Containment Purge Accountability
(or The Anatomy of a Containment Purge)

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Overview

This document analyzes the processes used at CCNPP to calculate and report activity discharged during a containment purge. The use of grab samples and radiation monitors provides assurance that accountability is accurate, complete, and well understood. This practice, and practices like this, help ensure an effective radioactive effluent control program at CCNPP. A case study is presented involving the containment purge accountability for the 2003 Unit #2 refueling outage (RFO).

Introduction

As of 2002, CCNPP had a special version of EMS that included site-specific methodology for containment purge ("buildup" calculations and other methodology). The procedure governing containment purges and available documentation for the EMS program was not very specific about the methods of accountability. The methodology was not well documented, and the procedure was quite general in nature. CCNPP has used continuous radiation monitoring systems to augment sample analysis results and to assist in radioactive effluent accountability. Although the methodology for using radiation monitors is documented in the ODCM, specific details regarding their use for effluent accountability are not well documented. The chemistry procedure governing containment purge mandated when a purge permit could be prepared, and as a result, only one containment purge preliminary permit was prepared for the entire RFO. After the 2003 RFO was over, it was necessary to finalize the containment purge permit.

In mid-2002, a new version of EMS was purchased (Version 6). This new version contained a revised containment purge methodology. The new version of EMS treats a containment purge similar to a "batch" release. It uses one sample analysis result and assumes a constant concentration is discharged for the entire discharge period. Because containment atmosphere concentration does not remain constant during a purge, there are drawbacks to this methodology and implementation is challenging. In 2003, an effort was undertaken to more clearly define the entire containment purge process. This document provides some detail on the "anatomy" of a containment purge and discusses how accountability may be performed.

Sampling

As specified in Chemistry procedures (e.g., CP-604 and CP-213), prior to starting a containment purge, one or more air samples are collected in containment and analyzed for gamma emitters. The activity present in this sample should represent the activity in the containment atmosphere. In accordance with approved outage "scripts," additional samples of containment atmosphere are collected at 8-hour intervals until containment activity decreases below the grab-sample detection limits. A graph showing the sample results for the 2003 U-2 RFO is shown below.

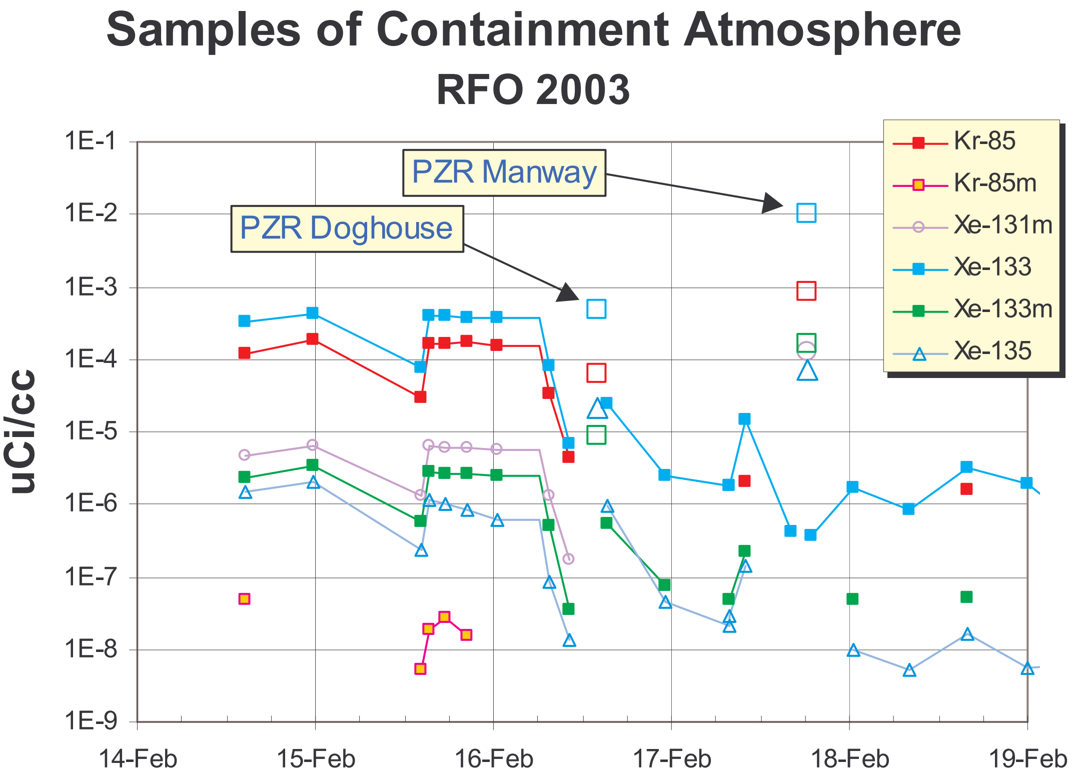


Figure 1: **Many samples are collected from the containment building during the RFO. The samples collected on 15-Feb indicate activity in containment prior to containment purge. Note one non-representative sample collected on 15-Feb is much lower than the other samples collected that day.**

The four samples collected immediately prior to containment purge (from 15-Feb at 15:30 to 16-Feb at 00:34) show good precision. All 4 results were within ±3% of the average. An earlier sample (15-Feb @ 13:00) appears to be non-representative of the bulk containment atmosphere. Because many samples were collected prior to the containment purge, the non-representative samples (if any) can be identified and rejected. Note that the Xe-135 samples from 15-Feb show the decay expected for a short-lived nuclide ($t_{1/2}$=9.1 hrs). Because the containment purge was not started until 16-Feb-03 at 06:04, the initial Xe-135 concentration can be decay corrected if desired.

Samples from near the pressurizer manway and from the pressurizer doghouse are much elevated in activity and show a different nuclide composition than samples from the bulk containment atmosphere. The ratio of Xe-133 to Kr-85 in the samples prior to starting containment purge (15-Feb) was 2.4. That ratio increased to 7.7 for the sample collected near the pressurizer doghouse and 11.8 for the sample collected near the pressurizer manway. Different radionuclide mixtures will create different responses on the radiation monitors.

From this graph, it is apparent that different nuclides appear at different times. At times, many of the nuclides were below the detection limits of the counting equipment. Even though some nuclides may—at times—be below the detection limits of the laboratory counting equipment, the nuclides may nonetheless be present in the containment atmosphere, and may be detected by the WRGM. Kr-85 is a prime example of this.

Preliminary Release Permit

A preliminary release permit must be prepared prior to starting containment purge. Accounting for containment purge activity is in accordance with approved plant procedures using the Effluent Management System (EMS). The FSAR and CP-604 identify containment volume as 5.66E4 cubic meters. Containment activity can be determined by multiplying containment volume by containment atmosphere grab sample analysis results. For the initial containment purge the following conditions are normally present:

1. There are no significant additions of activity during the containment purge.
2. The replacement air (i.e., the outside air drawn into containment) is free of contaminants.
3. Multiple samples are collected prior to initiating containment purge.
4. The gases inside containment are "well-mixed."

Because these conditions are normally present, the initial containment purge is normally very predictable. If the above conditions are true, the total activity released during the initial containment purge can be accurately calculated using the simplified volume-times-activity calculation. If the above conditions are not true, then additional uncertainty is introduced into the volume-times-activity calculation method.

Based on the 15-Feb 15:30 sample and a containment volume of 5.66E4 m^3, the containment was estimated to contain 32 curies of activity.

One disadvantage of the volume-times-activity method is that any source-term present would not be included in the final reporting. Another disadvantage of the volume-times-activity method of accountability is ensuring the grab sample is representative of the bulk containment atmosphere. This is especially problematic during a refueling outage when primary systems are opened or vented to containment while purge is running. Depending on the level of activity present, and the system maintenance performed, frequent sampling may be required to provide high confidence in the results. Continuous monitoring using radiation monitors has distinct advantages in this regard.

Radiation Monitoring

The wide range noble gas monitor (WRGM) continuously monitors the containment purge. For a typical containment purge there is rapid increase in WRGM response coincident with the start of containment purge fans. Once the purge fans are started, the WRGM response quickly increases to a maximum value, producing a peak or maximum response as shown in the figure below.

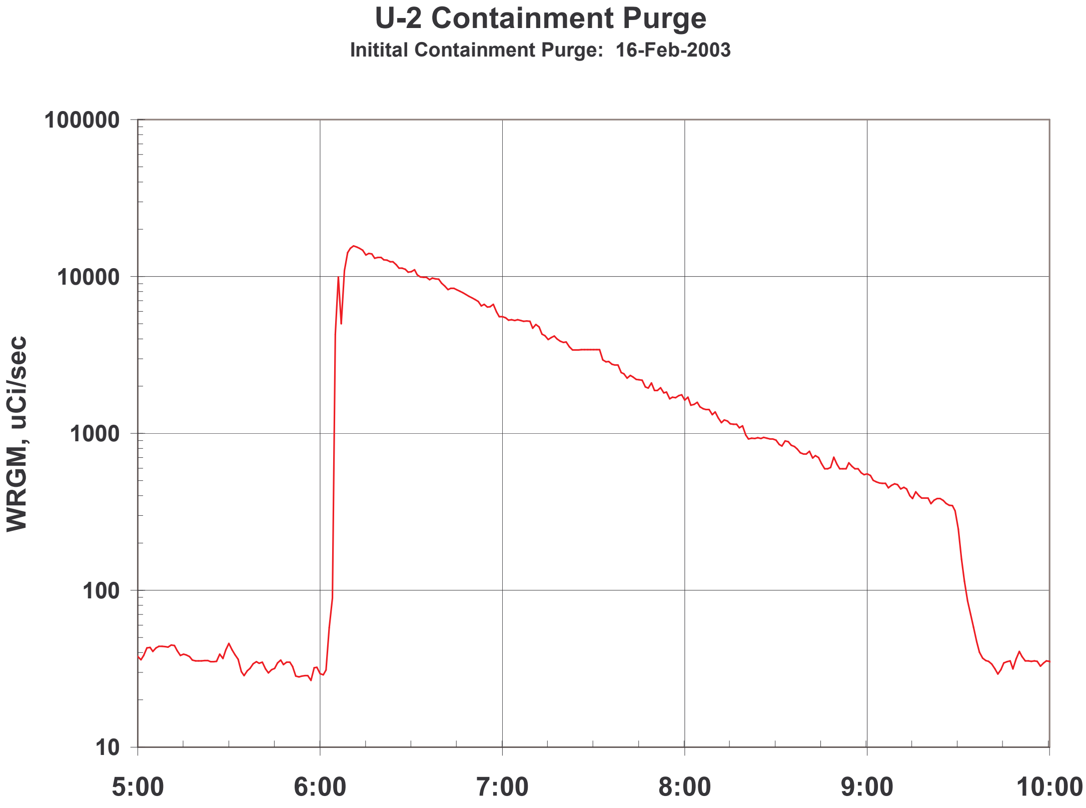


Figure 2: **The radiation monitor response increased rapidly when the purge fans were started at 06:04. Activity decreased when the purge fans were secured at 09:32. Note that some activity remained in containment.**

In order to understand this graph, it must be understood that the WRGM response is normalized to the nuclide Xe-133. This is often referred to as Xe-133 equivalent response, Xe-133 equivalent activity, or xenon equivalents. The units for the WRGM are uCi/sec as Xe-133 equivalents.

In order to convert Xe-133 equivalents to the activity of other radionuclides, a Xe-133 equivalent conversion factor is used. The Xe-133 equivalent conversion factor is normally determined using the primary calibration data or may be determined empirically by passing known radioactive material thru the detector. At CCNPP, these values were calculated in accordance with the RMS Reliability Assessment Program and the values are listed in Chemistry procedures (CP-604). The factors for the Unit-2 WRGM are shown in the table below.

Xe-133 equiv. Conversion Factors (uCi Xe-133/uCi nuclide i)

Kr-85	Xe-131m	Xe-133	Xe-133m	Xe-135
3.3	0.04	1	0.15	3.6

By using the Xe-133 equivalent conversion factors shown above, the maximum WRGM response may be estimated if the activity in containment in known. This is typically done while calculating the setpoint for the containment purge.

WRGM Setpoint:

The peak WRGM response can be estimated using the setpoint formula in the ODCM. The ODCM defines the method for establishing the adjustable setpoint for 2-RIC-5415 (U-2 WRGM). Essentially the ODCM equation determines the maximum theoretical Xe—133 equivalent concentration in the main vent stack based on the containment purge flow rate ($F_u = 20.2\ m^3/sec$), activity in containment atmosphere (A_{iu}), the Xe-equivalent conversion factors (e_i), and WRGM background (Bkg = 29 uCi/sec). This value is then multiplied by a safety factor (K_{sf}) of 1.5 to establish the setpoint. The complete calculation is shown below.

$$\mathbf{S_{adj} \leq (K_{sf})\,(c')\left\{[\,F_u\,\Sigma\,A_{iu}\,e_i] + Bkg\right\}} \qquad \textbf{Equation \#3}$$

S_{adj}= the adjustable setpoint for 1/2-RIC-5415 (uCi/sec)

K_{sf} = a constant, actually a safety factor, which allows for fluctuation in radiation monitor response (unitless)

F_u = maximum undiluted radwaste flow rate (m^3/sec)

A_{iu} = specific activity of radionuclide, i, in the undiluted waste stream (uCi/cc)

e_i = detector efficiency for nuclide, i (uCi Xe-133 equivalent per uCi nuclide i)

Bkg = an approximation of the detector background (uCi/sec)

c' = a conversion constant ($1E6\ cc/m^3$)

If the safety factor (K_{sf}) is excluded from the above calculation, the resulting value represents the expected peak WRGM response. Based on the 15-Feb-03 15:30 sample and the calculated flow purge fan flow rate of $20.2\ m^3/sec$, the maximum expected WRGM response is 18,904 uCi/sec as Xe133-equivalents. The actual, observed, peak WRGM response of 15,793 occurred at 06:11:16. The observed peak WRGM response was 3,111 uCi/sec less than predicted. This constitutes a 19.7% difference (relative to the observed response). The purge exhaust fans started at 06:04 and the peak WRGM response (15,793 uCi/sec) was observed about 7 minutes later, at 06:11:16. The smoothing algorithm in the WRGM, the dilution occurring between containment and the plant vent stack, and the transit time to the WRGM sample chamber all act together to cause a deficit in the rapid upscale deflection of the WRGM. This phenomenon is referred to in this document as the ballistic deficit.

Ballistic Deficit:

The ballistic deficit is the difference between the maximum observed WRGM response and the linear interpolated WRGM response at the start of the containment purge as shown in the graph below.

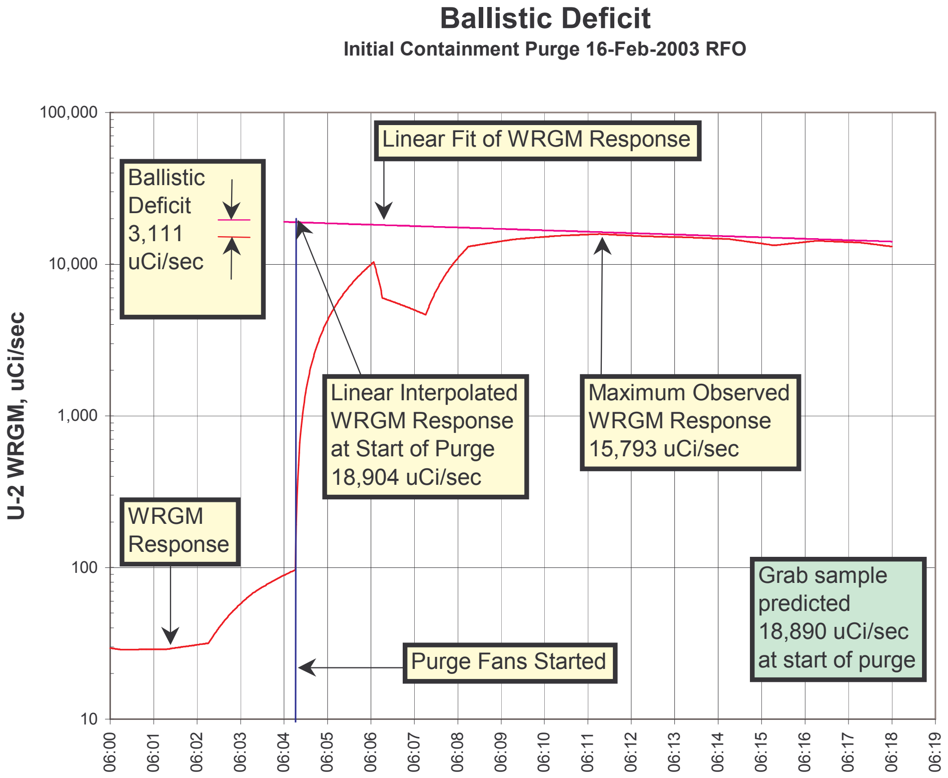


Figure 3: **Detail of first few minutes of the containment purge shows how the rapid increase in the WRGM response is stunted by the effects of dilution and transit of containment gases prior to reaching the radiation detector. As a result, there is a deficit in the maximum theoretical response of the radiation monitor.**

Based on the linear fit of the WRGM responses between 06:25 and 08:11, and extrapolating that line to the purge start time, a WRGM response of 18,904 uCi/sec would be expected. This is in excellent agreement with the predicted WRGM response (18,890 uCi/sec) based on the containment atmosphere sample and calculated in accordance with the ODCM methodology. (NOTE: If linear regression is performed on the data from 06:15 to 08:15, the expected WRGM response at 06:04 is 19,478 uCi/sec. This is only 2% different from the expected WRGM response and is still in excellent agreement with the predicted WRGM response.)

Purge Fan Flow Rate:

Inspection of figure #2 shows that ***following*** the maximum WRGM response, the trace decreases steadily and continuously in accordance with the formula for logarithmic decay.

$$\mathbf{A_t = A_0 e^{-\beta \Delta t}} \qquad \textbf{Equation \#1}$$

Where,

A_t = WRGM response at time, t (uCi/sec)
A_0 = Initial WRGM response (or WRGM response at time t=0) (uCi/sec)
Δt = elapsed time between t=0 and t (seconds)
β = F_p/V_c

And,

β = purification rate constant, (sec^{-1})
F_p = containment purge fan flow rate (m^3/sec)
V_c = containment volume, 5.66E4 m^3

Equation #1 assumes:

(1) the radiation monitoring system has good linearity,
(2) the distribution of radionuclides remains (relatively) constant during the discharge,
(3) no (significant) activity is added to containment after the purge is started,
(4) the containment purge fan flow rate is a known constant, and
(5) the containment volume is a known constant.

Simply selecting two WRGM responses (i.e., 1258 uCi/sec at 08:11 and 12,397 uCi/sec at 06:24), and substituting those values into equation #1 yields a purge fan flow rate of 20.17 m^3/sec. Selection of a different set of two WRGM responses will yield a slightly different flow rate. In order to objectively calculate the best estimate of the purge fan flow rate, it is necessary to select the WRGM responses from the most linear part of the WRGM trace. Obviously, the first few minutes of the purge should be expected to contain some non-linearity until equilibrium in established with plant vent stack flow rate and activity. Toward the end of the purge, any in-leakage into containment should be expected to introduce a non-linearity. As a result, the data between 06:15 and 08:15 is expected to be most linear, and was evaluated by linear regression. The results of that regression analysis calculated a purge fan flow rate of 19.90 m^3/sec. Because a fan flow rate of 20.2 m^3/sec was used to generate all purge permits, 20.2 m^3/sec will be used for the remainder of this document.

The following graph superimposes a line over the WRGM trace shown in Figure #2.

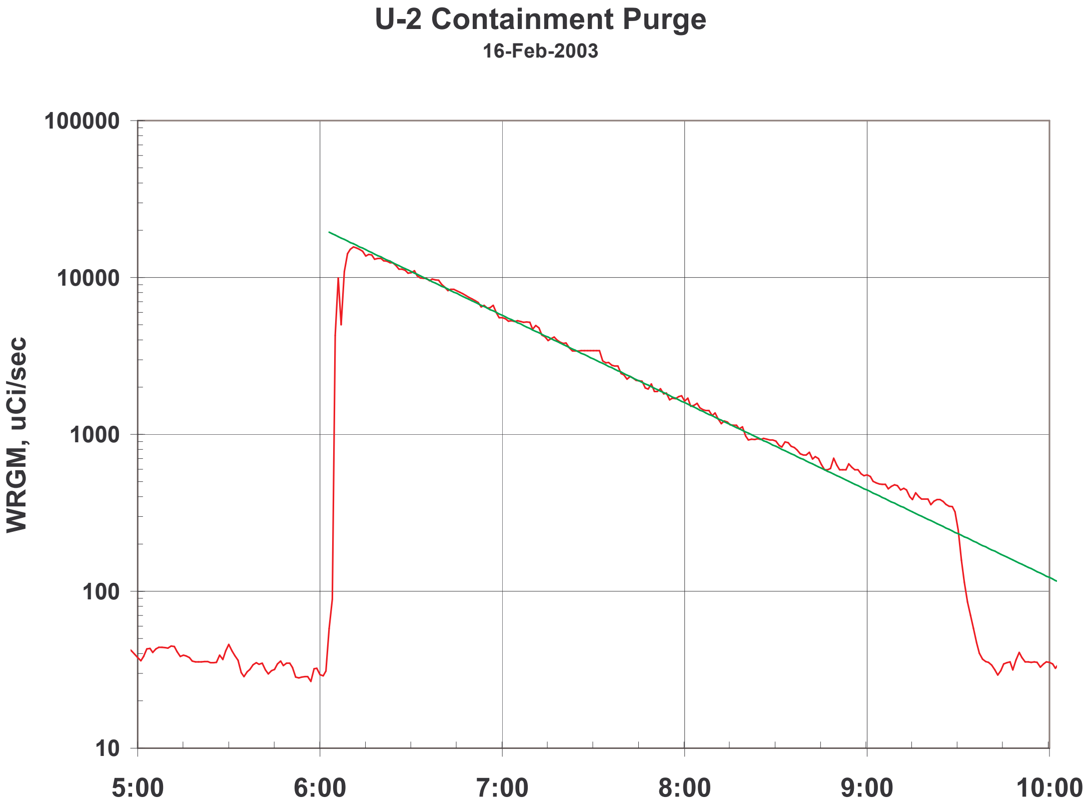


Figure 4: **Radiation monitor response for the initial containment purge is shown in red. A line was drawn between the WRGM responses at 06:24 and 08:11. The slope of the line is proportional to the purge fan flow rate. Deviation from linearity may be indicative of a source-term inside containment.**

The area under the curve represents the total activity discharged from containment.

Containment Purge Activity Based on WRGM Integration:

The area under the WRGM trace in Figure #2 represents the activity discharged from containment. Integration of the area under the WRGM trace (shown in Figure #2) yields 49 Ci as Xe-133 equivalent activity released during the first containment purge. This is obtained by simply summing the WRGM responses for all of the time intervals (minutes or seconds) for the duration of the purge.

If one assumes that the containment atmosphere sample collected before the start of the containment purge (i.e., from 15:30 on 15-Feb) is representative of the nuclides discharged from containment, then 49.13 curies of Xe-133 equivalent activity corresponds to 29.8 curies for the mixture of nuclides present in containment atmosphere.

Containment Purge Activity Based on Containment Volume and Grab Sample:

For the 2003 Unit-2 RFO, several samples were collected prior to the initial containment purge. Using the 15-Feb-03 15:30 sample results, the containment activity was calculated as 32 curies as shown below.

$$\mathbf{A_T = \Sigma A_i * V_c * K} \qquad \textbf{Equation \#2}$$

$$= 5.66E\text{-}4 \text{ uCi/cc} * 5.66E4 \text{ m}^3 * (1E6 \text{ cc/ m}^3) * (\text{Ci}/1E6 \text{ uCi})$$

$$= 32 \text{ Ci}$$

Where,

A_T = Total activity in containment (Ci)
ΣA_i = Sum of the activities of all gas nuclides, i, in the containment atmosphere sample (uCi/cc)
V_c = Volume of containment = 5.66E4 m^3
K = conversion constants = 1E6 cc/m^3 * Ci/1E6 uCi

200% Accountability ("Reckoning"):

The information presented above suggests there are two independent methods to calculate activity discharged in containment purge: (1) by integrating WRGM responses, and (2) by volume-times-activity calculations. If the results of the two methods agree within the expected uncertainty, there is a high degree of confidence in the effluent accountability program. If both methods agree, containment purge accountability should be accurate and complete. Conversely, if the two methods do not agree, there may be issues with respect to one or both of the methods of calculating containment purge activity. In those cases where the two methods do not agree, the cause for the disagreement can often be identified. This method of reckoning can identify potential problems and strengthen the effluent control program.

The integrated WRGM activity of 29.8 curies agrees well with the volume-times-activity calculation of 32.0 curies (for the 15-Feb-03 15:30 sample) and 30.2 curies (for the 16-Feb-03 00:34 sample). The WRGM derived activity of 29.8 Ci is slightly less than the volume-times-activity value because containment purge was secured before all activity was discharged from containment. (Note: If the initial purge would have continued until "all" activity was discharged—the integrated WRGM activity would be 30.0 Ci for the nuclides present in the containment atmosphere.)

EMS Accountability:

The EMS software program is used for accountability at CCNPP. EMS allows several options for calculating and reporting the activity discharged during this initial containment purge. EMS software does not include a logarithmic-decay algorithm; instead EMS treats a containment purge in a manner similar to a "batch" release. For the first containment purge permit, the actual activity discharged was 29.8 Ci (for the mixture radionuclides actually discharged). In order to account for this release using EMS, one of the following methods could be used:

1. Enter the nuclide concentrations from the sample collected prior to the purge, use the purge exhaust fan flow rate, and adjust the duration so that the 29.8 curies are discharged. In this case, the duration will not be correct. EMS would record a "high" activity for a short period of time.
2. Enter the purge exhaust fan flow rate, use the actual duration of the purge, and adjust the nuclide concentrations so that the 29.8 curies are discharged. EMS would record an "average" activity for the correct duration of the containment purge.
3. Enter the nuclide concentrations from the sample collected prior to the purge, use the containment volume, and adjust the duration so that the 29.8 curies are discharged. In this case, the duration will not be correct. Additionally, if a source term is present while the purge is in progress, the source-term build-in will not be reported. EMS would record a "high" activity for a short period of time.
4. Other permutations of the above could also be used.

In order to finalize the initial containment purge, method #2 was chosen. In this case the specific activity of each nuclide was averaged over the entire duration of the discharge. This causes the total curies and the duration of the purge to be reported correctly, but the instantaneous release rate is calculated incorrectly.

Now that accountability is complete for the first containment purge, it is time to look at the second containment purge. Before we do that, however, it is instructive to look at one other "purge parameter" that may be calculated given the information presented thus far.

Purge Half Life:

Using equation #1, (setting $A_t = 0.5$ and $A_0 = 1.0$ and solving for Δt) the half-life for containment purge can be calculated. The half-life is 32 minutes. Because the half-life is short, any method of accountability based solely on a sampling program would have to include frequent sampling to ensure complete and accurate accountability of the activity discharged during containment purge. Use of a single sample would prove quite adequate provided no significant noble gas source-term is introduced during a containment purge. As primary systems are opened for RFO maintenance, however, gases leave the primary system and enter containment atmosphere. A sensitive, continuously indicating radiation monitor can detect the swings in activity that may be experienced during a RFO without the need for a large number of samples. The WRGM response for the RFO is discussed in the following section.

Now, let's look at the remaining containment purges.

WRGM response for entire RFO:

Thus far, the discussion has been limited to the first containment purge. Because the 2003 RFO was a steam generator replacement outage, and because CCNPP has a sizeable inventory of noble gases available for release during a RFO, many containment purge permits were required to account for the activity released. The following graph shows the WRGM response for the entire RFO.

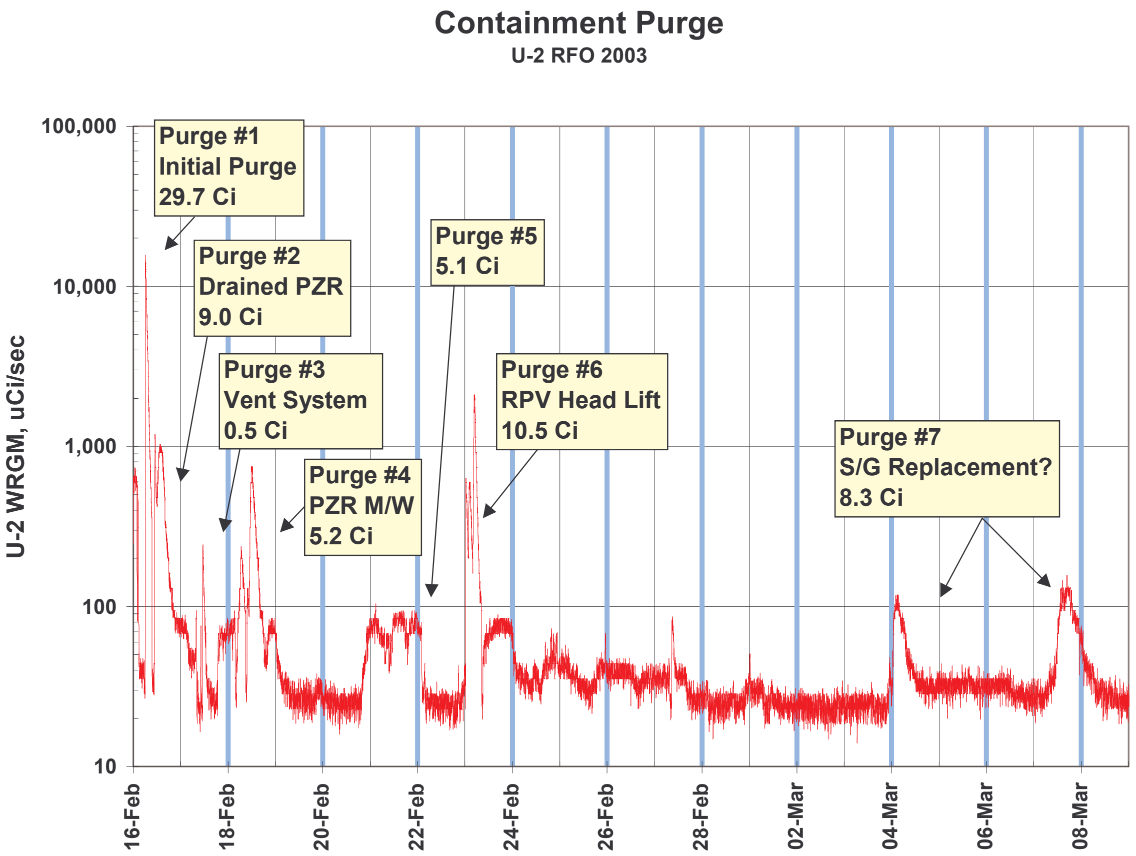


Figure 5: The vent stack radiation monitor continuously records activity discharged during the entire refueling outage. Spikes in activity are related to opening primary systems for maintenance.

In order to accurately account for the activity discharged during the RFO, several containment purge permits were prepared. In all, approximately 64 Ci were discharged from containment this RFO. The activity discharged during the time *between* containment purges was accounted for in the routine, weekly main-vent release permits. For all purge permits after the initial containment purge, a significant source-term was present during the purge. Evidence of this can be seen on purge permit #2.

Purge Permit #2

For all purge permits after the initial containment purge, a significant source-term was present during the purge. For an example, see the graph of purge #2 below.

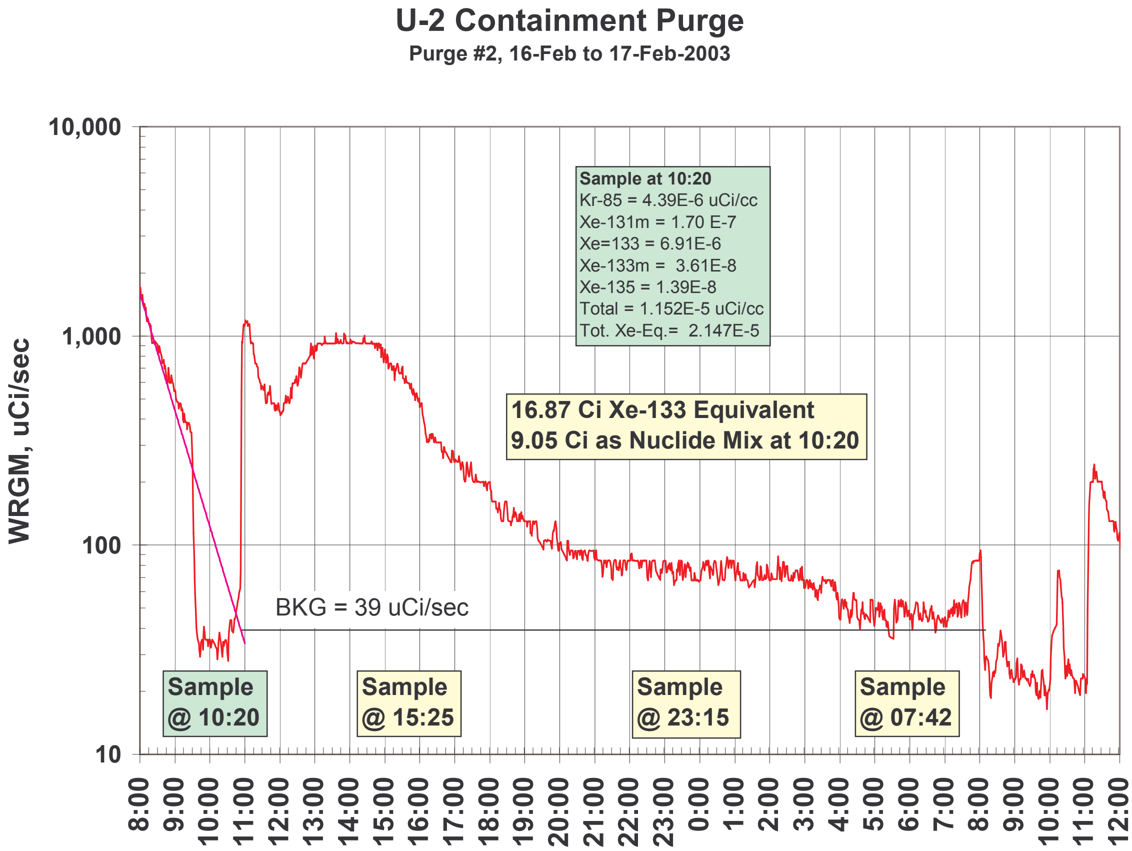
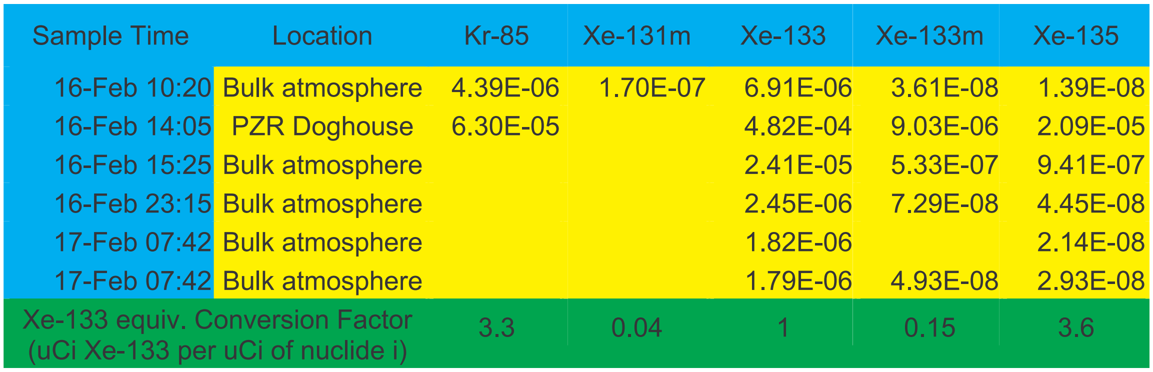


Figure 6: **The second containment purge permit started at 10:53 and shows logarithmic decay from 11:00 to 12:00 (16-Feb). The increase in activity observed from 12:00 to 14:00 is indicative of a source term.**

At the extreme left (of the figure above) is the final portion of the initial containment purge. The second containment purge started at 10:53 (16-Feb), and the WRGM showed a rapid upscale deflection to about 1,190 uCi/sec. From 11:00 to 12:00 the WRGM decreased from 1,190 uCi/sec to 418 uCi/sec. Thereafter, the WRGM increased to 1,030 uCi/sec. The increase in activity from 12:00 to 14:00 is indicative of a source-term. Because activity varies over time, it is very difficult to get a single sample that represents the activity discharged. Unless samples are collected very frequently, the peak activity may not be captured by a grab sample. Additionally, if a source-term is present, the composition of the noble gases may change over time. The containment atmosphere gas samples collected immediately before and during containment purge #2 are shown in the table below.



Sample Time	Location	Kr-85	Xe-131m	Xe-133	Xe-133m	Xe-135
16-Feb 10:20	Bulk atmosphere	4.39E-06	1.70E-07	6.91E-06	3.61E-08	1.39E-08
16-Feb 14:05	PZR Doghouse	6.30E-05		4.82E-04	9.03E-06	2.09E-05
16-Feb 15:25	Bulk atmosphere			2.41E-05	5.33E-07	9.41E-07
16-Feb 23:15	Bulk atmosphere			2.45E-06	7.29E-08	4.45E-08
17-Feb 07:42	Bulk atmosphere			1.82E-06		2.14E-08
17-Feb 07:42	Bulk atmosphere			1.79E-06	4.93E-08	2.93E-08
Xe-133 equiv. Conversion Factor (uCi Xe-133 per uCi of nuclide i)		3.3	0.04	1	0.15	3.6

Figure 7: Samples collected immediately before and during the second containment purge. All nuclide activities are shown as uCi/cc.

Normally, containment atmosphere samples collected for the purpose of representing the bulk containment atmosphere are collected at the 69' elevation in containment. As can be seen from the table above, the gases coming from the area of the pressurizer were significantly higher in activity and had a different composition than some of the other samples collected. Which sample(s) should be used to represent the activity in containment for purposes of accountability? The use of a continuous radiation monitor simplifies the task significantly. In Figure 6, The area under the curve (from 16-Feb at 10:34 to 17-Feb 08:00) was integrated to obtain a Xe-133 equivalent activity of 16.87 Ci. The Xe-133 equivalent activity can be obtained from the WRGM without knowledge of the sample activity.

In order to convert the WRGM response—in units of Xe-133 equivalents—to actual activity of the nuclide mixture present in containment, the sample analysis results must be used. The sum of all the noble gas nuclides in the 10:20 sample was 1.152E-5 uCi/cc. This is the true activity of the nuclide mixture. One may obtain the Xe-133 equivalent activity by multiplying the activity of each nuclide by its respective conversion factor listed at the bottom of Figure 7. This conversion factor is specific to the Unit-2 WRGM at CCNPP. The Xe-133 equivalent activity of the 10:20 sample is 2.147E-5 uCi/cc. So, for the radionuclide mixture corresponding the 10:20 sample, 1.152E-5 uCi/cc of the radionuclide mixture is equivalent to 2.147E-5 uCi/cc of Xe-133. Applying this fraction to the integrated WRGM response, the total curies of the nuclide mixture is obtained as shown below.

(16.87 Ci Xe-133 Equiv.)*(1.152 Ci nuclide mixture/2.147 Ci Xe-133 Equiv.) = 9.05 Ci as nuclide mix

The specific activity of each nuclide may be calculated in proportion to the nuclide composition of the gas mixture present in the 10:20 sample. It can be seen that the total curies calculated for purge #2 is dependent on (1) the WRGM response, and (2) the ***distribution*** of radionuclides in the 10:20 sample. The distribution of radionuclides is critical if using the WRGM to quantify effluents. Because the distribution is independent of total activity of the sample, this method should provide good accuracy even if the sample is not collected at the peak activity in containment. The remainder of the containment purge permits are calculated in a similar manner.

Conclusion:

Accountability of the activity discharged during containment purge is relatively simple. There are, however, many different assumptions that—if they are not true—tend to complicate the method of accountability. Some of the assumptions that are challenged include:

1. Do grab samples accurately represent containment atmosphere activity at peak concentration?
2. Is the default purge fan flow rate accurate?
3. Are the RMSs responses checked to ensure the default efficiencies are correct?
4. When primary systems are opened in containment, how is accountability performed?
5. Do effluent calculations adequately account for the activity discharged?

By using a number of the techniques described in this paper:

1. accountability for containment purge will be accurate and complete,
2. the accuracy of RMS responses may be verified, and
3. the RETS-REMP Program Manager can have confidence in the effluent control program.