Fort St. Vrain Nuclear Station
Decommissioning Project

PRESTRESSED CONCRETE REACTOR VESSEL (PCRV)

FINAL SURVEY EXPOSURE RATE MEASUREMENTS

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PRESTRESSED CONCRETE REACTOR VESSEL FINAL SURVEY EXPOSURE RATE MEASUREMENTS

1.0 INTRODUCTION

Public Service Company of Colorado (PSCo) submittal P-96039, dated May 17, 1996, describes instrumentation and the method for performing final survey exposure rate measurements at Fort St. Vrain (FSV) in all areas which are not influenced by activated concrete. The instrument used to perform these measurements is the MICROSPEC-2™, a portable gamma spectroscopy system utilizing a 2" x 2" NaI(Tl) detector. Since this instrument converts spectral data directly to effective dose equivalent rate, the response is not affected by detector energy dependence. The method discussed in P-96039 is detailed in FSV-FRS-TBD-202, *Final Survey Exposure Rate Measurements Using the MICROSPEC-2™*. This method determines the exposure rate due to licensed material using a spectral region of interest (ROI) for Co-60. Since this is a direct determination of exposure rate due to licensed material, the high and extremely variable background at FSV is not a concern. However, as indicated in the TBD, as well as the submittal, this method is not suited for measurement locations which are heavily influenced by activated concrete, with concentrations of europium (Eu) which interfere with the Co-60 ROI. Investigations have shown that these locations are limited to the internal surfaces of the prestressed concrete reactor vessel (PCRV). The purpose of this document is to describe the protocol for determining the exposure rate due to licensed material within the PCRV.

2.0 NATURAL RADIONUCLIDES PRESENT IN CONCRETE

Background exposure rate at FSV is predominantly due to the presence of naturally occurring radionuclides in soil/dirt and construction materials, such as brick, concrete, tile, etc. This is further enhanced by geometry or structural configuration. For instance, the more construction materials (concrete, block, brick, etc.) present at a measurement location, the higher the background exposure rate.

To determine the principal radionuclides in concrete contributing to exposure rate, several samples were obtained from various non-PCRV concrete structures at FSV and analyzed. The results of the analyses, presented in Table 1, indicate that the natural activity in concrete consists of K-40 and radionuclides in the thorium and uranium decay series. In fact, K-40 accounts for 83% of the natural activity (23.3 pCi/g average). Although this is an average, the percentage is consistent for all samples. The average K-40 activity in FSV concrete is slightly less than the average (89%) presented in draft NUREG-1501, *Background As A Residual Radioactivity Criterion For Decommissioning*, Table 2.7. The range of K-40 activity presented in Table 2.7 has a low of 9.2 pCi/g and a high of 27.7 pCi/g.

Table 1
Natural Radionuclide Activity In FSV Concrete
(pCi/g)

Sample Number	K-40	Thorium Series Tl-208	Thorium Series Pb-212	Thorium Series Bi-212	Thorium Series Ac-228	Uranium Series Bi-214	Uranium Series Pb-214	Uranium Series Ra-226
1	23.0	0.3	0.8	0.5	0.7	0.7	0.7	2.1
2	25.2	0.2	0.7	0.0[1]	0.7	0.7	0.7	0.0[1]
3	24.8	0.3	0.8	0.5	0.8	0.7	0.7	1.9
4	22.1	0.2	0.6	0.0[1]	0.6	0.6	0.6	1.6
5	20.6	0.3	0.8	0.4	0.7	0.8	0.8	2.1
6	22.3	0.3	0.8	0.6	0.8	0.7	0.7	1.6
7	22.9	0.3	0.7	0.5	0.8	0.7	0.8	2.0
8	23.7	0.2	0.7	0.0[1]	0.7	0.7	0.7	1.6
9	24.8	0.3	0.7	0.4	0.6	0.6	0.8	2.0
10	23.2	0.2	0.6	0.1	0.7	0.7	0.7	0.0[1]
Average	23.3	0.3	0.7	0.3	0.7	0.7	0.7	1.5

1 Radionuclide not identified in analysis

The average total activity from radionuclides in the thorium series is 1.96 pCi/g; and 2.90 pCi/g from radionuclides in the uranium series. This equates to 7% and 10% of the total activity respectively, and compares reasonably well with the averages in draft NUREG-1501, Table 2.7 (4% and 7%).

Additionally, several concrete core samples obtained from the external surface of the PCRV during the initial site characterization were analyzed. The analyses provided similar results and are presented in Table 2.

Table 2
Natural Radionuclide Activity In PCRV Concrete
(pCi/g)

		Thorium Series				Uranium Series		
Sample Number	**K-40**	**Tl-208**	**Pb-212**	**Bi-212**	**Ac-228**	**Bi-214**	**Pb-214**	**Ra-226**
1	20.7	0.2	0.6	0.0[1]	0.4	0.6	0.7	1.5
2	21.6	0.2	0.6	0.3	0.6	0.7	0.7	2.0
3	20.6	0.2	0.6	0.3	0.5	0.6	0.6	1.7
4	21.9	0.2	0.6	0.2	0.5	0.6	0.7	0.0[1]
Average	21.2	0.2	0.6	0.2	0.5	0.6	0.7	1.3

1 Radionuclide not identified in analysis

The average density of FSV concrete, including PCRV concrete, is 2.34 grams per cubic centimeter, determined from the samples collected and analyzed.

During FSV construction, a Gulf General Atomic batch plant was located on site to provide all concrete, including the PCRV. All concrete aggregate was obtained locally. It is understood that sand used in the concrete mix is the primary source of the naturally occurring radionuclides present. Although the geographical extent of the high natural radionuclide component from the sand source is not known, the location of a batch plant on site and the use of local aggregate for all concrete is probably the reason that the resulting natural radionuclide activity in FSV concrete is fairly uniform.

To further demonstrate the consistency among concrete, the K-40 average activity for all samples accounted for 83% of the total activity, with a range of 80% to 89%. Using MicroShield, the K-40 average effective dose equivalent rate without buildup accounted for 27% of the total activity average effective dose equivalent rate with buildup, with a range of 25% to 29%. This is equivalent to the MICROSPEC-2™ K-40 peak-to-total ratio (pttr), determined by comparing the partial effective dose equivalent rate for a K-40 ROI to the total spectrum effective dose equivalent rate. Measurements at each sample location using the MICROSPEC-2™ resulted in an average K-40 pttr of .23 or 23%, with a range of 22.5% to 23.5%.

3.0 BACKGROUND EXPOSURE RATE INFLUENCE DUE TO GEOMETRY

The influence of geometry on the background exposure rate has been previously discussed in PSCo submittal P-96039. To determine the magnitude of this effect, the sample radionuclide concentrations were used to calculate the exposure rate using MicroShield Version 4.10 from a slab source. These calculations also demonstrate that the background exposure rate can be predicted with reasonable accuracy, based on naturally occurring radionuclide concentrations in FSV concrete.

The source thickness used in these calculations was 1 meter and the surface area was 100 m^2. Also, at each sample location, the effective dose equivalent rate (EDER), which is equivalent to the MicroShield EDER with buildup in concrete, was determined using the MICROSPEC-2™. Since the MICROSPEC-2™ EDER is due to sources from all directions, and the natural radionuclide concentrations are consistent for all concrete, a comparison of the results provides an indication of the effects due to geometry. This comparison is provided in Table 3. It is noted that some error exists in sample analysis and reporting of radionuclide concentrations.

Table 3
Comparison of MICROSPEC-2™ and MicroShield Exposure Rates

Sample Number	MICROSPEC-2™ EDER (μrem/hr)	MicroShield V4.10 EDER (μrem/hr)	Geometry Factor[1]
1	14.9	5.5	2.7
2	8.6	5.7	1.5
3	10.8	5.9	1.8
4	8.1	5.0	1.6
5	8.6	5.3	1.6
6	11.1	5.6	2.0
7	9.4	5.7	1.6
8	9.0	5.9	1.5
9	8.7	5.6	1.6
10	8.0	5.5	1.5

1 Geometry factor determined by dividing the MICROSPEC-2™ result by the MicroShield calculated result. This factor estimates the magnitude of the contribution to the EDER at a single location from sources in all directions which is measured with the MICROSPEC-2™.

Sample number 1 was obtained from the empty diesel generator room. This location is a room approximately 42 feet long by 16 feet wide with a ceiling 14 feet high. All surfaces, including walls, floor and ceiling are concrete. The empty diesel generator room is an example where the influence of geometry is extreme. Sample number 6 was obtained from a room of similar size. However, this room contains a concrete block wall behind metal components causing the lower geometry factor. The lower geometry factor (compared to sample area number 1) is primarily due to the lack of a solid concrete wall, with additional attenuation from the metal components. Sample number 3 was obtained from a location adjacent to a single concrete wall in an otherwise open location. At this location the exposure rate was measured at a distance of one meter from both the floor and wall surfaces. The geometry factor is slightly higher than the remaining seven locations due to the presence of the single concrete wall. The remaining seven sample locations were relatively open areas within a concrete building, with the predominant source of the exposure rate from the floor. These locations displayed an average geometry factor of 1.6 (rounded), with a range of 1.5 to 1.6.

To further validate the geometry influence (geometry factor) as well as evaluate the accuracy of modeling the source, the EDER from sources originating in all directions within the sample location exhibiting the extreme geometry influence (location number 1) was calculated using MicroShield and the sample activity results. This required determining the exposure rate contribution from six sources (floor, four walls and ceiling) at the same location where the MICROSPEC-2™ result was obtained. The source thickness for each slab was 1 meter and the surface area was determined using room dimensions. The calculated MicroShield result was 14.2 μrem/hr (without the cosmic component added), compared to the actual MICROSPEC-2™ measurement result of 14.9 μrem/hr. The MicroShield results for each source within the diesel generator room are provided in Table 4.

Table 4
Diesel Generator Room
Background Exposure Rate Calculations
(μrem/hr)

Source	Effective Dose Equivalent Rate
North Wall	0.5
South Wall	0.5
East Wall	1.6
West Wall	4.3
Ceiling	2.3
Floor	5.0
Total	**14.2**

This evaluation substantiates that the geometry factor determined in Table 3 is a true indication of the geometry influence on background exposure rate, and that the background exposure rate due to naturally occurring radionuclides can be estimated by modeling with reasonable accuracy.

4.0 EXPOSURE RATE DETERMINATION WITHIN THE PCRV

Exposure rate measurements within the PCRV will be performed using the MICROSPEC-2™. As indicated previously, use of this instrument eliminates the energy dependence of typical NaI dose rate instruments. However, the protocol described in TBD-202 can not be used when the radionuclides associated with activated concrete, particularly Eu-152, contribute to the exposure rate. Therefore, an alternate application must be identified using the MICROSPEC-2™.

PCRV exposure rates will be determined using a combination of the conventional method described in draft NUREG/CR-5849, *Manual for Conducting Radiological Surveys in Support of License Termination*, and the method contained in TBD-202. The conventional portion requires the determination of gross exposure rates within the PCRV which are then converted to net exposure rate by the subtraction of background. Although concrete activation may have occurred along the entire vertical height of the PCRV, it is presently not known how all measurement locations will be affected by associated radionuclides and will not be completely understood until actual measurement results can be obtained. However, if activated concrete radionuclides do not affect the exposure rate at some locations, the method currently described in P-96039 and TBD-202 may be applied without modification.

5.0 PCRV BACKGROUND EXPOSURE RATE

The response of the MICROSPEC-2™ to the background exposure rate in the vicinity of the PCRV is the result of two principal components. The first, and least significant component is the MICROSPEC-2™ exposure rate due to cosmic radiation. The second is the exposure rate due to naturally occurring radionuclides in the PCRV concrete. Due to the shielding afforded by the PCRV, the contributions to the exposure rate from other reactor building structural elements outside of the PCRV are minimal and are neglected.

5.1 Exposure Rate Due To Cosmic Radiation

Draft NUREG-1501, Section 2.3.3.2, discusses the annual exposure due to cosmic radiation in the FSV area and estimates this to be 0.2 mSv (2.3 μrem/hr) higher than the average for the United States. The U.S. mean annual effective dose equivalent due to cosmic radiation, 0.27 mSv (3.1 μrem/hr), is presented in Draft NUREG-1501, Table 2.9. This equates to an average effective dose equivalent rate of 5.4 μrem/hr for the FSV area, which takes into account the time spent both indoors and out, and the associated indoor and outdoor exposure rates.

The total PCRV background EDER includes a small component due to cosmic radiation. Since the response of the MICROSPEC-2™ to cosmic radiation is a small percentage of the total counts in the energy spectrum, approximately 100 to 2500 keV, the EDER for this component is assumed to be 0 μrem/hr. This results in an underestimation of the background exposure rate, attributing the exposure rate due to the cosmic component to licensed radioactive material. This provides a small margin of additional conservatism in the estimation of the exposure rate due to licensed material.

5.2 PCRV Background Exposure Rate Calculation

Calculation of the PCRV background exposure rate is critically dependent on the proper choice of geometry. In fact, adequate modeling of the PCRV requires the evaluation of multiple geometries and summation of results.

An evaluation of the PCRV background exposure rate has been performed using the average naturally occurring radionuclide activities in concrete presented in Table 1. Exposure rates were calculated using MicroShield Version 4.10. This was performed to develop the PCRV model and generate a background exposure rate profile. The source thickness for all calculations was determined by calculating the maximum concrete thickness necessary to reduce the exposure rate due to natural radionuclide concentrations to less than 10% of the unattenuated exposure rate. This occurs with a concrete thickness of approximately 1 meter. To estimate the background exposure rate due to the variations in PCRV geometry, the following calculations were performed:

1. The PCRV was first modeled as an annular cylindrical source, with a slab source at the bottom end and open at the top. The total height of the PCRV from the surface of the bottom head to the refuel floor level is 27.6 meters. Exposure rates due to naturally occurring radionuclides were calculated at a distance of 1 meter from the PCRV internal wall surface beginning at the ledge created between the bottom head and the lower head C walls, approximately 2 meters above the bottom head floor surface, and continuing upward in 1 meter increments, ending approximately 0.5 meters below the refuel floor. The internal diameter of this cylinder, based on decommissioning design drawings, is approximately 11.1 meters.

2. The exposure rates below the lower head C walls, within the bottom head, were estimated using an annular cylindrical source, with a vertical height of approximately 2 meters and an internal diameter of 9.4 meters. The internal walls in this location are lined with 3/4 inch steel. Background exposure rates were calculated at distances of 1 and 2 meters above the bottom head floor surface.

3. The background exposure rate due to the bottom head floor surface was estimated, beginning at 1 meter from the floor surface and ending approximately 0.5 meters below the refuel floor. This area is also lined with 3/4 inch steel and contains helium circulator, steam generator and access penetrations. The penetrations reduce the floor surface area and source by 37%. Since this surface, with numerous penetrations, can not be easily modeled, the source was assumed present over the entire bottom head area, however, the source concentrations were reduced by 37% to account for the loss in source volume.

4. The increase in background exposure rates at elevation 4798.8 feet and above caused by the ledge between the lower beltline C walls and the bottom head were then calculated. The width of this ledge is approximately 0.8 meters (difference between the bottom head radius and the C wall radius). MicroShield V4.10 does not allow an internal or external dose point higher than annular cylindrical source vertical height. Therefore, it was necessary to estimate the exposure rates using 4 vertical slab sources creating a square with a central open area and dimensions sufficient to provide an internal area equivalent to the circular area within the PCRV. The same approach was necessary for the ledge created between the A and B walls. The A walls were sectioned in a manner which created a hexagon above the B walls, and the ledge varies in width from 0.2 to 1.0 meter. A smaller change in diameter also occurs at elevation 4821.63 feet. However, this difference causes a negligible change in background exposure rate.

The estimated contribution from each of the components described above are presented in Table 5. Table 6 presents the summed background exposure rate at 1 meter intervals within the PCRV. Figure 1 is a structural diagram of the PCRV and calculated background exposure rates.

Table 5
PCRV EDER Due To Individual Components
(μrem/hr)[1]

Height Above Bottom Head (meters)	PCRV Cylinder Wall	Bottom Head Floor Surface	Bottom Head Cyl. Wall	Bottom Head/ C Wall Ledge	A / B 0.2 m Ledge	A / B 1 m Ledge
27	7.4			0.1	0.6	1.0
26	8.8			0.1	0.8	1.2
25	9.7			0.1	1.0	1.7
24	10.4			0.1	1.6	2.4
23	10.9	0.1		0.1		
22	11.2	0.1		0.1		
21	11.5	0.1		0.1		
20	11.7	0.1		0.1		
19	11.9	0.1		0.1		
18	12.0	0.1		0.1		
[illegible]	12.1	0.1		0.1		
16	12.1	0.1		0.2		
15	12.2	0.1		0.2		
14	12.2	0.1		0.2		
13	12.2	0.1		0.3		
12	12.2	0.2		0.3		
11	[illegible]	0.2		0.4		
10	12.0	0.2		0.4		
9	11.9	0.2		0.5		
8	11.8	0.3		0.6		
7	11.6	0.3		0.8		
6	11.4	0.4		1.0		
5	11.0	0.4		1.3		
4	10.6	0.5		[illegible]		
3	10.0	0.6		2.5		
2	9.2	0.9	2.2			
1	8.0	1.2	2.8			

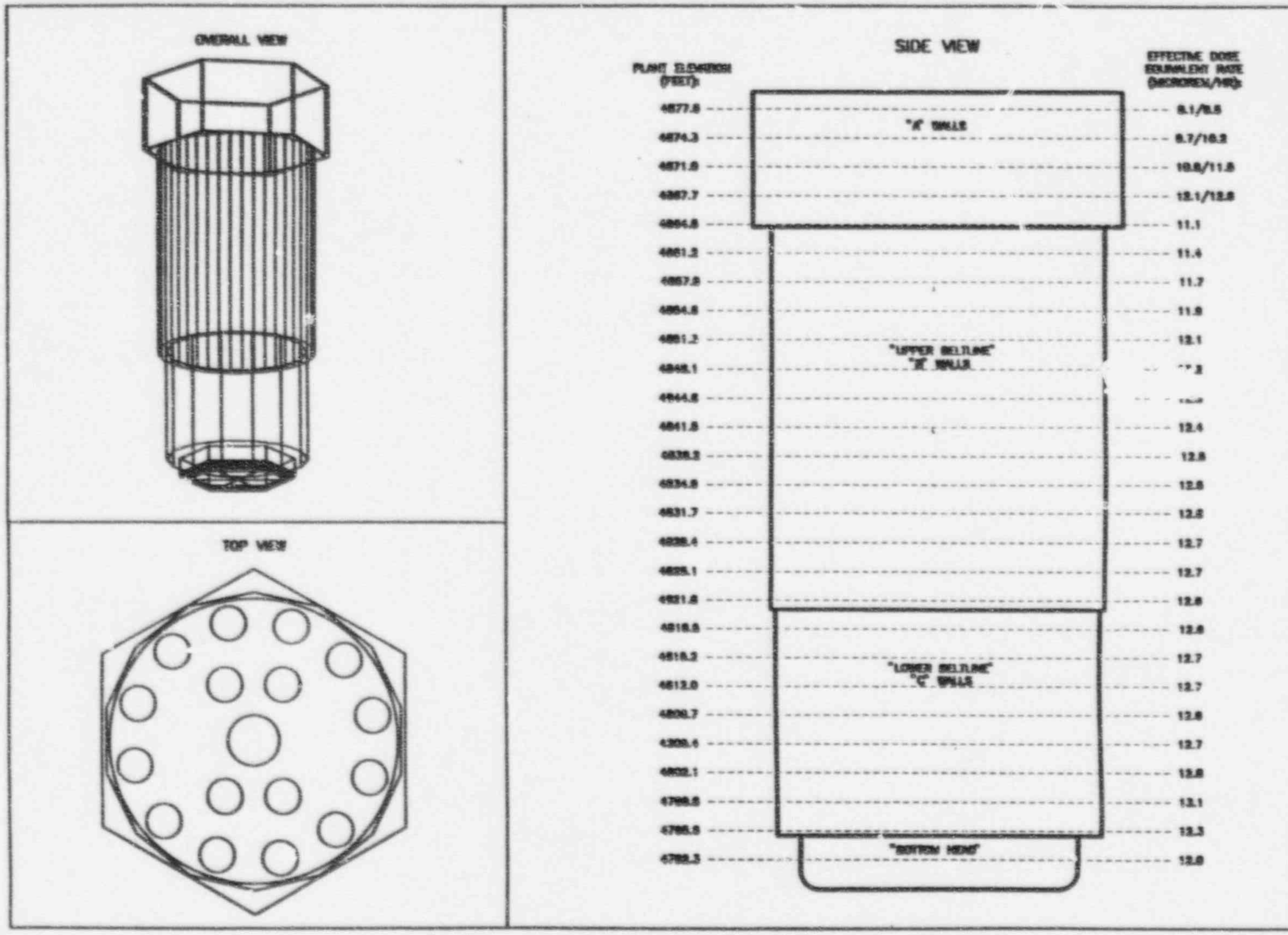
1 If a value is not presented (blank cell) the component does not contribute to the EDER at the specified distance.

Table 6
Calculated PCRV Background EDER

Plant Elevation (feet)	Height Above Bottom Head Surface (meters)	Effective Dose Equivalent Rate (μrem/hr)
4877.6	27	8.1/8.5[1]
4874.3	26	9.7/10.2[1]
4871.0	25	10.8/11.5[1]
4867.7	24	12.1/12.9[1]
4864.5	23	11.1
4861.2	22	11.4
4857.9	21	11.7
4854.6	20	11.9
4851.3	19	12.1
4848.1	18	12.2
4844.8	17	12.3
4841.5	16	12.4
4838.2	15	12.5
4834.9	14	12.5
4831.7	13	12.6
4828.4	12	12.7
4825.1	11	12.7
4821.8	10	12.6
4818.5	9	12.6
4815.2	8	12.7
4812.0	7	12.7
4808.7	6	12.8
4805.4	5	12.7
4802.1	4	12.8
4798.8	3	13.1
4795.6	2	12.3
4792.3	1	12.0

1 The wall surfaces above elevation 4864.17 feet form a hexagon creating a ledge which varies [illegible] width from approximately 0.5 feet to 3.4 feet. T[illegible] lower [illegible]DER value is for the former and the higher value is [illegible] the latter.

Figure 1


OVERALL VIEW
TOP VIEW
SIDE VIEW
PLANT ELEVATION (FEET)
EFFECTIVE DOSE EQUIVALENT RATE (MICROREM/HR)
"UPPER BELTLINE"
"LOWER BELTLINE"
"BOTTOM HEAD"

Based on these calculations, the PCRV background exposure rate remains relatively constant beginning 4 meters above the surface of the bottom head until reaching a height of approximately 15 meters. A very small increase is observed at 3 meters due to the ledge at this distance. Below 3 meters the exposure rate drops slightly. Above 15 meters the exposure rate drops continuously until the upper ledge is encountered and the exposure rate increases again. Above the upper ledge, the exposure rate drops until a minimum is obtained approximately 50 centimeters below the top of the PCRV, elevation 4879.5 feet.

5.3 PCRV Internal Surface Concrete

Following the sampling and analyses previously discussed, fifteen concrete samples were obtained from the internal surface of the PCRV and analyzed. Sample locations were chosen to represent all wall surfaces and included the following:

PCRV "A" Walls	3 samples	Plant elevation: 4872 feet	(A1-A3)
PCRV "B" Walls	3 samples	Plant elevation: 4845 feet	(B1-B3)
	3 samples	Plant elevation: 4826 feet	(B4-B6)
PCRV "C" Walls	3 samples	Plant elevation: 4809 feet	(C1-C3)
	3 samples	Plant elevation: 4799 feet	(C4-C6)

Samples at each location were obtained over an area of approximately 2 feet by 2 feet with a surface depth no greater than ½ inch. Table 7 presents the naturally occurring radionuclide activity in these samples.

Table 7
Natural Radionuclide Activity In PCRV Internal Surface Concrete
(pCi/g)

		Thorium Series				Uranium Series		
Sample Number	**K-40**	**Tl-208**	**Pb-212**	**Bi-212**	**Ac-228**	**Bi-214**	**Pb-214**	**Ra-226**
A1	25.3	0.3	0.7	0.0[1]	0.7	0.9	0.8	2.4
A2	26.3	0.4	0.6	0.0[1]	0.7	0.9	1.0	2.2
A3	24.8	0.4	0.6	0.3	0.7	0.7	0.9	2.4
B1	21.3	0.3	0.5	0.2	0.6	0.9	0.7	2.0
B2	30.0	0.4	0.7	0.0[1]	0.9	1.3	1.0	0.0[1]
B3	21.5	0.2	0.5	0.0[1]	0.6	0.9	0.7	2.1
B4	22.3	0.3	0.6	0.4	0.5	0.7	0.8	2.0
B5	24.5	0.3	0.7	0.3	0.6	0.8	0.8	2.05
B6	21.3	0.3	0.6	0.0[1]	0.6	0.6	0.7	0.0[1]
C1	22.0	0.3	0.6	0.3	0.6	0.6	0.7	1.5
C2	29.4	0.3	0.8	0.0[1]	0.8	0.9	1.0	2.5
C3	22.3	0.3	0.5	0.0[1]	0.7	0.6	0.7	2.0
C4	23.6	0.3	0.6	0.0[1]	0.7	0.8	0.8	0.0[1]
C5	23.2	0.3	0.6	0.4	0.7	0.7	0.8	1.8
C6	21.6	0.3	0.6	0.0[1]	0.5	0.8	0.8	0.0[1]
Average	24.0	0.3	0.6	0.1	0.7	0.8	0.8	1.5

1 Radionuclide not identified in analysis

These results indicate that the natural activity in concrete is uniform throughout the PCRV. The average activities in Table 7 compare extremely well with those presented in Table 1 which were used in the MicroShield calculations for the determination of background exposure rates in Tables 5 and 6. Based on these results, when gross exposure rate measurements are obtained within the PCRV, the appropriate background exposure rate from Table 6 will be applied to determine the net exposure rate due to licensed material.

During the final survey, several exposure rate measurement locations within the PCRV will be chosen for the collection of paired measurements with MICROSPEC-2™ and the PIC. The results will be evaluated to further confirm the adequacy of this approach.

6.0 CONCLUSION

The method for determining exposure rates due to licensed material described in TBD-202 is not suited for locations where the exposure rate is influenced by radionuclides associated with activated concrete. However, since the results provided by the MICROSPEC-2™ do not require adjustment to account for the energy response characteristics of typical NaI dose rate instruments, the MICROSPEC-2™ remains the preferred instrument for measuring exposure rates within the PCRV.

Exposure rate measurements within the PCRV (internal surfaces only) will be determined using the method described in NUREG/CR-5849, i.e., subtracting background exposure rates from gross exposure rate measurement results obtained with the MICROSPEC-2™. However, since no unaffected structure on site or off site is constructed similarly to the PCRV and/or of comparable material, i.e., concrete with the same aggregate source, the background exposure rate has been calculated based on the activities of naturally occurring radionuclides in PCRV concrete, and an appropriate model that accounts for the various geometries. Determination of the background exposure rate in other locations using this method has been satisfactorily demonstrated, resulting in calculated values within 5% of actual measurements.

7.0 REFERENCES

7.1 Draft NUREG/CR-5849, *Manual for Conducting Radiological Surveys In Support Of License Termination*, J. D. Berger, 1992.

7.2 Draft NUREG-1501, *Background As A Residual Radioactivity Criterion For Decommissioning*, K. Miller, 1994.

7.3 FSV-FRS-TBD-202, Fort St. Vrain Decommissioning Project Technical Basis Document, *Final Survey Exposure Rate Measurements Using The MICROSPEC-2™*.

7.4 MicroShield™, Version 4.10, Grove Engineering, Inc.