Fort St. Vrain Nuclear Station
Decommissioning Project

FSV FINAL SURVEY EXPOSURE RATE MEASUREMENTS

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1.0 INTRODUCTION

Determination of compliance with the decommissioning limits for exposure rate is based on the identification of net values above natural background attributable to licensed radioactive material. Using conventional methods for the determination of net exposure rate due to licensed radioactive material described in draft NUREG/CR-5849, *Manual for Conducting Radiological Surveys in Support of License Termination*, the background exposure rate conditions must be relatively low and uniform. For situations where the background is significant, or the exposure rate is variable due to factors other than licensed material the task becomes difficult, if not impossible to achieve without numerous, costly investigations. Even when these investigations are performed and licensed material is determined to be a contributor to the exposure rate, the ability to differentiate or distinguish net exposure rate at the decommissioning limits among a high and/or variable background is very difficult.

At Fort St. Vrain (FSV), the background exposure rate is influenced primarily by the concentration of naturally occurring radionuclides in materials of construction and surrounding soil, and by elevation above sea level (cosmic). However, the cosmic component is so outweighed by the concentrations of naturally occurring radioactive material, that it is almost insignificant with respect to exposure rate. As a result, the background is highly variable and very dependant on location, materials, and, for exposure rate, geometry. For instance, background exposure rates have typically been found as low as 2 μR/hr and as high as 35 μR/hr within an area of very close proximity. This variability makes it extremely difficult to demonstrate compliance with the site decommissioning criteria, i.e. 5 μR/hr above background averaged over 10 m^2 for indoor areas or 100 m^2 for outdoor areas, and 10 μR/hr above background for individual measurements.

2.0 CURRENT MEASUREMENT APPROACH

Measurements of exposure rate are presently collected using a Ludlum Model 2350 (M2350) coupled to a LMI 44-2 1" x 1 " sodium iodide (NaI(Tl)) detector. This equipment is operated in accordance with FSV-RP-INST-I-221, *Operation of the Ludlum 2350 Data Logger*. The 44-2 NaI detector is highly energy dependant and displays an increasing over response (compared to true tissue equivalent exposure rate) as the predominant or average gamma energy falls below approximately 500 keV.

Exposure rate measurements are typically normalized to an industry recognized standard, such as a Reuter-Stokes pressurized ion chamber (PIC). PIC measurements are collected at the same location as NaI or a significant number of NaI measurement locations to

provide representative results. The results of measurements for exposure rate collected using the two types of instruments are compared to determine a correction factor which accounts for the energy dependence of the NaI detector. The PIC also displays an increasing over response as the gamma energy drops below 500 keV, reaching a maximum over response of approximately 75% around 100 keV. However, the over response is much less than the over response of the 44-2 NaI detector. Below 500 keV, even the PIC or PIC corrected NaI does not provide a true value for the actual exposure rate.

To quantify the exposure rate due solely to presence of licensed radioactive material or demonstrate that there is no component of exposure rate due to licensed material, it is first necessary to define the background exposure rate. Typically, this is accomplished by obtaining background NaI measurements from an off-site structure which displays similar characteristics or from on-site locations that were unaffected by plant operations. At each background location a measurement is also obtained with a PIC. This value is used to generate a PIC correction factor which is applied to NaI data to compensate for the NaI energy response characteristics at the specific measurement location.

3.0 BACKGROUND CONSIDERATIONS AT FORT ST. VRAIN

At an optimum decommissioning location, the approach described in draft NUREG/CR-5849 and discussed above for the collection or identification of background exposure rate would require minimal effort, since the background exposure rate is low and the spatial variance in exposure rate is also low. However, at FSV this is not the case. The concentration of naturally occurring radioactive material (NORM) at FSV is significant resulting in outdoor exposure rates ranging from 17 to 23 μR/hr. This is due to the high concentrations of NORM in soil (or minerals within the soil). As expected, structures of masonry, stone, brick, block, etc. contribute to elevated exposure rate collected from the interior of structures.

3.1 Naturally Occurring Radionuclide Concentration

Naturally occurring radionuclides present in materials such as soil, concrete, brick, block, etc. emit photons which may be scattered due to interactions within the media and/or air prior to reaching the detector. This scatter causes a "softening" or reduction in the average gamma energy detected. Because of the high energy dependence of the 44-2 NaI detector, a small downward shift in gamma energy can have a large influence on the over response of the detector. The degree of scattered radiation will be influenced by the origin of the photons within the media (i.e., photons originating at or near the surface of a medium will result in much less scatter than photons originating throughout a volume of the same media to a specific depth). For instance, a thin concrete pad over soil displays a higher degree of scatter more representative of the underlying soil than a thick pad over soil which serves to attenuate the scatter from the soil. The scattered photon

fraction may be increased if the size of the area is small and surrounded by concrete, block or brick walls in close proximity. If the area is occupied by steel, such as tanks, pipes, valves, etc., the scatter (as well as background) will be reduced due to attenuation. Therefore, the amount of scatter will be a function of the depth of the contaminant in a medium, structure geometry and attenuating materials in the measurement area. The value of the PIC correction factor provides a measure or indication of the degree of scatter; the higher the correction factor, the higher the amount of scatter.

To demonstrate the variability in NORM and the degree of scatter, spectra obtained from investigations using the MICROSPEC-2™ (described in Section 4) indicate that the K-40 contributions to the effective dose equivalent rate has a spatial variation of at least 250% over a relatively small population of buildings at FSV. These values were obtained from various structures, including concrete, block, brick, metal and wood in typical construction configurations, i.e. concrete on concrete, block on concrete, brick on concrete, wood on concrete, etc. Other radionuclides identified in the spectra were typical gamma emitters from the uranium and thorium decay series, i.e. Bi-214, Th-228, Ac-228. The distribution or contribution of these radionuclides to the effective dose equivalent rate showed no consistency, with a variance (all photopeaks from all radionuclides other than K-40) of 500%. An indication of the amount of scattered gamma radiation is provided by the "peak-to-total ratio" (pttr), which is obtained from the MICROSPEC-2™ spectra. For this application, the pttr is determined by summing the effective dose equivalent rate from all photopeaks and dividing this by the total spectrum dose equivalent rate. The lower the pttr, the greater the amount of scatter. The pttr from the same measurements discussed above also had a variance of 255% (0.09 to 0.23).

3.2 Geometry

Geometry also has a significant influence on the response of an instrument to exposure rate. Not only does geometry influence the number of photons reaching the detector, but also the amount of scattered gamma radiation at that point. For instance, a measurement from within the center of a small room constructed of concrete may result in an increase in exposure rate because the origin of the photons is in close proximity to the detector, as well as a higher fraction of scattered radiation compared to a measurement obtained from within a larger open room of similar construction. The number of different geometries which may be encountered during the final survey makes compiling similar background values a very difficult, time consuming and costly process. Examples of the various structure geometries include:

1. Thin concrete pad over soil with wood walls and ceiling

2. Thick concrete pad with block walls and wood ceiling
3. Thin or thick concrete pad with steel walls and ceiling
4. Wood floor over soil with wood walls and ceiling
5. Concrete floor with concrete walls and ceiling, etc.

Not only do these different structure geometries result in various background exposure rates and PIC correction factors, each measurement location may have different geometry factors resulting in lower or higher exposure rates and/or PIC correction factors. These may include, but are not limited to the following:

1. The presence of attenuating material within the location, such as steel tanks, pipes, pumps, valves, etc.
2. Grating over pipes, valves, etc. which is a significant distance from the lower elevation concrete
3. The interface of concrete and wall, such as where a concrete floor meets a steel, block, brick or wood wall, all of which result in differing exposure rates and PIC correction factors
4. The interface of concrete and grating or an open pit area, again resulting in differing exposure rates and PIC correction factors
5. An open area with no equipment or piping, concrete floor and high concrete ceiling
6. An open area with equipment, piping, etc., concrete floor and high ceiling, resulting in a lower exposure rate and/or PIC correction factor in the immediate vicinity of the equipment, but changing with distance from the equipment, increasing as the area becomes more open
7. Steel walls with measurements at increasing vertical distance from the floor surface, exposure rates decreasing with increasing distance, etc.

There are many more construction configurations and these lists could go on quite extensively. However, the point is that all affect the exposure rate and PIC correction factor and no single value will adequately define the background and PIC correction factors for a given location. In fact, the only real measure of the background in an area can be obtained from the measurements in that area (sample mean) and if the variance in the results is large, the application of a single background value may result in a significant number of measurements which exceed the action level for investigation. The use of the sample mean for background is acceptable in unaffected areas where it is known or proven that there is no contribution to exposure rate from licensed material. However, in affected areas, an alternative must be identified.

3.3 Results of Background Effects at Fort St. Vrain

Approximately 12,062 exposure rate measurements have been collected from unaffected areas at FSV. These locations include various buildings immediately outside the facility restricted area (Group A), buildings within the restricted area but external to the turbine/reactor building (Group B) and the turbine building (Group C). Figure 1 is a graph of the gross μR/hr measurements. These measurements have a range of 2 μR/hr to 41 μR/hr, and an average of 14 μR/hr.

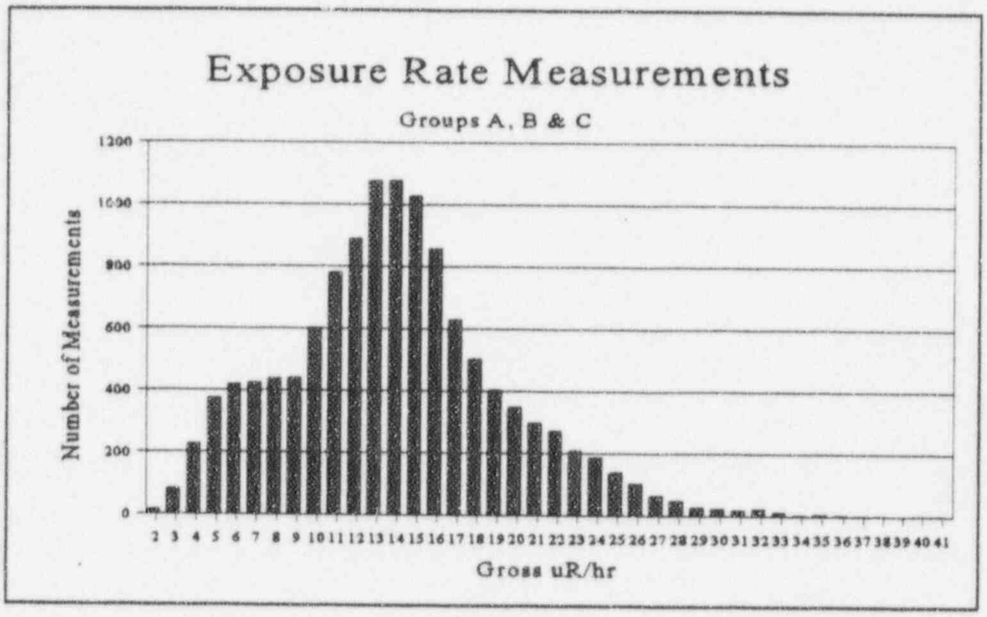

Figure 1
Distribution of Gross Measurement Results

Figure 2 presents the same measurement data with a PIC correction factor applied. The PIC corrected gross measurements have a range of 3 μR/hr to 26 μR/hr, and an average of 13 μR/hr. Application of a PIC correction factor reduces the range slightly by minimizing the effects due to the energy dependence of the 44-2 NaI detector. However, the range is still large as a result of differing concentrations of naturally occurring radionuclides, geometry and scatter.

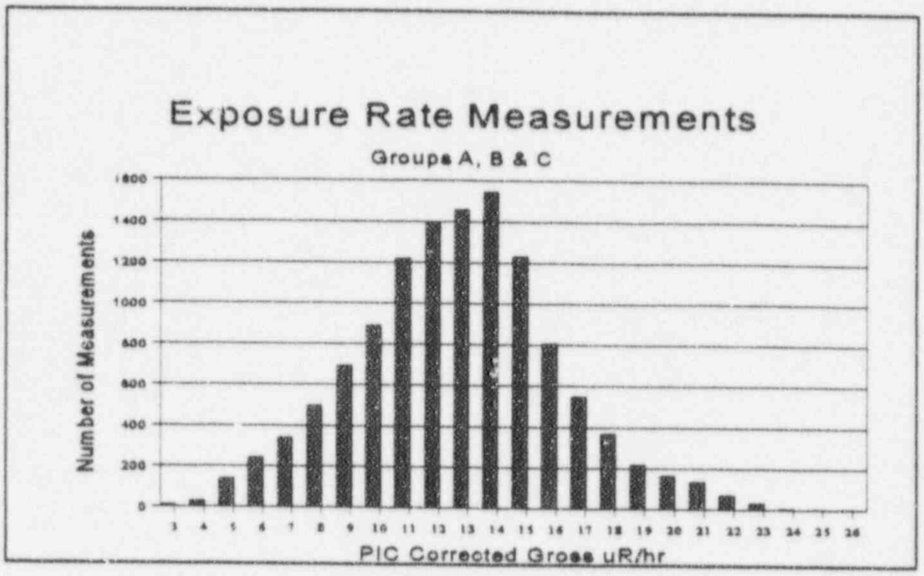

Figure 2
Distribution of PIC Corrected Measurement Results

Although the problems associated with the collection of exposure rate measurements are apparent in all survey locations at FSV, the effects of geometry and scatter can be demonstrated very well using two unaffected survey locations. The first is the main conference room in the visitor center. This is a circular room, approximately 25 to 30 feet in diameter, with brick walls and concrete floor. The exposure rate measurements from the perimeter of the room next to the brick wall were the highest and gradually decreased as the distance from the wall increased until the lowest measurement result was obtained at approximately the center of the circular room. Just outside this room is a smaller circular room approximately 6 feet in diameter, also with brick walls and concrete floor. However, in this location the measurements along the walls are lowest and increase as the distance from the walls increases until a maximum is reached at the center of the room.

The second location, the two diesel generator rooms on Level 5 in the turbine building, demonstrates the effects of both geometry and scatter. The two rooms are constructed identically, with concrete floor, walls and ceiling. However, only one room contains a diesel generator and supporting equipment. The other room is completely empty. Exposure rate measurements in the empty room resulted in an average of 16.9 μR/hr and a PIC correction factor of 1.3, while measurements from the room with the generator in place resulted in an average of 11.9 μR/hr and a PIC correction factor of 1.1. The primary cause of the reduced measurements is the presence of a significant amount of attenuating material in the area. As indicated, the choice of either of the averages as the background to be applied to the other would result in a net of +5 μR/hr or -5 μR/hr, both requiring investigation.

4.0 CHANGE IN EXPOSURE RATE MEASUREMENT PROTOCOL

The problems identified with the selection and application of appropriate background exposure rate values and PIC correction factors are numerous and difficult to resolve using the current measurement protocol. The simplest, most direct and complete resolution would eliminate the need to quantify the background exposure rate. This is the subject of the required change in measurement protocol.

FSV has selected an instrument and developed a protocol defined in a Technical Basis Document, FSV-FRS-TBD-202, *Final Survey Exposure Rate Investigations Using the MICROSPEC-2™* [1], which provides a direct measure of the exposure rate due to licensed radioactive material, regardless of background. Bubble Technologies, Inc., located in Canada, has developed and markets an instrument which utilizes spectral data and converts this data directly to exposure rate. The instrument, MICROSPEC-2™, utilizes a 2" x 2" NaI detector coupled to a 220 channel portable multi-channel analyzer. Because the instrument converts spectral data directly to exposure rate using conversion coefficients published in ICRU Report 47, *Measurement of Dose Equivalents from External Photon and Electron Radiations*, the concern regarding the energy dependence of the NaI is overcome.

The protocol for use of the MICROSPEC-2™ developed by FSV and presented in TBD-202 defines a region of interest (ROI) limit for Co-60 based on several conservative assumptions:

1. Using the same radionuclide distribution as that used to generate the site specific guideline values, (gamma emitting radionuclides), the predominant radionuclide contributing to exposure rate was identified using Microshield[2]. Microshield was also used to determine exposure rate fraction contributed by all other gamma emitting radionuclides (in all mixes applicable to exposure rate outside the PCRV, Co-60 results in 95+% of the total exposure rate due to licensed radionuclides). For conservatism, 0.90 was used for the Co-60 ROI limit.
2. The fraction of the exposure rate due to scattered gamma radiation was determined by modeling a source behind 3" of concrete using Microshield. This resulted in a conservative value of 0.30 to account for scatter (this assumes that 70% of the exposure rate from Co-60 is due to scatter). The value is actually dependent on several factors, such as origin of the photons within the media and other scattering surfaces/structures within the measurement area. In fact, experimental measurements show that Co-60

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[1] MICROSPEC-2 is a registered trademark of Bubble Technologies, Inc.

[2] Microshield is a software product copyrighted and licensed by Grove Engineering, Inc.

distributed on the surface of concrete within an open area results in approximately 40% to 45% of the exposure rate due to scatter. The conservative value was chosen to take into consideration a pipe or other structure below the surface of concrete resulting in measurable exposure rate above concrete.

By applying these values to the 5 μR/hr limit for investigation, a ROI limit for Co-60 has been identified which can easily be measured in the field and assures that if the ROI limit is not exceeded, the exposure rate due to licensed radioactive material could not exceed an administrative action level.

The exposure rate due to all gamma emitting licensed radionuclides based on the Co-60 ROI partial dose equivalent rate obtained with the MICROSPEC and the correction factors presented above can also be determined using the following equation:

$$Total\ Exposure\ Rate = \frac{ROI\ Exposure\ Rate}{0.3\ x\ 0.9}$$

Note: The factors in the denominator may be adjusted to reflect the actual conditions in the measurement area based on analysis of the MICROSPEC spectral data or samples obtained from the area.

Use of this method, in lieu of the existing conventional protocol, provides a more reliable method to quantify the exposure rate due only to licensed radioactive material. Results can be reported with a higher degree of confidence that the true exposure rate due to licensed radioactive material has been defined, without having to subtract background. If necessary, however, the MICROSPEC-2™ can be used in a manner similar to conventional instrumentation by subtracting background from gross measurement results. This may be desirable when measuring the exposure rate from areas where the protocol described in TBD-202 is not applicable, such as the PCRV or other areas with a significant fraction of the exposure rate due to radionuclides associated with activated concrete. This still provides a more accurate measure of the exposure rate due to licensed radioactive material since the energy dependence of typical NaI detectors is eliminated.

5.0 FINAL SURVEY PLAN CHANGES

Minimal changes will be necessary to revise the FSV Final Survey Plan and associated FSV procedures to implement this new protocol.

Changes will be necessary to Sections 3.3.3, 3.3.6, 4.2, 4.4, 5.1, 5.2, and Figure 5.6 to allow the measurement of exposure rate due to licensed material directly using the Microspec, without the determination and subtraction of background or correction to equate results to the PIC. Also, a single measurement from the floor at 1 meter from a wall using the Microspec satisfies both wall and floor surface area measurement requirements. These changes are straightforward and are not presented here.

In addition to using the Microspec to establish exposure rates, PSCo has also requested approval to allow exposure rate measurements to be taken only for floor and lower wall surfaces. This change is explained in the cover letter and in Attachment 1 to this report, and is consistent with the guidance in Draft NUREG/CR-5849.

Section 4.3.3, **Measurement Frequency,** is being revised to reflect these changes, as shown below. This revision also reflects the revision to take one exposure rate measurement every 4 m^2, previously approved by the NRC in their letter dated February 12, 1996 (G-96014). To implement this change and taking into account different sizes of survey units, the minimum number of exposure rate measurements is also being revised. For suspect affected survey units, the number of measurements will be based solely on the surface area of the floor and lower walls, unless the surface area is sufficiently small that the Student "t" value (used in Section 5.2.5) is prohibitively large, necessitating additional measurements. Section 4.3.3 is proposed to be revised as follows:

Building Surfaces and Structures

- ***Suspect Affected Survey Units***

The final survey of suspect affected survey units includes a scan of 100% of accessible surface area and a minimum of 30 measurements per survey unit for removable activity (smears) and total activity (fixed point measurements). The location of these measurements will ensure uniform coverage of the area and the investigation of potentially elevated areas of activity identified during the scan survey. One exposure rate measurement will be collected for every $4m^2$ of accessible floor and lower wall surface area. In the design of the final survey, at the perimeter of a room where the floor surface meets a wall, exposure rate measurements collected at a spacing of 1 measurement for each $4m^2$ at one meter above the floor and 1 meter from the wall will satisfy both floor and wall measurement requirements for that location. For example, an exposure rate measurement collected at the perimeter of an area 1 meter from the floor and 1 meter from the wall satisfies the $4m^2$ measurement requirement for the floor AND

the $4m^2$ measurement requirement for the lower wall. In the corner of an area where the measurement is 1 meter from the floor and 1 meter from both wall surfaces making up the corner satisfies the $4m^2$ measurement requirement for the floor AND $8m^2$ of lower wall surface ($4m^2$ for each lower wall surface making up the corner).

If the area is gridded, measurements for removable activity and total activity will be collected at each grid intersection. Exposure rate measurements will be collected at the center of each $4m^2$ of accessible floor surface. Where survey units are not gridded, the number of measurement locations will be based in part on the size of the area being surveyed. To ensure adequate coverage in survey units that are not gridded, the following measurement frequencies have been established:

For survey units ≤ 20 square meters	*A minimum of 30 measurement locations for removable and total activity; 5 exposure rate measurements if the accessible area = $20m^2$, 4 for smaller areas.*
For survey units > 20 square meters	*Equivalent to 1 meter intervals for removable and total activity; 1 measurement per $4m^2$ of accessible area for exposure rate.*

- ***Non-Suspect Affected Survey Units***

The final survey of non- suspect affected survey units above 2 meters includes a minimum of 30 measurements per survey unit for removable activity (smears) and total activity (fixed point measurements), and a scan survey of the accessible surfaces at each measurement location. In general, these areas will not be gridded. Measurement locations will be selected from locations most likely to accumulate activity and the investigation of potentially elevated areas of activity identified during the scan. The number of measurement locations will be based in part on the size of the area being surveyed.

For survey units ≤ 600 square meters	*A minimum of 30 measurement locations for removable and total activity*
For survey units > 600 square meters	*A minimum of 1 measurement location for each 20 m^2 surveyed*

Exposure rate measurements are not collected in non-suspect affected survey units.

- ***Unaffected Survey Units***

The final survey of unaffected survey units includes a scan of approximately 10% of the accessible surface area comprising floors and walls below two meters, and a minimum of 30 measurements per survey unit for removable activity (smears) and total activity (fixed point measurements). In general, these areas will not be gridded. Measurement locations will ensure uniform coverage of the area and the investigation of potentially elevated areas of activity identified during the scan.

The number of measurement locations will be based in part on the size of the area being surveyed.

For survey units ≤ 1500 square meters	*A minimum of 30 measurement locations for removable and total activity*
For survey units > 1500 square meters	*A minimum of 1 measurement location for each 50 m^2 surveyed*

Exposure rate measurements will be collected at 1 meter from accessible floor surfaces, typically at the location of surface activity measurement. It is expected that the final survey of building exteriors will be in accordance with the protocol established for unaffected building surfaces and structures.

Requirements in Section 5.2.5 for determination of the 95% confidence level of the mean based on the actual number of exposure rate measurements performed will remain unchanged.

6.0 COST SAVINGS

To determine or estimate the potential savings which could be realized by utilizing the alternate instrumentation and application protocol at FSV, the following factors were applied:

1. The floor and lower wall surface area of the reactor building is approximately 15,000 m^2; the floor surface area is 7400 m^2.
2. If one measurement is required for each 4 m^2 of surface area, the total number of measurements for all surfaces is 3750; 1850 for the floors. Because of the manner in which the instruments are used and set-up for collection, a measurement should be obtained at each location for all surfaces using the 44-2, whereas a single measurement from the floor at one meter from a wall using the MICROSPEC-2™ satisfies both wall and floor surface area measurement requirements.
3. If a survey package includes 30 exposure rate measurements, the total number of packages for all surfaces is 125; 62 for the floors.

4. Each survey package includes at least 5 measurements with the PIC which results in 625 measurements for all surfaces; 310 for the floors. Based on testing described in response to the NRC comments, the MICROSPEC-2™ provides more accurate results in the presence of high and/or variable background than the PIC. Using the MICROSPEC-2™ and TBD-202 protocol, PIC measurements will not be required.
5. Draft NUREG-1501 identifies the cost per exposure rate measurement. The cost for standard instrumentation (Ludlum Model 2350 with 44-2) is $50.00 per measurement and $100.00 for the PIC. Although the cost for standard instrumentation is reasonable, the PIC cost appears high. For this estimate, the PIC measurement cost is assumed to be $75.00.
6. Draft NUREG-1501 estimates the cost per in-situ gamma measurement to be $100-$300. Because of the simplicity in the application and use of the MICROSPEC-2™ and the fact that the application is more like a direct exposure rate measurement than typical in-situ measurements using more complicated and costly instrumentation, the cost per measurement using the MICROSPEC-2™ is assumed to be $75.00.
7. Using standard instrumentation and the protocol described in draft NUREG/CR-5849, it is estimated that at least 60% of the measurements will require investigation, which includes a repeat of the measurements and a minimum of 8 engineering person-hours per package for data evaluation, investigation direction and package preparation/revision, investigation documentation and preparation of supplemental documentation for the Final Survey Report (4 engineering person-hours per package for initial data).
8. Using the information in 7 above, at least 50% of the investigations will be closed by using the MICROSPEC-2™ to obtain results.

The estimated cost for collecting initial exposure rate measurements in the reactor building from floors and lower walls is $267,000.00. The additional cost for investigations and package closure is $292,000.00. The total using standard instrumentation and conventional protocol is $559,000.

Using the MICROSPEC-2™, the total cost for all required measurements, data evaluation and report preparation is $155,000.00.

The difference between the two cost estimates results in a minimum savings of **$404,000.00**. Actual cost savings could be much greater if the investigations are greater than the percentages used in the estimate.

7.0 CONCLUSION

The background exposure rate at FSV is high and extremely variable. This high background is primarily due to the concentrations of Naturally Occurring Radioactive Material (NORM) found in construction materials and enhanced by the various structure geometries present within the facility. Variability is due to differences in these concentrations in the various materials and is also affected by geometry.

Conventional instruments used to collect exposure rate measurements display a large energy dependence and the variability in material NORM concentrations can cause an extreme over response of the instrument to the exposure rate. The high background limits the sensitivity of instruments which provide an exposure rate response (rate meters). This limitation extends to the Pressurized Ion Chamber (PIC).

To overcome these conditions and accurately determine the exposure rate due to licensed material an alternate method must be identified. The simplest, most direct and complete resolution to this problem would eliminate the need to quantify the background exposure rate and provide a mechanism to measure the exposure due to licensed material, from both uncollided and scattered photons. The MICROSPEC-2™ and the protocol defined in TBD-202 provides such a method. The MICROSPEC-2™ provides results, which, once corrected to account for scatter, have acceptable accuracy even in the presence of high and variable background. Results can be reported with a higher degree of confidence that the true exposure rate due to licensed material has been defined, without having to subtract background or apply corrections to equate the results to the PIC.

The minimum cost savings which could be realized using the MICROSPEC-2™ is $404,000.00.

8.0 REFERENCES

8.1 Draft NUREG/CR-5849, ORAU-92/C57, *Manual for Conducting Radiological Surveys in Support of License Termination*, J. D. Berger, 1992.

8.2 *Fort St. Vrain Nuclear Station Decommissioning Project, Final Survey Plan for Site Release*, prepared by Scientific Ecology Group/RE&DS Radiation Protection Department Fort St. Vrain Nuclear Station, and Public Service Company of Colorado, Revision 2, October 1995.

8.3 MicroShield™, Version 4.0, Grove Engineering, Inc.

8.4 *BTI, Portable Smart Survey Meter, MICROSPEC-2™ for High Sensitivity Radiation Surveying with Isotope Identification Manual*, Bubble Technology Industries, Inc., January, 1994.

8.5 ICRU Report 47, *Measurement of Dose Equivalents from External Photon and Electron Radiations*, International Commission on Radiation Units and Measurements, April 15, 1992.

8.6 FSV-FRS-TBD-201, Fort St. Vrain Decommissioning Project Technical Basis Document, *Site Specific Guideline Values for Surface Activity*.

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

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

RESPONSE TO COMMENTS PROVIDED 3/19/96

1. **What values were used to develop ratios for determining major licensed radionuclide contributors to exposure rate?**

Section 5.3 of TBD-202 discusses exposure rate calculations using the 10CFR61 nuclide mix presented in TBD-201. This is the same mix used to develop the Site Specific Guideline Values. Several waste streams were eliminated from further use in TBD-202, with discussion of the reason/justification for elimination provided in the text. It has been demonstrated that the limitations in use of a 220 channel multi-channel analyzer do not allow evaluation of locations containing an activated concrete volume, such as the interior of the PCRV. This limitation is stated in the TBD.

2. **The Technical Basis Document (TBD) contains a lot of assumptions. These need to be discussed further and how the assumptions affect the final result.**

Although several factors presented in the TBD may appear to be simple assumptions, they are in fact based on knowledge of the application and/or evaluations performed, but currently not discussed in detail in the TBD. The basis for the use of several factors which appear to be of concern are presented below. The TBD will be expanded to further clarify the approach.

- The equation used to calculate the Co-60 ROI limit incorporates a "peak-to-total ratio" (pttr) of 0.3 to account for the contribution to exposure rate from scattered gamma radiation with energies less than the photopeak energy. This factor was derived from actual measurements with a Co-60 source behind 3" of concrete. This source/shield geometry was chosen to represent the worst case scattering condition, i.e., a pipe or other source containing gamma emitting radionuclides embedded in concrete, with 3" of concrete between the source and the surface of the media.

  To further substantiate this geometry as worst case, several additional measurements were performed, each with a different geometry. The results of these measurements are presented below.

  1. A Co-60 source (100 μCi) was placed in an area at the interface of a concrete floor and concrete wall. The measurement was obtained at the standard distance of 1 meter (all measurements were performed at this distance). The result of this measurement provided a pttr of 0.47, higher (less conservative) than the pttr used in the equation.
  2. The Co-60 source was then placed in a location with several metal objects (pipes, valves, etc.) between the source and the detector, also in close proximity to a concrete floor and concrete wall interface. The resulting pttr

for this configuration was 0.41, again higher than the pttr used in the equation.

3. The source was then placed in a very small area with concrete block walls approximately 3' apart and concrete floor. The resulting pttr was 0.48, also higher than the pttr used in the equation.
4. The source was placed in an open area on a concrete floor with no interfering surfaces closer than 6' from the measurement location. The resulting pttr was 0.53.
5. Finally, the source was placed in the same location as the first measurement. For this measurement a 3" section of solid concrete was placed between the source and the detector. The resulting pttr was 0.32, very similar to the initial result presented in the TBD.

The results of these additional measurements further support and substantiate the use of a pttr of 0.3, which will provide conservative measurement results. As indicated above, this conservative value will result in an overestimate of the exposure rate due to licensed radioactive material if the source geometry is different from the geometry which generated this factor. Since the degree or amount of scattered gamma radiation can not be predicted prior to measurement, 0.3 was chosen as an appropriate value to provide a conservative starting point. The TBD does allow for the evaluation of this factor should a measurement approach or exceed the ROI limit. Should the measurement result or other evaluations indicate that a pttr of 0.3 is too conservative, the factor and resulting ROI limit may be evaluated and modified to more accurately represent the actual conditions at the measurement location, if justified based on the evaluation. Otherwise follow-up actions will be in accordance with the Plan and applicable implementing procedures.

- The equation used to calculate the Co-60 ROI limit also incorporates a factor of 0.9 to account for licensed radionuclides other than Co-60 which contribute to the exposure rate. The majority of the remaining 10% is due to Cs-137. Again, the TBD states that the method is not appropriate for activated concrete which has a large fraction of Eu-152. As indicated in Table 5-7 and discussed in the text, this factor is conservative for the radionuclide mix determined outside of the PCRV or not associated with the PCRV. In fact for the radionuclide mix not associated with PCRV concrete, Co-60 results in 96.2 to 99.8% of the exposure rate due to licensed radioactive material. As stated above, should the measurement result or other evaluations indicate that this factor is too conservative, this factor and the resulting ROI limit may be modified to more accurately represent the measurement location.

The result of the conservatism included in the two factors used to determine the Co-60 ROI limit (pttr and Co-60 fraction) may result in an initial overestimate of the exposure rate due

to licensed radioactive material of 100% or more. However, it should be stressed that the conservative ROI limit is intended as a "screening" limit. This provides a quick indication of the radiological status of an area with respect to exposure rate, with a very high level of confidence that the Co-60 partial dose equivalent rate is less than the ROI limit and an action level has not been exceeded.

3. **Discuss the MICROSPEC Quality Control checks.**

The MICROSPEC is operated in accordance with procedure FSV-RP-INST-I-421. This procedure allows use of the MICROSPEC to perform qualitative measurements such as determining which, if any, licensed radionuclides contribute to the exposure rate at a specific location; or quantitative measurements, such as those necessary to determine the exposure rate due to licensed radionuclides.

When using the MICROSPEC to perform qualitative measurements, the only pre-use requirement is the performance of an energy calibration. To perform quantitative measurements, quality control checks must be performed in addition to the energy calibration. These checks must be performed daily when the instrument is used for this purpose and includes a check of the area (peak counts) for the two Na-22 peaks, 511 keV annihilation peak and 1274.5 keV photopeak. The area of both peaks are compared to the +/- 2 and +/- 3 sigma values. QC limits (sigma values) are determined monthly or prior to instrument use, if used less frequently. If either value exceeds +/- 3 sigma, supervision must be notified and the instrument taken out of service until the condition is evaluated and corrected. The total spectrum dose rate is also determined during the QC check. If this is greater than +/- 10% of the mean which is determined at the same time as the peak area limits, the same actions as above must be taken.

As an additional check and verification of the stability of the instrument, the ROI settings must be verified prior to collection of field measurements, or if any change is suspected. This change (gain shift) may be caused by movement of the instrument to an area of different temperature. If a check of the ROI indicates that a significant gain shift has occurred, a new energy calibration must be performed.

4. **Compare MICROSPEC results with the Pressurized Ion Chamber (PIC). What corrections will be applied to the results obtained with the MICROSPEC to compensate for response differences (MICROSPEC vs. PIC)?**

Several evaluations have been performed using the MICROSPEC and the PIC in an attempt to better understand the response of the two instruments. These evaluations were also designed to determine the need to correct the results of the MICROSPEC to provide PIC equivalent exposure rate and the result of this correction.

- The first of these evaluations involved determining the response of both

instruments at various angles of incidence, beginning at 0 degrees (directly in front of the MICROSPEC NaI detector and top center of the PIC) and continuing around the instrument at 22.5 degree increments to a maximum of 337.5 degrees. This was performed initially with a Co-60 source and then repeated with Cs-137. To ensure consistency in comparison of the response of the two instruments, the source was placed at a distance measured from the detector centerline for all measurements. When measuring the source distance for the PIC, the detector centerline was assumed to be the center of the 1 ft^3 outer box.

Measurements were performed at a source distance of 9" from the detector centerline for both instruments and both sources (Figures 3 and 4), then repeated at a distance of 27" (Figures 5 and 6). At the 9" measurement distance, the MICROSPEC response was uniform to an angle of 112.5 degrees, increasing to 135 degrees as the distance was increased to 27". As expected the response decreased as the angle approached 180 degrees. However, when the source distance was increased, the response improved at these angles with a maximum 9% under response for Co-60 and 18% under response for Cs-137 at 180 degrees. The PIC displayed a similar response, uniform to 157.5 degrees, with a maximum under response at 180 degrees. This response also improved as the source distance was increased, with a maximum under response of 7% for Co-60 and 8% for Cs-137 at 180 degrees. It is important to note that 180 degrees on the PIC was found at the location where the steel plate is attached to the box for securing the detector tripod. At most measurement locations this is the angle of interest (source term contributing to exposure rate from underneath the detector). Graphs of the angular response for the PIC and MICROSPEC at both measurement distances are attached.

- The second evaluation compared the response of the PIC and MICROSPEC to increasing exposure rate from Co-60.

This evaluation compared the response of the two instruments, first in an area of low background (low background at FSV), with licensed radioactive material (Co-60) contributing to the exposure rate with a range which covers the decommissioning limits. These results are presented in Tables 1 and 2. The evaluation was repeated using the same source, however, in an area where the MICROSPEC background was almost a factor of five higher and a factor of two for the PIC. These results are presented in Tables 3 and 4.

Measurements in both locations were performed using a 0.5 μCi Co-60 source, beginning at a distance of 30" and decreasing to a minimum of 6". At 30" background predominated the PIC measurement result (approximately 10 μR/hr in the low background area; 17.7 μR/hr in the higher background area). The MICROSPEC background exposure rate 3.2 μR/hr and 15.1 μR/hr, respectively.

LOW BACKGROUND MEASUREMENT LOCATION
(MICROSPEC BKG 3.2 μR/hr; PIC BKG 10 μR/hr)

Table 1
MICROSPEC Measurements

Distance (inches)[1]	Gross Result (μR/hr)	Net Result (μR/hr)	Calculated (μR/hr)	Net vs. Calc. % Error
30	4.4	1.2	1.1	+9.1
26	4.9	1.7	1.5	+13.3
22	5.3	2.1	2.1	0.0
18	6.1	2.9	3.1	-6.5
14	7.9	4.7	5.1	-7.8
12	9.4	6.2	6.9	-10.1
10	12.0	8.8	9.9	-11.1
8	16.6	13.4	15.6	-14.1
7	20.1	16.9	20.3	-16.7
6	27.2	24	27.7	-13.4

1 Distance is measured from the detector centerline.

Table 2
PIC Measurements

Distance (inches)[1]	Gross Result (μR/hr)	Net Result (μR/hr)	Calculated (μR/hr)	Net vs. Calc. % Error
30	10.0	0.0	1.1	-100.0
26	10.4	0.4	1.5	-73.3
22	11.1	1.1	2.1	-47.6
18	11.8	1.8	3.1	-41.9
14	13.4	3.4	5.1	-33.3
12	15.1	5.1	6.9	-26.1
10	17.3	7.3	9.9	-26.3
8	21.7	11.7	15.6	-25.0
7	25.7	15.7	20.3	-22.7
6	33.9	23.9	27.7	-13.7

1 Distance is measured from the detector centerline.

HIGHER BACKGROUND MEASUREMENT LOCATION
(MICROSPEC BKG 15.1 μR/hr; PIC BKG 17.7 μR/hr)

Table 3
MICROSPEC Measurements

Distance (inches)[1]	Gross Result (μR/hr)	Net Result (μR/hr)	Calculated (μR/hr)	Net vs. Calc. % Error
30	16.3	1.2	1.1	+9.1
26	16.5	1.4	1.5	-6.7
22	17.2	2.1	2.1	0.0
18	17.9	2.8	3.1	-9.7
14	19.5	4.4	5.1	-13.[illegible]
12	20.9	5.8	6.9	-15.9
10	23.6	8.5	9.9	-14.1
8	28.1	13	15.6	-16.7
7	32.5	17.4	20.3	-14.3
6	39.3	24.2	27.7	-12.6

1 Distance is measured from the detector centerline.

Table 4
PIC Measurements

Distance (inches)[1]	Gross Result (μR/hr)	Net Result (μR/hr)	Calculated (μR/hr)	Net vs. Calc. % Error
30	18.0	0.3	1.1	-72.7
26	18.6	0.9	1.5	-40.0
22	19.2	1.5	2.1	-28.6
18	19.9	2.2	3.1	-29.0
14	21.6	3.9	5.1	-23.5
12	23.2	5.5	6.9	-20.3
10	25.1	7.4	9.9	-25.3
8	29.4	11.7	15.6	-25.0
7	33.0	15.3	20.3	-24.6
6	41.5	23.8	27.7	-14.1

1 Distance is measured from the detector centerline.

The net exposure rates in the tables presented above were determined by subtracting the location specific background from the gross result for both instruments. For these measurements, licensed radioactive material (Co-60 in the form of a sealed source) was placed at the desired measurement distances. Background was determined before bringing the source into the area and after the source was removed. The background spectra obtained in both areas did not identify the presence of licensed radioactive material. **Subtraction of location specific background exposure rate in this evaluation should not be confused with the problems discussed with identification of appropriate background values to be applied to affected survey units.** As discussed on many occasions, background exposure rate can not be determined at the specific measurement location in affected survey units. Rather, using the conventional approach, a background value should be determined from a location similar to the measurement area.

The data shows that in the exposure rate range of interest (0 to 10 μR/hr), the MICROSPEC provided favorable results, with an error range of +13.3% to -11.1% in the low background area and +9.1% to -15.9% in the higher background area. However, the PIC measurements in this exposure rate range resulted in unsatisfactory error, with an error range of -26.1% to -100% in the low background area and -25.3% to -72.7% in the higher background area. It was not until the PIC measurements were twice background that the error in the result was less than 20%. This indicates that the PIC (or any rate meter) does not have the required sensitivity to identify the exposure rate due to licensed material in the range of interest (decommissioning limits) when in the presence of high background with an acceptable level of error. This further substantiates the necessity for an alternate method for determining exposure rate due to licensed radioactive material. Even though the first measurement location was termed a "low" background area, it is only low for FSV, and would be considered high at most other locations.

It should be noted that as the source to detector distance is decreased, the accuracy in source placement becomes more important (slight error in placement can cause a large error in the measurement result). Extreme care was exercised to ensure that the source to detector distances for all measurements were as accurate as possible.

As stated, MICROSPEC results presented above were determined by subtracting background from gross measurement results. For comparison, the corrected MICROSPEC results based on a Co-60 ROI and associated partial dose equivalent rate using the protocol established in TBD-202 are presented in the following tables. Using the factors in the equation for ROI limit determination provided in TBD-202, the partial dose equivalent rate is first corrected using a pttr of 0.3 for both cases (measurements from low and higher background areas) to account for

scatter gamma radiation which falls below the photopeak but contributes to the exposure rate due to Co-60. A factor of 1.0 is used instead of 0.9 since it is known that the only licensed gamma emitting radionuclide was Co-60. This data is presented in Tables 5 and 7 using a pttr of 0.3. Tables 6 and 8 presents the same data, however, the correction is based on a better estimate of the pttr in the measurement area (0.55 for the low background area; 0.45 for the higher, both determined using actual spectral data obtained from the measurements).

LOW BACKGROUND MEASUREMENT LOCATION

Table 5
MICROSPEC ROI Measurements
pttr = 0.3

Distance (inches)[1]	ROI Result (μR/hr)	Corrected Result pttr = 0.3 (μR/hr)	Calculated (μR/hr)	Corr. vs. Calc. % Error
30	0.6	2.0	1.1	+81.8
26	0.9	3.0	1.5	+100.0
22	1.2	4.0	2.1	+90.5
18	1.7	5.7	3.1	+82.8
14	2.9	9.7	5.1	+89.5
12	3.6	12.0	6.9	+73.9
10	6.0	20.0	9.9	+102.0
8	9.4	31.3	15.6	+100.9
7	12.5	41.7	20.3	+105.3
6	17.4	58.0	27.7	+109.4

1 Distance is measured from the detector centerline.

Table 6
MICROSPEC ROI Measurements
pttr = 0.55

Distance (inches)[1]	ROI Result (μR/hr)	Corrected Result pttr = 0.55 (μR/hr)	Calculated (μR/hr)	Corr. vs. Calc. % Error
30	0.6	1.1	1.1	-0.8
26	0.9	1.6	1.5	+9.1
22	1.2	2.2	2.1	+3.9
18	1.7	3.1	3.1	-0.3
14	2.9	5.3	5.1	+3.4
12	3.6	6.5	6.9	-5.1
10	6.0	10.9	9.9	+10.2
8	9.4	17.1	15.6	+9.6
7	12.5	22.7	20.3	+12.0
6	17.4	31.6	27.7	+14.2

1 Distance is measured from the detector centerline.

HIGHER BACKGROUND MEASUREMENT LOCATION

Table 7
MICROSPEC Measurements
pttr = 0.3

Distance (inches)[1]	ROI Result (μR/hr)	Corrected Result pttr = 0.3 (μR/hr)	Calculated (μR/hr)	Corr. vs. Calc. % Error
30	0.5	1.7	1.1	+51.5
26	0.9	3.0	1.5	+100.0
22	1.0	3.3	2.1	+58.7
18	1.1	3.7	3.1	+18.3
14	2.0	6.7	5.1	+30.7
12	3.0	10.0	6.9	+44.9
10	4.8	16.0	9.9	+61.6
8	7.0	23.3	15.6	+49.6
7	9.5	31.7	20.3	+56.0
6	12.9	43.0	27.7	+55.2

1 Distance is measured from the detector centerline.

Table 8
MICROSPEC ROI Measurements
pttr = 0.45

Distance (inches)[1]	ROI Result (μR/hr)	Corrected Result pttr = 0.45 (μR/hr)	Calculated (μR/hr)	Corr. vs. Calc. % Error
30	0.5	1.1	1.1	+1.0
26	0.9	2.0	1.5	+33.3
22	1.0	2.2	2.1	+5.8
18	1.1	2.4	3.1	-21.1
14	2.0	4.4	5.1	-12.9
12	3.0	6.7	6.9	-3.4
10	4.8	10.7	9.9	+7.7
8	7.0	15.6	15.6	-0.3
7	9.5	21.1	20.3	+4.0
6	12.9	28.7	27.7	+3.5

1 Distance is measured from the detector centerline.

Figure 7 is a graph titled "PIC/MSPEC vs. Calculated Value" which was created using net exposure rate results from the "low" background area.

Section 5.1 of TBD-202 discusses comparison of dose equivalent rate as measured using the MICROSPEC with the calculated value from a Cs-137 calibration source. This indicated an over response of the MICROSPEC to the Cs-137 source of 9.45% (average).

This data indicates that when the exposure rate due to licensed radioactive material is slightly in excess of background, the MICROSPEC and the approach defined in TBD-202 provides greater assurance that the increase in exposure rate will be detected and accurately reported compared to results provided by the PIC (as stated, when using the "screening" pttr fraction of 0.3, the result is an over estimate of the exposure rate due to licensed material which can be improved, if necessary, by defining a pttr which is more representative of the measurement location). When the PIC exposure rate due to licensed radioactive material exceeds the background by a factor of 2 or more, the results of the two instruments compare more favorably.

The results provided by the MICROSPEC and discussed in TBD-202 are based on a Co-60 ROI which provides a direct measure of the exposure rate due to licensed radioactive material without regard for background. It has been shown that the application of the approach discussed in TBD-202 for exposure rate measurements obtained with the MICROSPEC provides initial results which will be conservative (over estimate the exposure rate due to licensed radioactive material). These results can be corrected, if necessary, by application of a measurement location specific pttr to more accurately represent the true exposure rate due to licensed radioactive material. However, as discussed and presented in the previous tables, the PIC resulted in a significant under estimate of the exposure rate due to licensed radioactive material when attempting to measure the exposure rate at the decommissioning limits. This is not a problem inherent with the PIC. The problem is with the use of any rate meter for collection of exposure rate measurements where the background exposure rate may be as high as an order of magnitude greater than the decommissioning limits imposed.

Therefore, the application of a PIC correction factor to the results obtained with the MICROSPEC will result in a value which may be significantly in excess of the exposure rate due to licensed radioactive material. As indicated, the MICROSPEC exposure rate measurement should stand alone without correction to PIC equivalent, which, if applied, will introduce additional error.

5. How does altering the Region of Interest (ROI) affect the overall result?

The MICROSPEC allows the determination of total spectrum dose equivalent rate and partial dose equivalent rate for any established ROI. A ROI can be set up for any group of channels or energy range in the spectrum. This allows the evaluation of a specific part

of the spectrum which may be of interest. TBD-202 requires a ROI set up from the beginning of the 1173 keV Co-60 peak to the end of the 1332 Co-60 peak. Prior to collection of field measurements, a brief count is required using a Co-60 check source to verify correct ROI settings. This is necessary to compensate for slight gain shifts which may occur. Following collection, each measurement is saved on computer disk and later transferred to a desk top computer for further evaluation, if necessary. The desk top computer runs the same data analysis software as the MICROSPEC. During the evaluation, the left and right ROI settings are checked and adjusted, if necessary, to ensure the greatest partial dose equivalent rate is achieved for the ROI. If the ROI is initially set up correctly, no further adjustments are necessary.

Adjustment of the ROI is intended to optimize the settings to provide the highest estimate of exposure rate due to licensed radioactive material. This has no affect on the total spectrum dose equivalent rate provided by the MICROSPEC.

6. **What is the MDA of the measurement system?**

Section 5.5 of TBD-202 discusses the determination of count time necessary to achieve a specific Minimum Detectable Dose Equivalent Rate (MDDER). The equation to calculate MDDER is also provided in this section. A MDDER for Co-60 has been established at 50% of the ROI limit or 0.675 μR/hr. A second criteria requires the ability to detect Cs-137 at 0.15 μR/hr. This criteria allows validation of the Co-60 exposure rate fraction (0.9). Typically, the required MDDER for Co-60 and Cs-137 can easily be achieved with a count time of 4 minutes (a minimum field count time of 5 minutes is initially established in survey instructions, but may be increased if necessary due to high background count rates). Even with the presence of a significant quantity of K-40 in the spectrum, the ROI can be adequately placed to achieve 25% of the ROI limit (in a 220 channel spectrum, the 1460 keV K-40 peak may interfere with the 1332 keV Co-60 peak which imposes a 25% limitation).

Conversely, it has been shown that in the presence of high and/or fluctuating background, it is not possible to accurately detect an increase in exposure rate due to licensed radioactive material at or below the decommissioning exposure rate limit using the PIC.

7. **If background is a concern, how is the background count rate determined for calculating the required count time?**

A background count is required to be performed in the general proximity of the measurement location or an area similar to the measurement location. The count rate from this measurement is used to determine the minimum count time necessary to achieve the required MDDER. The limiting criteria is that licensed material must not be detected in the background count. This is quite different from and actually has no similarity to the problems discussed with the conventional approach for determining net exposure rate

which requires accurate determination of background for subtraction from gross measurement results. The MICROSPEC background count is not performed to determine an appropriate value for subtraction. As discussed, determination of the exposure rate due to licensed materials without regard for background is the most distinct advantage in the use of the MICROSPEC and application described in TBD-202.

8. **Need to perform an in-depth error analysis. What error has been introduced?**

The computer algorithm used by the MICROSPEC to generate exposure rate results is the property of Bubble Technologies, Inc. and not available for review. Although the general method and factors are known, the exact calculations incorporated in the algorithm are not known. Since a direct validation of the calculations used in the algorithm can not be performed and analyzed, standard practice requires use of an indirect method, such as comparison of results with known or calculated values. This has been performed and is discussed in response to comment number 4.

As stated previously, a positive bias has been intentionally introduced in the determination of the ROI limit. This results in a conservative limit used in the initial screening of measurement results which may be as much as factor of 2.1 higher than necessary (depending on the actual scatter fraction and Co-60 fraction at the measurement location). If the results are below this limit, it can be concluded with a high degree of confidence that an action level has not been exceeded. However, the factors used in the equation can be modified if it is concluded that they are overlv conservative based on actual measurement conditions.

To minimize the error in ROI settings, a Co-60 check source is used to establish and verify appropriate settings during field measurements. Any error in placement or change in peak location or width due to gain shift or peak area degradation which may occur during acquisition is determined and corrected as a result of spectrum evaluation and optimization of the ROI partial dose equivalent rate.

The error associated with data collection is the same as any in-situ device. However, most applications require the determination of radionuclide concentration in a specific media and then determination of an appropriate conversion from concentration to exposure rate at some distance with correction to account for scatter. Since the MICROSPEC converts raw data (counts per channel) directly to tissue equivalent dose rate, the error associated with the multiple steps required to provide similar results using these other applications is avoided.

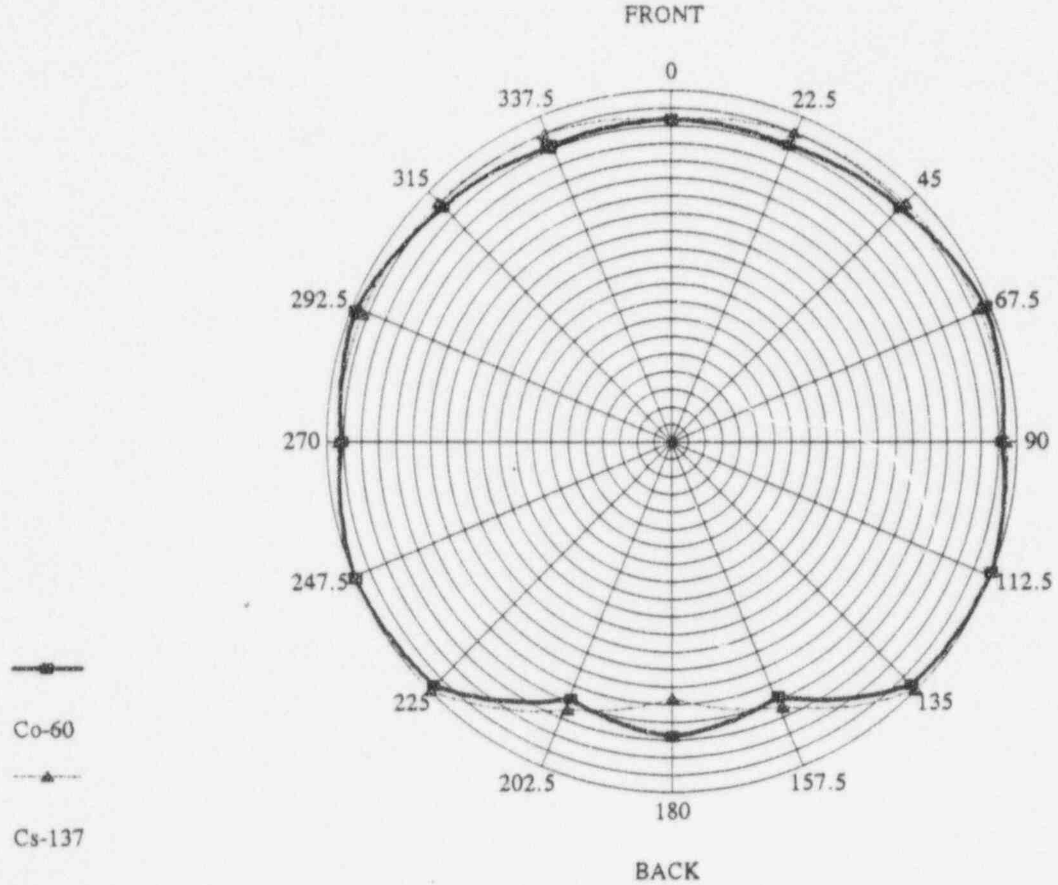
Any difference between the response of the MICROSPEC compared to the PIC can be accounted for by the application of a PIC correction factor. In the survey locations where the MICROSPEC will be used to collect exposure rate measurements (reactor building and other affected survey units), preliminary data from 5 reactor building survey packages,

which included 78 exposure rate measurements collected with the MICROSPEC and the PIC, resulted in an average response of the MICROSPEC which was 10% less than the response of the PIC. As discussed and shown previously, this does not necessarily mean that when determining net exposure rate due to licensed radioactive materials the result will be more accurate when a PIC correction factor is applied. It has been demonstrated that the under response of the MICROSPEC-2™ compared to the PIC only occurs when comparing gross measurements. When determining the exposure rate due to licensed material using the MICROSPEC-2™ and the protocol defined in TBD-202, the initial results are over estimated due to the conservatism in the applied factors and the final results are more accurate when measuring net exposure rate at the decommissioning limit in the presence of high and/or variable background. In fact, the data collected indicates that the inclusion of a PIC correction factor will further bias the result positive, by 10% or greater. Therefore, FSV intends to use the results of the MICROSPEC without correction to relate the result to PIC equivalent.

FIGURE 3

MICROSPEC ANGULAR RESPONSE

Co-60 & Cs-137 at 9"

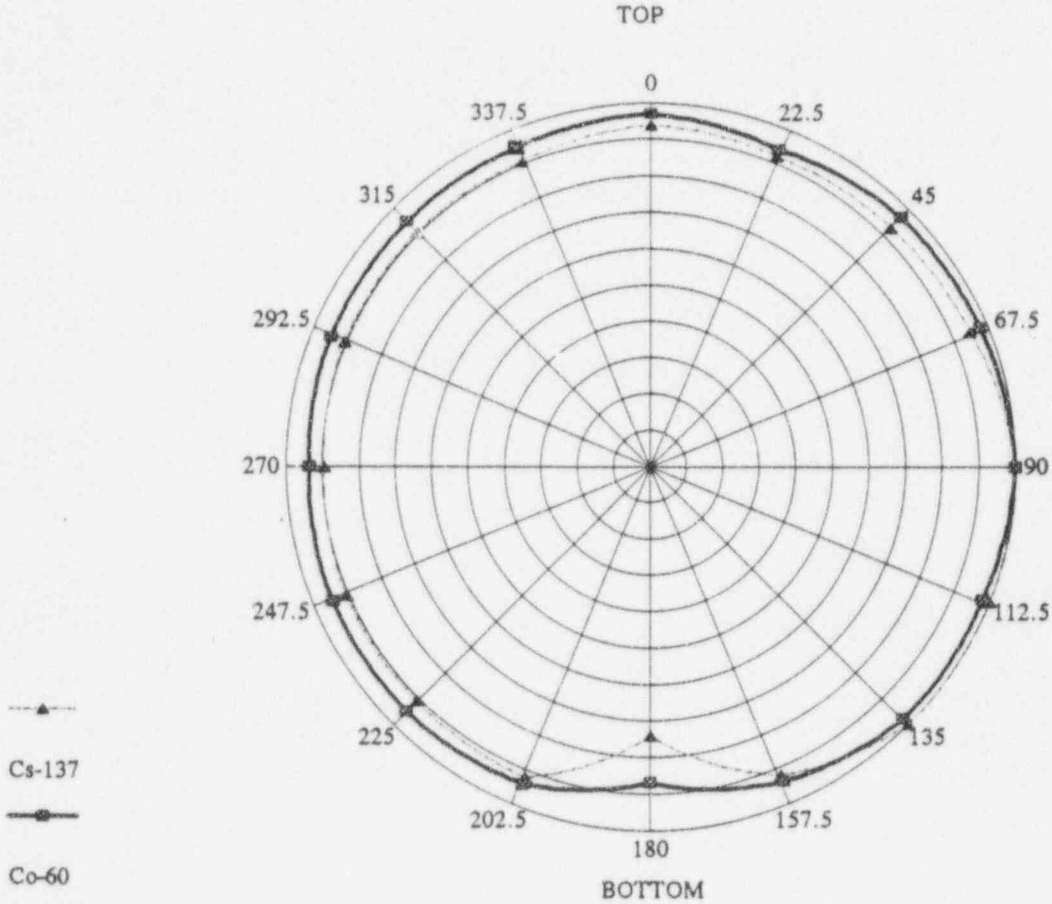


Note: Polar grids are laid out using values of 0.0 to a maximum of 1.0. Plotted values are the ratio of the measurement result at that location to the maximum value obtained for all measurements and are unitless.

FIGURE 4

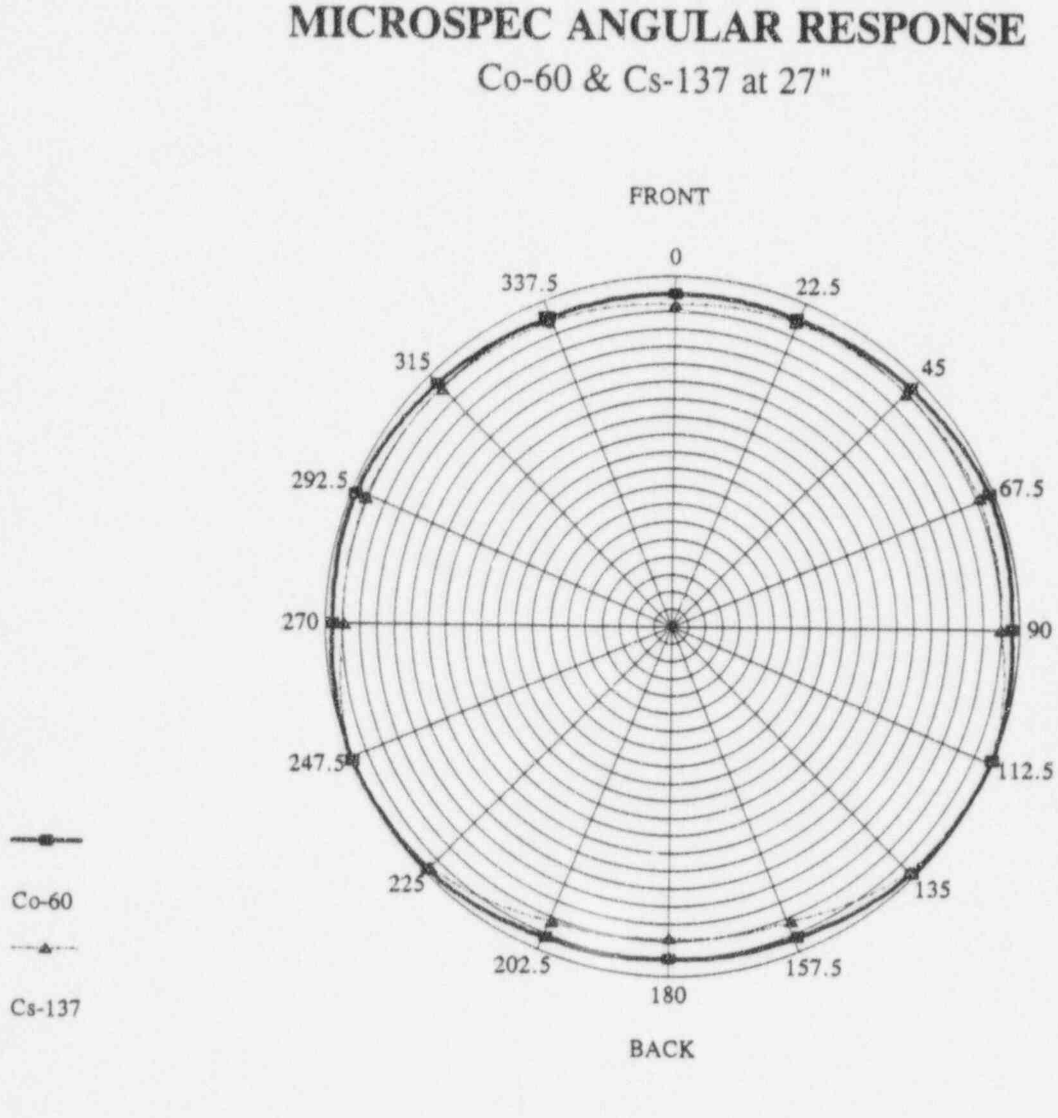
PIC ANGULAR RESPONSE

Co-60 & Cs-137 at 9"



Note: Polar grids are laid out using values of 0.0 to a maximum of 1.0. Plotted values are the ratio of the measurement result at that location to the maximum value obtained for all measurements and are unitless.

FIGURE 5

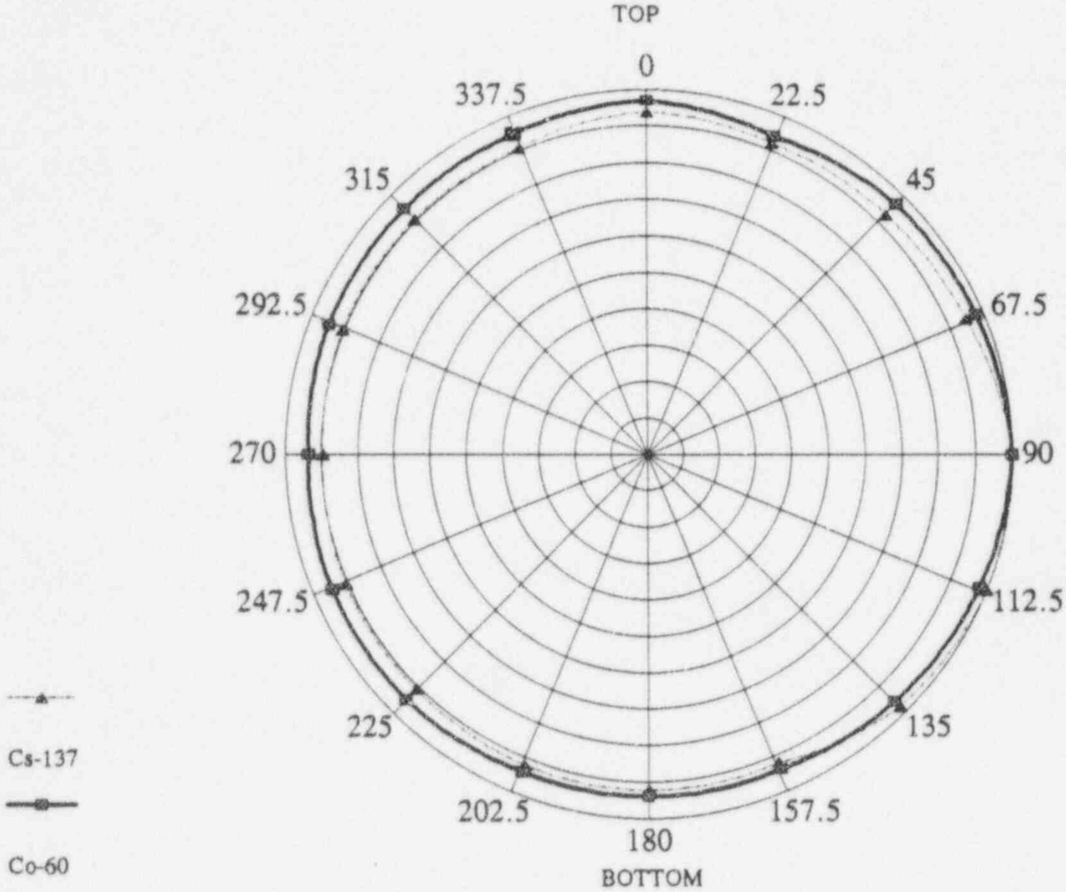


Note: Polar grids are laid out using values of 0.0 to a maximum of 1.0. Plotted values are the ratio of the measurement result at that location to the maximum value obtained for all measurements and are unitless.

FIGURE 6

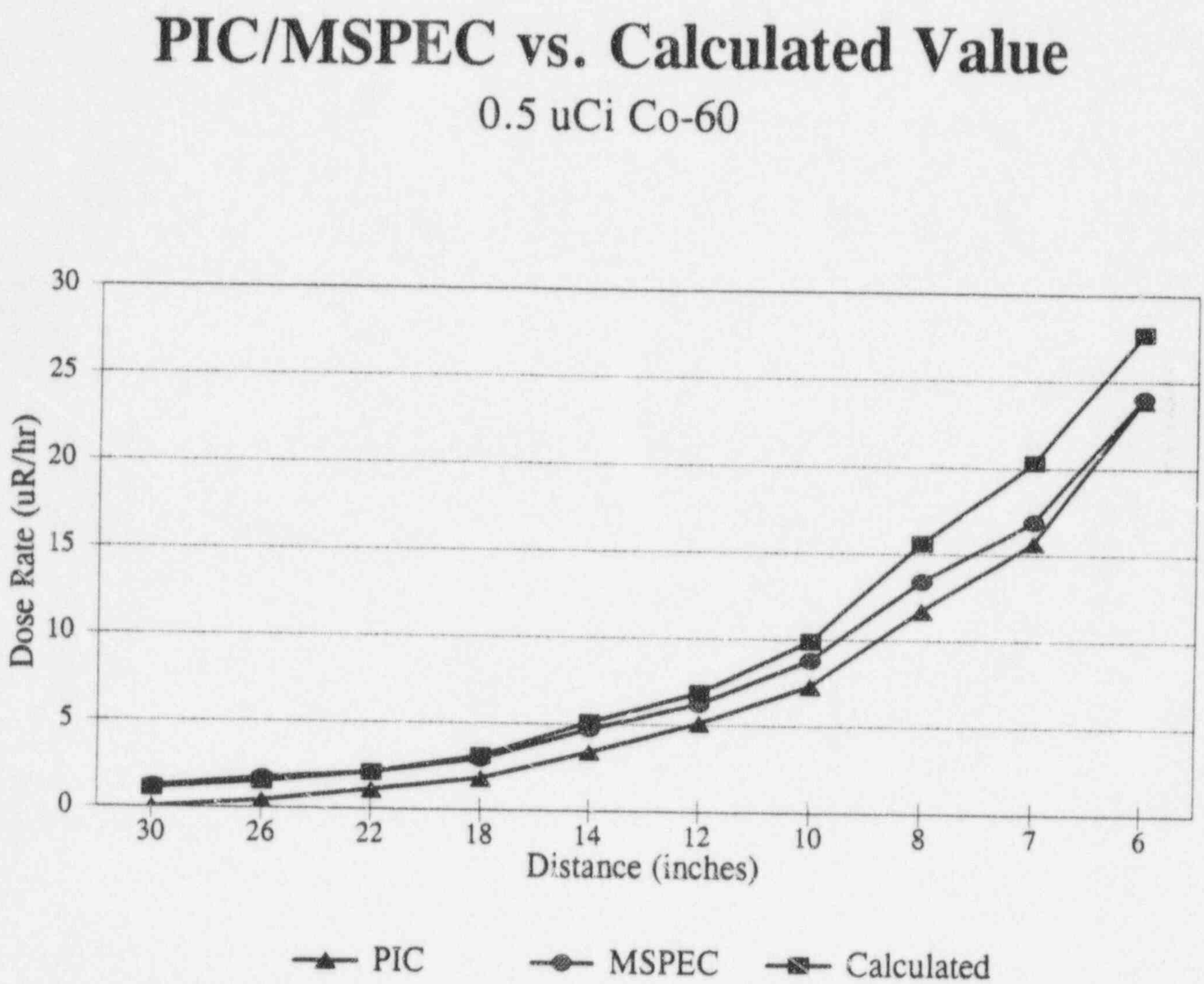
PIC ANGULAR RESPONSE

Co-60 & Cs-137 at 27"



Note: Polar grids are laid out using values of 0.0 to a maximum of 1.0. Plotted values are the ratio of the measurement result at that location to the maximum value obtained for all measurements and are unitless.

FIGURE 7


PIC/MSPEC vs. Calculated Value
0.5 uCi Co-60
30
25
20
15
10
5
0
Dose Rate (uR/hr)
30
26
22
18
14
12
10
8
7
6
Distance (inches)
PIC
MSPEC
Calculated

ATTACHMENT 1
TECHNICAL JUSTIFICATION FOR EXPOSURE RATE MEASUREMENT REQUIREMENTS

This attachment provides justification for the PSCo request to limit exposure rate measurements to accessible floor and lower wall surfaces below 2 meters and not upper walls (above 2 meters) and ceilings.

It is difficult to measure the benefit of performing exposure rate measurements in areas where surfaces and the interiors of piping and equipment have been decontaminated to activity levels below the decommissioning limits, and not influenced by neutron activated material. It is particularly difficult to measure the benefit of performing surveys in overhead areas, where the occupational hazards involved with the survey effort far outweigh the benefit of the results obtained. Although decommissioning limits are provided and used to determine the suitability for license termination, these limits do not define the endpoint in decontamination. Decontamination is designed to remove as much contamination as physically and economically feasible. Typically, these efforts result in average surface activity well below the decommissioning limits. The data presented in this attachment is presented as additional justification for not performing exposure rate measurements where the residual surface activity present on surfaces and in piping and equipment is well below that which could produce exposure rates equivalent to the limit of 5 μR/hr averaged over 10 m^2 for indoor areas.

The evaluation starts with a simple scenario assuming that the exposure rate at 1 meter from the floor is due to floor surface activity alone. The scenario is then modified to include various diameter pipes with internal contamination under 3" and 1" of concrete, and then completely exposed in the area of surface contamination. A second scenario is then evaluated to determine the exposure rate at two meters from the surface. This uses the worst case data from the first scenario and adds in a single pipe in the overhead with a one meter exposure rate point at the same location as the exposure rate point from the floor surface, two meters. Following the first step in evaluating Scenario 1 (using the radionuclide mix from TBD-201), all additional evaluations are performed assuming that the only contaminant on the floor surface and inside the pipes is Co-60. In all calculations, the location where the exposure rate is determined was the center of the disk or midpoint of pipes (which also corresponded to the center of the disk). This results in the highest exposure rate for each source.

To demonstrate the potential exposure rate at a distance of one meter above a floor surface it is first necessary to define an appropriate source term. For this evaluation, the source term was first determined using the radionuclide mix presented in TBD-201, excluding all but gamma emitting radionuclides. The fractions for this mix were determined from sample activity which has been decayed to 1/1/96. These fractions were then used to determine surface activity based on the decommissioning limits for each radionuclide. Contrary to the goals of decontamination stated above, these evaluations assume that the activity is uniformly distributed on the surface at the decommissioning limit, unless otherwise noted. This provides a conservative estimate of the

exposure rate from all sources. The floor surface was assumed to be a disk and calculations performed for areas of 10 m^2, 100 m^2 and 1000 m^2. Table 1 presents the results of these calculations for five samples and the average of all individual results in units of μR/hr. Exposure rate calculations in this attachment were performed using Microshield Version 4.0.

Table 1
Exposure Rate Using TBD-201 Data
(μR/hr)

Surface Area (m^2)	PCRV[1] Smear	PCRV Shield Plug	PCRV Access Flange	FHM[2] Smear	HSF[3] Smear	Average
10	0.86	0.77	0.94	0.88	0.95	0.88
100	2.09	1.87	2.29	2.14	2.32	2.14
1000	3.44	3.07	3.76	3.52	3.81	3.52

1 Prestressed Concrete Reactor Vessel
2 Fuel Handling Machine
3 Hot Service Facility

The exposure rate due to floor surface activity at a distance of 1 meter was then determined assuming the only gamma emitting contaminant was Co-60. Again, the activity was assumed to be distributed uniformly over the surface area at the decommissioning limits (4000 dpm/100 cm^2). Table 2 provides the results of these calculations using the same surface areas as above.

Table 2
Exposure Rate Using Co-60
(μR/hr)

Surface Area (m^2)	Exposure Rate At 1 Meter Due To Co-60 Only; Uniform Contamination At 4000 dpm/100cm^2
10	1.04
100	2.53
1000	4.15

Next, the effect on the exposure rate at one meter from the floor surface due to pipes under 3" and 1" of concrete, and completely exposed was then evaluated. The pipe wall thickness for all pipe exposure rate calculations was assumed to be 1/8 inch. Again, the contamination was assumed to be Co-60 uniformly distributed throughout the pipe. This and the remainder of the evaluation only considered a floor surface area of 100 m^2 or 1076.4 ft^2 (32.8' x 32.8'). Although NUREG/CR-5849 recommends averaging over 10 m^2 or 107.5 ft^2 (the size of a small office 10.4' x 10.4') for indoor measurement areas, this in not a realistic surface area for representing survey

areas within the facility not used for offices, i.e., reactor building, radioactive material storage locations, etc. A very large surface area of 1000 m^2 or 10,751 ft^2 (103.7' x 103.7') is also not realistic for these measurement locations.

PSCo submittal P-95077 discusses the proposed treatment of embedded pipes, which are defined as 3" diameter or less pipes typically encased in concrete with a maximum length of 70'. As stated in this submittal, the contamination levels inside these pipes are 50,000 dpm/100 cm^2 or less. Table 3 presents the results of calculations of the exposure rate at 1 meter from the floor surface for 3" and 1" pipes uniformly contaminated with Co-60 at 50,000 dpm/100cm^2. First the exposure rate due to the pipe only is presented, then the total exposure rate due to the pipe plus surface activity. The surface activity used to calculate the total was that due to Co-60 for an area of 100 m^2 (2.53 μR/hr). The pipes are assumed to be present under concrete with a length equal to the diameter of the disk.

Table 3
Exposure Rate From Embedded Pipe
50,000 dpm/100 cm^2 Internal Contamination
(μR/hr)

Pipe Diameter (inches)	Exp. Rate at 1 Meter 3" concrete	Total Exp. Rate at 1 m (Pipe + Surface)	Exp. Rate at 1 Meter 1" concrete	Total Exp. Rate at 1 m (Pipe + Surface)
3	0.74	3.27	1.25	3.78
1	0.27	2.80	0.61	3.14

Table 4 presents the exposure rate at 1 meter due to a pipe at the surface of concrete, then the total exposure rate due to the pipe plus surface activity. The surface activity used to calculate the total was that due to Co-60 for an area of 100 m^2 (2.53 μR/hr). In this case, the pipes are not considered embedded and the internal surface contamination limit would be 4000 dpm/100 cm^2. Pipe diameters evaluated include 6", 3" and 1". Again, the contamination is assumed to be due to Co-60 uniformly distributed at the limit.

Table 4
Exposure Rate From Exposed, Non-Embedded Pipe at Concrete Surface
4000 dpm/100cm^2 Uniform Internal Contamination
(μR/hr)

Pipe Diameter (inches)	Exposure Rate At 1 Meter, Exposed Pipe at Concrete Surface	Total Exposure Rate (Pipe + Surface)
6	0.25	2.78
3	0.13	2.66
1	0.05	2.58

Table 5 presents the maximum exposure rate at 1 meter from the floor surface assuming that a pipe is embedded in concrete and an additional pipe is present at the floor surface. The values used are those which produced the highest exposure rates in Tables 2, 3 and 4.

Table 5
Exposure Rate at 1 Meter From Combined Sources
(μR/hr)

Surface Activity Exposure Rate (Co-60)	Embedded 3" Pipe Exp. Rate Under 1" Concrete	Exposed 6" Pipe At Concrete Surface	Total Exp. Rate at 1 m (Pipes + Surface)
2.53	1.25	0.25	4.03

Next, the exposure rate at or above two meters from the floor surface was evaluated using the data which provided the results in Table 5 (surface activity, embedded pipe activity and exposed pipe activity). A distance of 2 meters was chosen as worst case (resulting in the highest exposure rate) for evaluating potential exposure rate in the overhead. In addition to the results from Table 5 data, an additional 6" pipe is added in the overhead with a 1 meter exposure rate distance equal to the two meter floor measurement distance (the exposure rate from all sources is at a distance of 2 meters from the floor). Again, the pipe in the overhead is assumed to be uniformly contaminated with Co-60 at the limit (4000 dpm/100 cm^2). Table 6 presents the results of these calculations.

Table 6
Exposure Rate at 2 Meter From Combined Sources
(μR/hr)

Surface Activity Exposure Rate (Co-60)	Embedded 3" Pipe Exp. Rate Under 1" Concrete	Exposed 6" Pipe At Concrete Surface	Exposed 6" Pipe In The Overhead	Total Exp. Rate at 2 m (Pipes + Surface)
1.58	0.61	0.11	0.21	2.51

From the data presented in Table 6, the overhead could contain as many as twelve 6" pipes with internal contamination at the decommissioning limits and the combined exposure rate from all sources would still be less than 5 μR/hr.

ADDITIONAL INFORMATION

The following tables present the maximum internal contamination which could be present in an embedded pipe under 3" and 1" of concrete, and a pipe found at the surface of the concrete floor. The calculation is based on ensuring that the total exposure rate at 1 meter from the floor surface is less than 5 μR/hr. Surface activity is used in determining the total exposure rate is 2.53 μR/hr, provided in Table 2 for an area of 100 m^2. All activity is assumed to be Co-60. The length of pipe is assumed to be equal to the diameter of the 100 m^2 disk.

Table 7
Embedded Pipe Below 3 Inches of Concrete

Pipe Diameter (inches)	Maximum Co-60 Contamination (dpm/100cm2)	Pipe Exposure Rate (μR/hr)	Total Exp. Rate at 1 m (Pipe + Surface)
3	166,500	2.46	4.99
1	450,000	2.46	4.99

Table 8
Embedded Pipe Below 1 Inch of Concrete

Pipe Diameter (inches)	Maximum Co-60 Contamination (dpm/100cm2)	Pipe Exposure Rate (μR/hr)	Total Exp. Rate at 1 m (Pipe + Surface)
3	98,000	2.46	4.99
1	271,000	2.46	4.99

Table 9
Exposed Pipe At the Surface of Concrete

Pipe Diameter (inches)	Maximum Co-60 Contamination (dpm/100cm2)	Pipe Exposure Rate (μR/hr)	Total Exp. Rate at 1 m (Pipe + Surface)
6	39,800	2.46	4.99
3	75,500	2.46	4.99
1	215,500	2.46	4.99

SUMMARY

As demonstrated in the above tables, the most conservative assumptions result in a total exposure rate at 1 meter and 2 meters or higher (overhead) which does not exceed 5 μR/hr. These conservative assumptions are extremely unrealistic. Only under extreme and rare circumstances would residual uniform contamination on any surface following decontamination approach the decommissioning limits. In fact, in most cases the contamination would be less than 50% of the limit, which would not be distributed uniformly, but present at discrete locations. Therefore, in reality the total exposure rate following decontamination would be a fraction of that presented in the tables.