.83E+07	5.40E+07	0.02376
8.3	2.46E+07	2.93E+07	5.39E+07	0.02287
8.6	2.37E+07	3.02E+07	5.38E+07	0.022
8.9	2.28E+07	3.10E+07	5.38E+07	0.02118
9.2	2.19E+07	3.18E+07	5.37E+07	0.02036
9.5	2.10E+07	3.26E+07	5.37E+07	0.0196
9.8	2.02E+07	3.34E+07	5.36E+07	0.01885
10.1	1.94E+07	3.41E+07	5.35E+07	0.01814
10.4	1.87E+07	3.48E+07	5.35E+07	0.0144
13.8	1.19E+07	4.08E+07	5.28E+07	0.00542

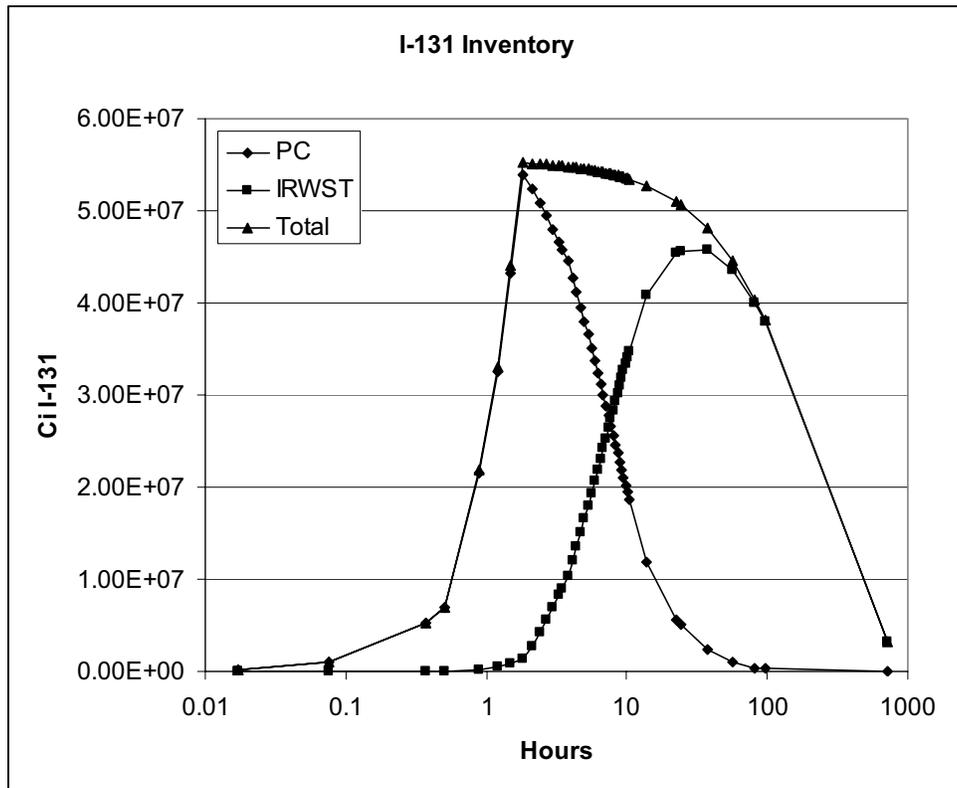
**Table 15.00.03-30-1—Post-LOCA Iodine Activity  
(2 Sheets)**

Post-LOCA Time (hr)	Post-LOCA I-131 Activity (Ci) (Based on 40% core release fraction and natural deposition, corrected for decay)			Undecayed I-131 Equivalent Core Release Rate Directly to the IRWST <sup>(a)</sup> (fraction/hr)
	Airborne in PC	Waterborne in IRWST	Total	
22.2	5.63E+06	4.55E+07	5.11E+07	0.00209
24	5.08E+06	4.57E+07	5.07E+07	0.00138
37.5	2.37E+06	4.57E+07	4.81E+07	0.00041
56.9	1.01E+06	4.36E+07	4.46E+07	0.00005
82	4.18E+05	4.00E+07	4.04E+07	-

## Notes:

- a) The fractional releases in the right-hand column are based on an I-131 core inventory of  $1.39\text{E}+08$  Ci. Because the release fractions are for undecayed activity, they are applicable to all the iodine isotopes.

**Figure 15.00.03-30-1—Iodine-131 Activity Distribution**



**Figure 15.00.03-30-2—Fractional Core Release Rate for Iodine to IRWST**

