Kerr-McGee

TECHNICAL CENTER
DECOMMISSIONING PROJECT

Request for Additional Information(RAI) on the

INDOOR FINAL STATUS SURVEY REPORT

(SUBMITTED ON APRIL 14, 2004)

December 2004

KERR-MCGEE

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December 3, 2004

VIA OVERNIGHT MAIL

Ms Rachel Browder
Fuel Cycle Decommissioning Branch
United States Nuclear Regulatory Commission
Region IV
611 Ryan Plaza Drive, Suite 400
Arlington, TX 76011-8064

DEC - 6 2004

Dear Ms. Browder:

On September 28, 2004, Kerr-McGee received a Request for Additional Information (RAI) on the Indoor Final Status Survey Repot submitted for the Technical Center on April 15, 2004. The RAI focused mainly on the issue of embedded piping and the scenario developed to account for exposures related to removal of that material. On October 21, 2004, a conference call was held between Kerr-McGee, NRC Region IV and NRC staff in Washington, DC to further discuss the RAI and what would be expected in a response.

Attached are three copies each of the following documents that address the RAI and issues raised in the conference call.

- Line by Line responses to the September 28, 2004 RAI
  - This contains response to each of the questions posed in the RAI.
- Technical Memorandum 04-26 *Benchmarking of the MCNP Calculated Models as Applied to the 3"x1/2" NaI(Tl) Detector.*
  - This document validates the ability of the MCNP model to predict the sensitivity of a 3"x1/2" NaI detector for any given exposure rate.
- Technical Memorandum 04-28 *Examination of Variability Between NaI Probe and Count Rate Meter Combinations.*
  - This document shows that the variation between all available detectors is less than 20%, which conforms to the guidance for allowable instrument variations contained in the American National Standards Institute N323A-1977, section 4.2.2 on surface contamination measurement instruments.
- Technical Memorandum 04-29 *Derivation of Embedded Piping DCGLs for Renovation and Occupational Exposure Scenarios at KMTC.*

- This document demonstrates that the exposure scenario submitted in the Indoor Final Status Survey report is more protective than the Occupational and Renovation scenarios developed at the request of NRC staff made during the October conference call.

We believe this submittal addresses all of the questions and concerns raised by the agency. We propose that we get together on a conference call in mid- December to discuss any questions you or the Washington staff may have. In the meantime, if you have any questions, please feel free to call.

Sincerely,

Russell H. Jones
Project Manager

Attachments

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Response to NRC RAI

These responses are to the NRC Request for Additional Information (RAI)[1]. The responses to the seven individual questions are as follows:

Question 1 Although use of the MCNP code can accurately model the photon interaction rate in the NaI detector, the simulation cannot accurately predict the output of the detection system resulting from this interaction rate. The simulation therefore appears to have assumed a specific relationship between the interaction rate in the crystal and the count rate of the system. The staff finds such an assumption as insufficiently reliable, and therefore the results from this simulation is lacking an adequate technical basis for the intended purpose. Further work, or an alternative approach, to establish an acceptable relationship between contamination levels in the pipe and the detector count rate is therefore required.

Response NEXTEP benchmarked the MCNP code to the measured results of a NaI 3" x 0.5" detector. NEXTEP Technical Memorandum (TM) 04-26[2] validates the ability of the MCNP model to predict the sensitivity of a 3"x ½" NaI for any given exposure rate[3]. Further, TM 04-28[4] documents that the variation between the available[5] detectors is less than 20% based upon the guidance for allowable instrument variation contained in the American National Standards Institute (ANSI) N323A-1997[6]. Any 3" x ½" NaI probe and Ludlum count rate meter combination may therefore be utilized for surveys without preference to a particular instrument.

Question 2 The Microshield runs and output data provided in Attachment C (C-1 through C-17, pages 214-247) indicate a source dimension of 65.0 cm. This source is assumed to be the length of the pipe. However, on page 251, for calculation of the exposure using a pipe source, an individual is assumed to be exposed to a 20 m length of contaminated pipe. Please explain or reconcile.

Response TM 04-02[7] used a detector on contact with the piping in order to estimate the MDC as well as estimate the counts from the proposed DCGLs (i.e. contamination

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[1] U.S. NRC, Letter to R.H. Jones: Request for Additional Information. Sept. 28, 2004.
[2] NEXTEP Tech Memo 04-26, Benchmarking of the MCNP Calculational Models as Applied to the 3" x ½" NaI(Tl) Detector. H.J. Newman, CHP.
[3] The term exposure rate is used to convey all information related to energy fluence.
[4] NEXTEP Tech Memo 04-28, Examination of Variability Between NaI Probe and Count Rate Meter Combinations. A.H. Thatcher, CHP.
[5] All detector configurations in current calibration for the Cushing, Cimarron, and Tech Center sites.
[6] ANSI. American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments. N323A-1997. 1997.
[7] NEXTEP Tech Memo 04-02. Use of the 3" x ½" NaI Detector for Measurement of Contamination Inside Pipes for KMTC. N. Zhang.

on the inside of the piping). In an on-contact setting, a pipe length of 65 cm resulted in greater than 90% of the infinite count rate and is therefore appropriate. In the derivation of the DCGL performed in TM 04-03[8] however, the exposure to a hypothetical individual at a distance of 1 meter from the pipe is assumed. The modeling for this exposure used a pipe length of 20 meters in order to insure an infinite pipe. Both geometries are appropriate for the conditions used.

Question 3 The Microshield runs and output data provided in Attachment C (C-1 through C-17, pages 214-247) indicate results of the total exposure rates for different piping configurations and for different radionuclides and mixtures. These exposure rates were reported in the range of 1 E–03 to 4.5 E-01 mR/hr. The report did not provide a direct conversion of these exposure rates to dose using a realistic exposure time of an average member of the critical group. It is unclear how these derived exposure rates were used in the dose calculations or in deriving the DCGLs. Please explain.

Response The Microshield code was used in TM 04-02 to provide a photon flux resulting from a contaminant concentration at the DCGL (provided in TM 04-03) for the on-contact configuration in order to predict the NaI count rate using the MCNP code. TM 04-02 did not serve as the basis for the exposure modeling. TM 04-03 serves as the basis for the exposure modeling and the results from TM 04-03 should be used for exposure rate extrapolation.

Question 4 The source input values of Microshield runs in Attachment C (C-1 through C-17, pages 214-247) were provided as total radioactive source inventory (e.g. curies) and surface concentration μCi/cm². Please provide information on assumptions or data for deriving radionuclide source inventory and surface area contamination.

Response For TM 04-02, a background concentration was assumed that matched well with on-site measurements. The concentrations used for predicted counts in TM 04-02 were based upon the predicted DCGLs derived in TM 04-03. For TM 04-03, the modeling assumed a unit concentration of activity in order derive the DCGL based upon an allowable exposure limit (25 mrem/y). No assumptions were made as to the total source activity. The Microshield code does provide the total source activity as part of its output but this value has no bearing on the analysis or scenarios used.

Question 5 For the building renovation scenario, the external exposure to contaminated material was assumed to be 50 hours. Please provide the rationale for selecting this occupancy time, taking into consideration the much longer occupancy period for the building occupancy scenario.

Response A number of scenarios are available when modeling exposures for an industrial setting. A traditional occupational scenario[9] assumes a 2000 hr/yr exposure rate.

[8] NEXTEP Tech Memo 04-03. Derivation of Embedded Piping DCGLs for KMTC. A.H. Thatcher, CHP.

[9] NUREG 5512, Table 6.21.

A building renovation scenario[10] assumes a 500 hr (one time) exposure. The exposure time of 50 hours used in TM 04-03 is not an "occupancy time" in the traditional sense of an occupancy scenario. The 50 hours represents the estimated time any single individual might be exposed to the embedded piping in relatively close proximity. The 50 hours represents 1/10 of the renovation scenario in NUREG 5512 as TM 04-03 assumes that the entire building is not undergoing renovation, only the piping. Were the entire building included in the renovation scenario (i.e. 500 hours of exposure), the exposure distances would have to be significantly greater to account for that portion of the time that an individual spent away from the potentially contaminated piping which occupies a small area of the building. Similarly, for a traditional occupational exposure scenario, a very small fraction of the time would be spent in chaseways or spaces in proximity to the potentially contaminated piping. For context, TM 04-29[11] was developed to further explore the potential dose to a 500 hour renovation scenario and a 2,000 hour occupational scenario.

Question 6 For calculation of the inhalation exposure, the KMTC assumed that the inhalation of radioactive contamination only occurs during 20 mechanical disturbances, where each disturbance lasts only for 3 seconds. In a typical building occupancy scenario, it is assumed that the inhalation time is the same as the indoor or outdoor exposure time corresponding to the indoor/outdoor occupancy time. In other words, it is assumed that mechanical disturbances of the source occur during individual occupancy. Please provide further explanation for using a total of one minute per year for the total mechanical disturbance time of the source.

Response Similar to the discussion in the response to Question 5, significant differences exist in the assumptions used for a traditional occupational exposure scenario and that of the renovation scenario in TM 04-03. For a building occupancy scenario as applied to KMTC embedded piping, no inhalation exposure would exist when the only source of exposure would be the internal contents of enclosed and undisturbed piping. A traditional building occupancy scenario is generally designed to analyze the potential impact of contaminated building surfaces and is therefore fundamentally different from the exposure analysis to embedded piping. In TM 04-03, the renovation scenario assumed that all of the material was stockpiled and crushed such that all of the potential contamination were available. It is then assumed that 20 resuspension events occurred with the three second exposure time based upon the wind speed for the resuspended plume. This total one minute of inhalation exposure sounds like a short period of time but the small air volume used in the calculation and the total activity made available actually work to make this a conservative scenario. In contrast to the analysis in TM 04-03, for a total building renovation scenario (such as developed in TM 04-29), the potential airborne exposure is limited by a smaller area of contamination available and a significantly larger dilution volume.

[10] NUREG 5512, Table 6.20.

[11] NEXTEP Tech Memo 04-29. Derivation of Embedded Piping DCGLs for Renovation and Occupational Exposure Scenarios at KMTC. A. H. Thatcher, CHP.

Question 7 The reference, ICRP 1995, provided for the DCFs on pages 260 and 262 should include the ICRP series number or a complete reference.

Response ICRP, *Age-Dependent Doses to Members of the Public From Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients*, ICRP Publication 72, Oxford, Pergamon Press, 1995.

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TECHNICAL MEMORANDUM 04-26

December 1, 2004

Originator: Harry J. Newman, CHP

Subject: *Benchmarking of MCNP Calculational Models and Methods as Applied to the 3" x ½" NaI(Tl) Detector*

Revision: *0*

ENDORSEMENT: This document contains the results of research and technical analysis which have been reviewed and approved for publication by the Technical Director, NEXTEP Environmental, Inc.

H J Newman — 12/2/2004

Harry J. Newman, CHP, Technical Director — Date

1. INTRODUCTION

1.1 Predictive models are used in certain environmental applications when the direct measurement results are not feasible or practical. Application examples include the predicted counts which will be recorded by a measurement system from contaminated material such as concrete, large area buried or surface contamination, and external measurements of internally contaminated piping.

1.2 This Technical Memorandum (TM) benchmarks a model developed by Nextep using the Monte Carlo N Particle (MCNP) code[1] to both measured and calculated results of a 3" x ½" NaI detector.

1.3 The benchmarking in this TM involves four parts as delineated in the Scope & Methods section. Each part is introduced and summarized, and the results associated with each method are reported.

1.4 Finally, a recommendation regarding the applicability of the MCNP model used by NEXTEP for problem evaluation is presented.

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[1] The model developed by NEXTEP using the MCNP code is hereafter referred to as the "MCNP Model"

2. SCOPE & METHODS

2.1 The benchmarking performed in this investigation validates the ability of the MCNP model to predict the sensitivity of a 3"x ½" NaI detector for a given input energy and photon flux. The detector model used for the benchmark comparisons is described in detail in Nextep Technical Memorandum (TM) 03-14.[2]

2.2 The benchmarking is performed in a series of four stages:

2.2.1 In Part I, the sensitivity of a 3" x ½" NaI detector to gamma emissions from a mono-energetic point source (Cs-137) positioned 15 cm from the face of the detector in the unshielded configuration is calculated by two methods and compared with the MCNP model.

2.2.2 In Part II, Laboratory test results for a shielded 3"x ½" NaI detector positioned 30 cm above a poly-energetic point source (0.377 μCi Ra-226) are compared with the MCNP model configured for the same source, detector, and geometry.

2.2.3 In Part III, the sensitivity of the 3"x ½" NaI detector to gamma emissions from a poly-energetic point source (3.54% enriched U) positioned 15 cm from the face of the detector is calculated based on a predicted photon flux[3] and a tabulated energy-based absolute sensitivity.[4]

2.2.4 In Part IV, the calculated efficiency (cpm/μR/hr) from Part III is compared to an MCNP modeled efficiency (cpm/μR/hr) initially developed in TM 03-24[5].

3. RESULTS AND DISCUSSION

3.1 PART I - 3"X1/2" NAI DETECTOR SENSITIVITY IN CPM/(μR/H) FOR CS-137

3.1.1 Method 1 - Calculation from Basic Principles

3.1.1.1 Method 1 is a manual calculation of the expected count rate from a 3" x ½" detector given a 1 μR/hr exposure rate (Cs-137 in a narrow beam geometry).

3.1.1.2 The expected count rate from a 3"x ½" NaI detector is calculated from first principles as follows.

3.1.1.2.1 The count rate can be calculated using Equation 1:

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2 NEXTEP TM 03-14, *NaI Scan Survey of Concrete Rubble in Sector 8 of the Kerr-McGee Cushing Facility,* N. Zhang.

3 Obtained using Microshield software: Grove Engineering, Microshield, Version 5.03, Rockville, MD. 1998.

4 C. C. Grosjean, W. Bossaert, Table of Absolute Detection Efficiencies of Cylindrical Scintillation Gamma-ray Detectors

5 NEXTEP TM 03-24, *NaI Scan Survey of Concrete Rubble Containing SNM in Section 10 of the Kerr-McGee Cushing Site,* N. Zhang.

Equation 1

$$Count\ Rate\,(cpm) = \varphi \times A \times 60\left[1 - e^{-\mu_{NaI}\,x}\right]$$

Where:

φ = *Gamma fluence (photons/cm^2*s)*
A = *Detector area (45.6 cm^2)*
μ_{NaI} = *linear attenuation coefficient for NaI (0.3/cm)*[6]
x = *thickness of detector (1.27 cm)*

3.1.1.2.2 The photon fluence is calculated by Equation 2:

Equation 2

$$\varphi = \frac{D}{\frac{\mu_m}{\rho} * E}$$

Where:

D = *dose rate in air (µR/hr)*
E = *photon energy (MeV)*
$\frac{u_m}{p}$ =*mass energy absorption coefficient (cm^2/g), see 3.1.1.3 below*

3.1.1.3 A standard plot of energy vs. mass energy absorption[7] is presented in Figure 1. The mass energy absorption coefficient for air was determined by interpolation of values using a 6th order polynomial curve fit equation presented in Equation 3. Equation 3 is an empirical fit[8] and is valid only over the region shown in Figure 1. It has descriptive value only.

Equation 3

$$y = -0.0048x^6 + 0.037x^5 - 0.1151x^4 + 0.1866x^3 - 0.1671x^2 + 0.0741x + 0.0172x$$

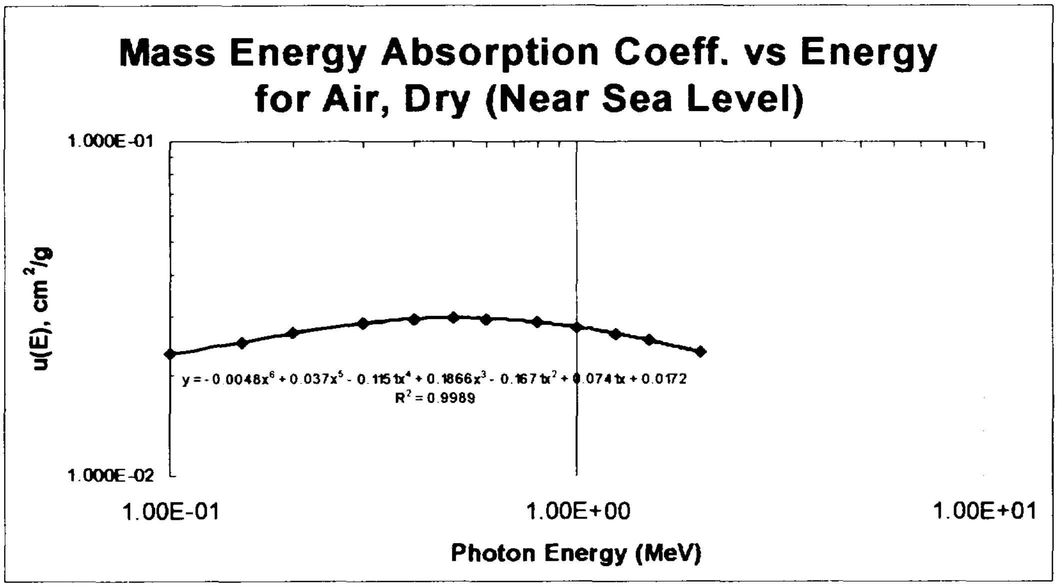
where:

y = *the mass energy absorption coefficient in cm^2/g*
x = *the energy of the gamma in MeV.*

6 St. Gobain Crystals, "*Efficiency Calculations for Selected Scintillators*", p. 4., available at http:// www.detectors.saint-gobain.com/media/documents/S0000000000000000003/SG%20efficiency%20Calulations%20804.pdf

7 Values plotted in Figure 1 were obtained from: http://physics.nist.gov/PhysRefData/XrayMassCoef/ComTab/air.html

8 Correlation coefficient $R^2 = 0.9989$



Mass Energy Absorption Coeff. Vs. Energy for Air, Dry
(Near Sea Level)
Figure 1

3.1.1.4 For the 0.6617 MeV gamma of Cs-137, the interpolated mass energy absorption coefficient is 0.0294 cm^2/g. Using 1μR/h as the exposure rate in air in Equation 2, the photon fluence was calculated as 0.894 photons/cm^2-sec @ 1μR/h. By substituting this photon fluence into Equation (1), the resulting count rate[9] was **774 cpm/(μR/h)** for Cs-137.

3.1.1.5 Manual calculations using Method 1 were also performed and compared to the manufacturer's reference values[10] for several NaI detector sizes (see Table 1). The results, plotted for reference in Figure 2, are within about 17% of the manufacturer's stated values. Given the small percentage difference for these detector configurations, the calculated value for the 3" x ½" NaI detector is expected to have similar accuracy.

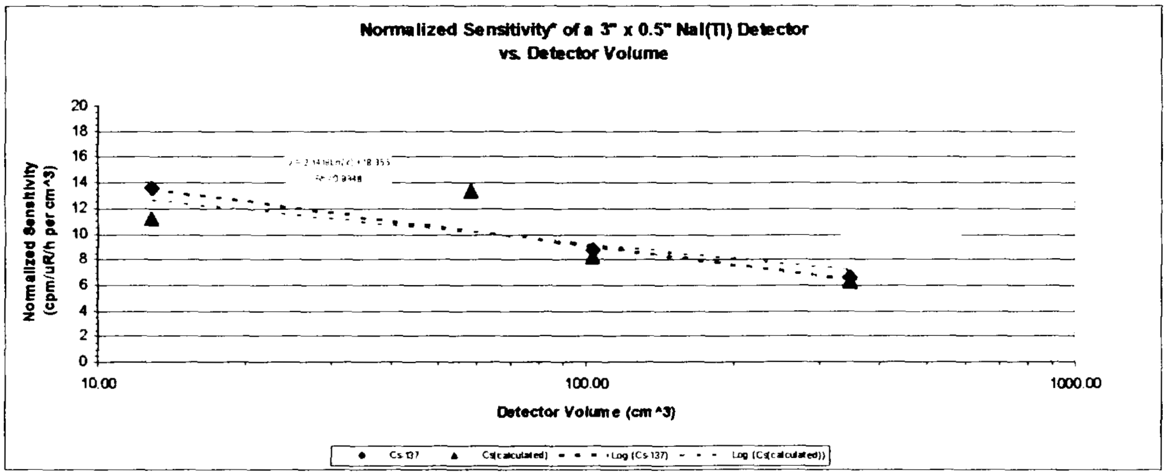
[9] Although termed a counting rate, this result is also correctly identified as a sensitivity (i.e. counts/activity) since a unit exposure rate was assumed.

[10] A manufacturer's reference value is not available for the 3" x ½" detector. The values are those reported by Ludlum Measurements for several detector sizes

Table 1

Manual Calculations and Manufacturer Reference Values of 3" x ½" NaI Detector Efficiency

	Diameter	Height	Volume			cpm/uR/h	cpm/uR/h	(Manuf.) normalized	(Calculated) normalized	
Nuclide	cm	cm	cm^3	Area (cm^2)	cps	(from manuf.)	(calculated)	cpm/uR/h per cm^3	cpm/uR/h per cm^3	%diff
Cs-137	7.62	7.62	347.3	45.580554	3.66E+01	2300	2.20E+03	6.6	6.3	-4.5
Cs-137	7.62	1.27	57.9	45.580554	1.29E+01	Not Avail	7.74E+02	Not Avail	13.4	N/A
Cs-137	5.08	5.08	102.9	20.258024	1.42E+01	900	8.50E+02	8.7	8.3	-5.6
Cs-137	2.54	2.54	12.9	5.064506	2.41E+00	175	1.45E+02	13.6	11.3	-17.2



*The sensitivity has been normalized based on detector volume from that reported by Ludlum Measurements, Inc. Their statement was given in terms of the cpm as a function of μR/h. The data point at 58 cm^3 represents the 3" x ½" detector.

Correlation of Calculated NaI Detector Sensitivity with Manufacturer's Specs
Figure 2

3.1.2 Method 2 – Calculation Using Grosjean Sensitivity Tables

3.1.2.1 According to Grosjean[11], the absolute sensitivity of a NaI(Tl) detector with different configurations and different source-detector geometries can be calculated from the average energy of photons impinging on the detector. The simplest case is that of an isotropic point source. Grosjean provides sensitivity tables for different detector configurations and different source-detector distances.

3.1.2.2 Using the same source/geometry combination as in Method 1, the Microshield code was used to generate the total number of gammas which would be emitted from the source. Microshield was also used to calculate the exposure rate at a distance of 15cm from the source. The Microshield output for this configuration is presented in Attachment 1.

[11] C. C. Grosjean, W. Bossaert, Table of Absolute Detection Efficiencies of Cylindrical Scintillation Gamma-ray Detectors

3.1.2.3 The total number of gammas times the absolute sensitivity derived above can then be used to derive the count rate. This count rate divided by the exposure rate will give the sensitivity in units of cpm/(μR/h).

3.1.2.4 The detector sensitivity in cpm/(μR/h) was calculated as follows:

3.1.2.4.1 Total gammas per minute from the point source:

34,040 photons/sec x 60 sec/min = 2,042,400 photons/min

3.1.2.5 The closest table in Grosjean to 0.66 MeV for a 3" x ½" NaI detector is for photons with an energy of 0.594 MeV.[12] The absolute sensitivity is given as:

T(E) = Tp(E) = 4.58764E-03 counts/photon

The count rate in cpm can therefore be calculated as:

2,042,400 photons/min x 4.58764E-03 counts/photon = 9,370 cpm

3.1.2.6 From the Microshield output, the corresponding exposure rate at 15 cm from the point source is 14.51 μR/h. The sensitivity of the 3" x ½" NaI detector in cpm/(μR/h) can be calculated as:

9,370cpm / 14.51 μR/h = ***646 cpm/μR/h for Cs-137***

3.1.2.7 Given that the efficiency of a 0.661 MeV photon would be slightly less than that of the 0.594 MeV photon used in the calculations, the calculated value is expected to be within 20% of 774 cpm/μR/h as calculated using Method 1 above.

3.1.3 Method 3 - MCNP Simulation

3.1.4 The specific gamma-ray constant of Cs-137 is 0.33 ($R*m^2/Ci*h$). So, 3.03 μCi of Cs-137 in the same configuration will generate 1μR/h at the face of the detector. The MCNP model was run to obtain the absolute sensitivity of a 3" x ½" NaI detector for this geometry. The result was 1.045E-04 counts/photon. The detector sensitivity is calculated as follows:

(3.03 μCi x 3.7 E+04 photons/sec/μCi x 60 sec/min x 1.045E-04 counts/photon) / 1 μR/h
= 703 cpm/(μR/h)

3.1.5 The MCNP modeling process provided results that benchmark within 9 percent of either Method 1 or Method 2 for the 3" x ½" NaI detector.

3.2 PART II - 3" X ½" NAI DETECTOR SENSITIVITY IN CPM/(μR/H) FOR RA-226

3.2.1 NEXTEP performed laboratory tests using a NIST-traceable Ra-226 standard and a shielded 3" x ½" NaI detector coupled with a Ludlum 2221 scaler/ratemeter to determine the sensitivity in cpm/μR/h. The results were ***1,148 cpm/(μR/h)*** using the

[12] Grosjean, ibid., Equation (10), page 283.

"window out" mode. The "window out" mode accumulated those counts from pulses larger than 50mV. Each mV corresponds to approximately 1 keV photon energy, so the lower energy cut-off for the "window out" mode was approximately 50 keV. Experimental results are provided in Attachment 2.

3.2.2 The MCNP model was configured with an isotropic, 0.1 µCi, Ra-226 point source 30 cm away from a 3" x ½" NaI detector, in accordance with the geometry used during the laboratory tests. Running the MCNP model, the absolute sensitivity for this geometry was 0.0024 counts/photon using a 15 keV energy cut-off[13].

3.2.3 The Microshield code was used to model the photon flux from an 0.1 µCi Ra-226 point source (30 years decay was assumed). The total activity of this source as calculated by Microshield (see Attachment 3) is 85,080 photons/second (5,104,800 photons/minute).

(5,104,800 photons/min x 0.0024 counts/photon)/10 µR/h = **1,225** ***cpm/(µR/h)***

3.2.4 The MCNP model calculation is within 7% of the measured value of 1,148 cpm/(µR/h) for Ra-226 with a 50 keV energy cut-off.

3.3 PART III - 3" X ½" NAI DETECTOR SENSITIVITY IN CPM/(µR/H) FOR 3.54% ENRICHMENT URANIUM

3.3.1 This section provides a calculation of the sensitivity of the 3" x ½" NaI detector for gamma emissions from enriched uranium (3.54%). The calculation is based upon the referenced efficiency from Grosjean.

3.3.2 According to Table 6 of TM 03-24[14], the activity of U-235 and U-238 will be 0.0318 µCi and 0.135 µCi, respectively for a 1µCi source of 3.54% enriched U. The Microshield output (see Attachment 4) shows that the total activity is 1,940 photons/second (116,400 photons/minute). The exposure rate for this case is 0.211 µR/h. Grosjean[15] can be used to obtain an absolute sensitivity of 0.006819 counts/photon. The sensitivity is calculated as follows:

(116,400 photons/min x 0.006819 counts/photon)/0.211 µR/h = ***3762 cpm/(µR/h)***

3.4 PART IV – BENCHMARK CHECK AND VERIFICATION OF THE MCNP MODEL USING THE SENSITIVITY REPORTED IN PART III.

3.4.1 In TM 03-24, one geometry that was utilized for the MCNP model is the one shown in Figure 3. This geometry and the resulting modeling runs were used to benchmark the MCNP 3" x ½" NaI model.

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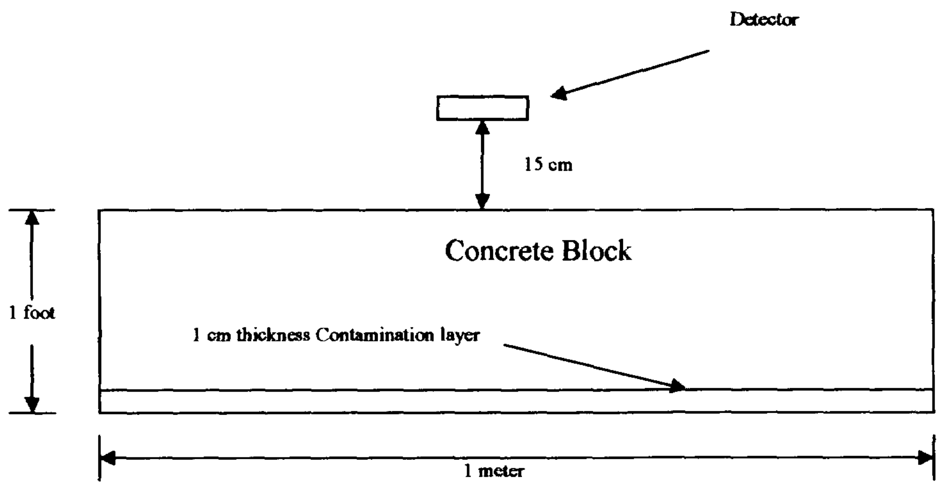
13 Ra-226 and its progeny have no significant photon energies lower than 50 keV so the two energy endpoints are equivalent.
14 NEXTEP TM 03-24, ibid.
15 Grosjean, ibid., p. 283.

3.4.2 The same geometry, materials, and nuclides were also modeled using Microshield (see Attachment 5) in order to obtain the exposure rate as an input for the comparison. The Microshield-calculated exposure rate at the point of interest (detector) was 0.003316 μR/h. By applying the efficiency result from Part III, which was 3,762 cpm/(μR/h), the counting rate for this case will be ***12 cpm***. These results are within 20% of those generated by the MCNP model and reported in Table 8(a) of TM 03-24, which were 15 cpm. The difference between the two results may be explained by the fact that the MCNP model did not have an energy cut-off at 15 keV, while the Microshield model did. Lower energy photons are known to interact with NaI with a higher sensitivity than higher energy photons.

3.4.3 The MCNP model produced results within 25% of the benchmark calculations for 3.54% enriched uranium. The MCNP results were higher in part because the model does not reflect the 15 keV cutoff used in the benchmark calculations.



MCNP Model Geometry from TM 03-24
Figure 3

4. CONCLUSIONS

4.1 The MCNP model for the 3" x ½" NaI detector provided results that benchmark within 9% of calculations from basic principles and calculation from Grossjean sensitivity tables for a Cs-137 point source. (Par. 3.1.5)

4.2 A field test using a NIST-traceable Ra-226 standard demonstrated that the NEXTEP MCNP model for the 3" x ½" detector was capable of determining sensitivity (in terms of cpm/μR/h) within 7% of the known value. (Par. 3.2.4)

4.3 The MCNP model produced results within 25% of the benchmark calculations for 3.54% enriched uranium. The MCNP results were higher in part because the model does not reflect the 15 keV cutoff used in the benchmark calculations. (Par. 3.4.3)

4.4 The MCNP model used by NEXTEP is an acceptable method for estimating the sensitivity and efficiency of the 3" x ½" NaI(Tl) detector when direct measurements are not feasible or practical.

5. RECOMMENDATION

5.1 The MCNP model should be used for estimating the sensitivity and efficiency of the 3" x ½" NaI(Tl) detector in complex situations and when direct measurements are not feasible or practical.

ATTACHMENT 1

MicroShield v5.03 (5.03-00027)
NEXTEP ENVIRONMENTAL INC.

Page 1
DOS File CS137 MS5
Run Date January 22 2004
Run Time 5 06 06 PM
Duration 00 00 00

File Ref ________
Date ________
By ________
Checked ________

Case Title: Case 5
Description: Case 5
Geometry: 1 - Point

Dose Points

	X	Y	Z
# 1	15 cm	0 cm	0 cm
	5 9 in	0 0 in	0 0 in

Shields

Shield Name	Material	Density
Air Gap	Air	0 00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels
Ba-137m	9 4600e-007	3 5002e+004
Cs-137	1 0000e-006	3 7000e+004

Buildup
The material reference is : Air Gap

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0 0318	7 246e+02	8 110e-03	8 165e-03	6 755e-05	6 801e-05
0 0322	1 337e+03	1 514e-02	1 524e-02	1 219e-04	1 227e-04
0 0364	4 865e+02	6 234e-03	6 276e-03	3 542e-05	3 566e-05
0 6616	3 149e+04	7 360e+00	7 369e+00	1 427e-02	1 429e-02
TOTALS	3 404e+04	7 389e+00	7 398e+00	1 449e-02	1 451e-02

ATTACHMENT 2

Laboratory Calibration

Dose rate Calibration of Ludlum 2221 w. 3x0.5 inch NaI probe

Ludlum 2221 Ser. No.		197779		Irving Powell, Terry Keane	
3 x 0.5 inch probe		312319		11/12/04	
Ra Std	SRM 4967				
	2729	Bq/gm			
	5.1167	gm			
	13,963.4743	Bq	13,664.33	Decay corrected value	
	3.77391E-07	Ci	3.69E-07	Decay corrected value	
Measuring Distance	30	cm			
Dose Rate at Distance*	3.27E-06	R/hour			

Window out	cpm	Average	net cpm	cpm/microR/hr
Shielded probe face on	5892	5865	3753	1148
	5919			
	5914			
	5815			
	5708			
	5885			
	5923			
	5861			
	5802			
	5928			
Background	2191	2112		
	2123			
	2054			
	2080			

Note: the dose rate at a distance of 30 cm from the radium source was calculated using the Microshield Code, Version 5.03

ATTACHMENT 3

MicroShield v5.03 (5.03-00027)
NEXTEP ENVIRONMENTAL INC.

Page : 1
DOS File : RA22630B MS5
Run Date : January 23, 2004
Run Time : 10 09 21 AM
Duration : 00 00 00

File Ref ________
Date ________
By ________
Checked ________

Case Title: Case 6
Description: Case 6
Geometry: 1 - Point

Dose Points

	X	Y	Z
# 1	30 cm	0 cm	0 cm
	11 8 in	0 0 in	0 0 in

Shields

Shield Name	Material	Density
Air Gap	Air	0 00122

Source Input
Grouping Method : Standard Indices
Number of Groups : 25
Lower Energy Cutoff : 0.015
Photons < 0.015 : Excluded
Library : Grove

Nuclide	curies	becquerels
Bi-210	6 0189e-007	2 2270e+004
Bi-214	9 8690e-007	3 6515e+004
Pb-210	6 0213e-007	2 2279e+004
Pb-214	9 8690e-007	3 6515e+004
Po-210	5 9522e-007	2 2023e+004
Po-214	9 8669e-007	3 6508e+004
Po-218	9 8709e-007	3 6522e+004
Ra-226	9 8709e-007	3 6522e+004
Rn-222	9 8709e-007	3 6522e+004

Buildup
The material reference is : Air Gap

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0 05	1 306e+03	5 732e-03	5 807e-03	1 527e-05	1 547e-05
0 08	8 418e+03	5 920e-02	5 985e-02	9 368e-05	9 471e-05
0 1	4 957e+01	4 359e-04	4 400e-04	6 668e-07	6 731e-07
0 2	3 933e+03	6 925e-02	6 965e-02	1 222e-04	1 229e-04
0 3	7 535e+03	1 991e-01	2 000e-01	3 777e-04	3 793e-04
0 4	1 397e+04	4 925e-01	4 942e-01	9 596e-04	9 629e-04
0 5	6 523e+02	2 875e-02	2 883e-02	5 643e-05	5 659e-05
0 6	1 761e+04	9 313e-01	9 337e-01	1 818e-03	1 823e-03
0 8	3 451e+03	2 435e-01	2 440e-01	4 631e-04	4 640e-04
1 0	1 143e+04	1 009e+00	1 010e+00	1 859e-03	1 862e-03
1 5	6 952e+03	9 203e-01	9 215e-01	1 548e-03	1 550e-03
2 0	9 772e+03	1 725e+00	1 727e+00	2 668e-03	2 671e-03
TOTALS	8 508e+04	5 684e+00	5 695e+00	9 982e-03	1 000e-02

ATTACHMENT 4

MicroShield v5.03 (5.03-00027)
NEXTEP ENVIRONMENTAL INC.

Page	1
DOS File	RA MS5
Run Date	January 23 2004
Run Time	10 36 25 AM
Duration	00 00 00

File Ref	
Date	
By	
Checked	

Case Title: Case 1
Description: Case 1
Geometry: 1 - Point

Dose Points

	X	Y	Z
# 1	15 cm	0 cm	0 cm
	5 9 in	0 0 in	0 0 in

Shields

Shield Name	Material	Density
Air Gap	Air	0 00122

Source Input
Grouping Method : Standard Indices
Number of Groups : 25
Lower Energy Cutoff : 0.015
Photons < 0.015 : Excluded
Library : Grove

Nuclide	curies	becquerels
Ac-227	7 1793e-012	2 6563e-001
Bi-210	1 2900e-018	4 7729e-008
Bi 211	7 1304e-012	2 6383e-001
Bi 214	6 6194e-018	2 4492e-007
Fr-223	9 9074e-014	3 6657e-003
Pa-231	2 0175e-011	7 4651e-001
Pa-234	2 1600e-010	7 9920e+000
Pa-234m	1 3500e-007	4 9950e+003
Pb-210	1 2933e-018	4 7851e-008
Pb-211	7 1304e-012	2 6383e-001
Pb-214	6 6194e-018	2 4492e-007
Po-210	1 2040e-018	4 4548e-008
Po-211	1 9466e-014	7 2024e-004
Po-214	6 6180e-018	2 4487e-007
Po-215	7 1305e-012	2 6383e-001
Po-218	6 6208e-018	2 4497e-007
Ra-223	7 1305e-012	2 6383e-001
Ra-226	6 6308e-018	2 4534e-007
Rn-219	7 1305e-012	2 6383e-001
Rn-222	6 6208e-018	2 4497e-007
Th-227	7 0501e-012	2 6085e-001
Th-230	1 5404e-015	5 6993e-005
Th-231	3 1800e-008	1 1766e+003
Th-234	1 3500e-007	4 9950e+003
Tl-207	7 1110e-012	2 6311e-001
U-234	1 1445e-011	4 2345e-001
U-235	3 1800e-008	1 1766e+003
U-238	1 3500e 007	4 9950e+003

Buildup
The material reference is : Air Gap

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0 015	2 213e+00	1 142e-05	1 149e-05	9 794e-07	9 856e-07

Page 2
DOS File RA.MS5
Run Date January 23, 2004
Run Time 10:36:25 AM
Duration 00:00:00

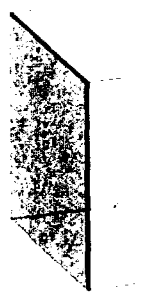
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.02	3.162e-03	2.208e-08	2.222e-08	7.647e-10	7.695e-10
0.03	1.725e+02	1.819e-03	1.831e-03	1.803e-05	1.815e-05
0.04	1.149e-02	1.619e-07	1.630e-07	7.162e-10	7.209e-10
0.05	2.568e-02	4.524e-07	4.554e-07	1.205e-09	1.213e-09
0.06	2.011e+02	4.254e-03	4.280e-03	8.449e-06	8.501e-06
0.08	1.453e+02	4.098e-03	4.120e-03	6.485e-06	6.520e-06
0.1	4.296e+02	1.515e-02	1.523e-02	2.318e-05	2.329e-05
0.15	1.858e+02	9.832e-03	9.870e-03	1.619e-05	1.625e-05
0.2	7.278e+02	5.137e-02	5.151e-02	9.066e-05	9.092e-05
0.3	7.773e-01	8.231e-05	8.249e-05	1.561e-07	1.565e-07
0.4	5.599e-01	7.907e-05	7.921e-05	1.541e-07	1.543e-07
0.5	7.301e-01	1.289e-04	1.291e-04	2.530e-07	2.534e-07
0.6	2.978e+00	6.310e-04	6.318e-04	1.232e-06	1.233e-06
0.8	1.659e+01	4.689e-03	4.694e-03	8.919e-06	8.928e-06
1.0	5.302e+01	1.873e-02	1.875e-02	3.452e-05	3.455e-05
1.5	1.118e+00	5.928e-04	5.932e-04	9.973e-07	9.980e-07
2.0	1.443e-01	1.020e-04	1.020e-04	1.577e-07	1.578e-07
TOTALS	1.940e+03	1.116e-01	1.119e-01	2.104e-04	2.111e-04

ATTACHMENT 5

MicroShield v5.03 (5.03-00027)
NEXTEP ENVIRONMENTAL INC.

Page	1	File Ref	___________
DOS File	CONBT MS5	Date	___________
Run Date	January 15. 2004	By	___________
Run Time	9 35 36 AM	Checked	___________
Duration	00 00 06		

Case Title: Case 1
Description: Case 1
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	1 0 cm	0 4 in
Width	100 0 cm	3 ft 3 4 in
Height	100 0 cm	3 ft 3 4 in

Dose Points

	X	Y	Z
# 1	45 72 cm	50 cm	50 cm
	1 ft 6 0 in	1 ft 7 7 in	1 ft 7 7 in

Shields

Shield Name	Dimension	Material	Density
Source	1 00e+04 cm³	Concrete	2 2
Shield 1	29 5 cm	Concrete	2 2
Air Gap		Air	0 00122

Source Input
Grouping Method : Standard Indices
Number of Groups : 25
Lower Energy Cutoff : 0.015
Photons < 0.015 : Excluded
Library : Grove

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Ac-227	1 5453e-010	5 7176e+000	1 5453e-008	5 7176e-004
Bi-210	7 3034e-012	2 7023e-001	7 3034e-010	2 7023e-005
Bi-211	1 5354e-010	5 6808e+000	1 5354e-008	5 6808e-004
Bi-214	2 8839e-011	1 0671e+000	2 8839e-009	1 0671e-004
Fr-223	2 1325e-012	7 8903e-002	2 1325e-010	7 8903e-006
Pa-231	4 1945e-010	1 5520e+001	4 1945e-008	1 5520e-003
Pa-234	4 3481e-009	1 6088e+002	4 3481e-007	1 6088e-002
Pa-234m	2 7175e-006	1 0055e+005	2 7175e-004	1 0055e+001
Pb-210	7 3166e-012	2 7072e-001	7 3166e-010	2 7072e-005
Pb-211	1 5354e-010	5 6808e+000	1 5354e-008	5 6808e-004
Pb-214	2 8839e-011	1 0671e+000	2 8839e-009	1 0671e-004
Po-210	6 9491e-012	2 5712e-001	6 9491e-010	2 5712e-005
Po-211	4 1915e-013	1 5509e-002	4 1915e-011	1 5509e-006
Po-214	2 8833e-011	1 0668e+000	2 8833e-009	1 0668e-004
Po-215	1 5354e-010	5 6809e+000	1 5354e-008	5 6809e-004
Po-218	2 8845e-011	1 0673e+000	2 8845e-009	1 0673e-004
Ra-223	1 5354e-010	5 6809e+000	1 5354e-008	5 6809e-004
Ra-226	2 8874e-011	1 0683e+000	2 8874e-009	1 0683e-004
Rn-219	1 5354e-010	5 6809e+000	1 5354e-008	5 6809e-004
Rn-222	2 8845e-011	1 0673e+000	2 8845e-009	1 0673e-004
Th-227	1 5178e-010	5 6160e+000	1 5178e-008	5 6160e-004
Th-230	4 4624e-009	1 6511e+002	4 4624e-007	1 6511e-002
Th-231	6 4013e-007	2 3685e+004	6 4013e-005	2 3685e+000
Th-234	2 7175e-006	1 0055e+005	2 7175e-004	1 0055e+001
Tl-207	1 5312e-010	5 6653e+000	1 5312e-008	5 6653e-004
U-234	1 6526e-005	6 1145e+005	1 6526e-003	6 1145e+001
U-235	6 4013e-007	2 3685e+004	6 4013e-005	2 3685e+000
U-238	2 7175e-006	1 0055e+005	2 7175e-004	1 0055e+001

Buildup

Page : 2
DOS File : CONBT.MS5
Run Date : January 15, 2004
Run Time: 9:35:36 AM
Duration : 00:00:06

The material reference is : Shield 1

Integration Parameters

X Direction	10
Y Direction	20
Z Direction	20

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	4.455e+01	8.763e-297	1.497e-31	7.516e-298	1.284e-32
0.02	6.615e-02	1.432e-135	3.600e-34	4.959e-137	1.247e-35
0.03	3.472e+03	5.245e-45	4.386e-29	5.198e-47	4.347e-31
0.04	2.330e-01	5.310e-28	2.500e-27	2.348e-30	1.106e-29
0.05	7.221e+02	7.288e-17	7.069e-16	1.941e-19	1.883e-18
0.06	4.049e+03	1.171e-12	1.926e-11	2.325e-15	3.826e-14
0.08	2.924e+03	6.965e-10	2.071e-08	1.102e-12	3.278e-11
0.1	8.894e+03	3.371e-08	1.424e-06	5.158e-11	2.179e-09
0.15	3.740e+03	2.575e-07	1.309e-05	4.240e-10	2.156e-08
0.2	1.465e+04	4.198e-06	1.969e-04	7.409e-09	3.476e-07
0.3	1.610e+01	2.601e-08	8.770e-07	4.934e-11	1.664e-09
0.4	1.177e+01	5.982e-08	1.475e-06	1.166e-10	2.874e-09
0.5	1.472e+01	1.757e-07	3.317e-06	3.449e-10	6.511e-09
0.6	6.046e+01	1.421e-06	2.141e-05	2.774e-09	4.180e-08
0.8	3.341e+02	2.207e-05	2.355e-04	4.199e-08	4.480e-07
1.0	1.068e+03	1.524e-04	1.253e-03	2.808e-07	2.310e-06
1.5	2.272e+01	1.207e-05	6.453e-05	2.031e-08	1.086e-07
2.0	3.190e+00	3.931e-06	1.630e-05	6.078e-09	2.521e-08
TOTALS	4.003e+04	1.966e-04	1.808e-03	3.604e-07	3.316e-06

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TECHNICAL MEMORANDUM 04-28

December 1, 2004

Originator: A.H. Thatcher, CHP, Senior HP Scientist

Subject: ***Examination of Variability Between NaI Probe and Count Rate Meter Combinations***

Revision: 0

ENDORSEMENT: This document contains the results of research and technical analysis which have been reviewed and approved for publication by the Technical Director, NEXTEP Environmental, Inc.

H. Newman 12/2/2004

Harry J. Newman, CHP, Technical Director Date

1. INTRODUCTION

1.1 This Technical Memorandum (TM) examines the results of eight 3" x ½" NaI probe/count rate meter combinations exposed to a Cs-137 source. The results are compared to determine whether the individual instrument combinations are within 20% of the Conventionally True Value (CTV)[1] as described in ANSI N323A-1997[2].

2. SCOPE

2.1 3" x ½" NaI detectors are used at Kerr-McGee facilities in Oklahoma for a number of surveys. In order to ensure that any 3" x ½" NaI probe/count rate meter combination may be used to perform the surveys, this TM is used to document that the variation between the available detectors[3].

2.2 The guidance for allowable instrument variation is obtained from the American National Standards Institute (ANSI) N323A-1997, Section 4.2.2. The section specifically states that "The exchange of probes shall be permitted if the variation between combinations of units provided to a given location has been documented to be within 20% of the CTV".

2.3 For all Kerr-McGee facilities in Oklahoma, count rate meter and 3" x ½" NaI probe combinations are not changed following calibration by practice so the possible combinations are limited to unique sets of 3" x ½" NaI probes and detectors.

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[1] The CTV, as applied in this TM, is the average of all individual count measurements.

[2] ANSI. American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments. N323A-1997. 1997.

[3] Implies any 3" x ½" NaI probe/count rate meter combinations which were currently in calibration.

Table 2
Net Individual Measurement Results and Averages (cpm)

Scaler Model/SN	L-2221/ 144880	L-2221/ 146344	L-2221/ 197779	L-2221/ 117646	L-2221/ 144890	L-2221/ 126535	L-2221/ 202350	L-2220/ 50058
Detector Model/SN	**L-44-82/ 408231**	**L-44-82/ 403155**	**L-44-82/ 312319**	**L-44-82/ 405103**	**L-44-82/ 403267**	**L-44-82/ 408232**	**L-44-82/ 403268**	**L-44-82/ CI - 129**
Count 1	3403	3731	3780	3688	3812	3763	3739	3907
Count 2	3440	3898	3807	3699	3938	3749	3569	3981
Count 3	3610	3787	3802	3762	3800	3698	3625	4084
Count 4	3387	3638	3703	3750	3778	3887	3868	3991
Count 5	3442	3789	3596	3662	3914	3657	3722	4058
Count 6	3465	3745	3773	3640	3738	3647	3606	3998
Count 7	3452	3937	3811	3684	3722	3800	3718	3899
Count 8	3504	3821	3749	3681	3769	3771	3665	3954
Count 9	3644	3777	3690	3572	3851	3860	3608	3817
Count 10	3543	3739	3816	3880	3892	3697	3691	3899
Net Average	**3489**	**3786**	**3753**	**3701**	**3821**	**3753**	**3681**	**3959**
Std Dev	**85.74**	**85.30**	**70.64**	**82.26**	**74.57**	**80.74**	**87.16**	**80.66**

4.3 The conventionally true value and upper and lower 20% acceptance criteria are included in Table 3. In addition, the upper and lower 10% of the CTV are included for perspective.

Table 3
Overall Average and Acceptance Values (cpm)

CTV	3743		
Lower 20%	2994	Lower 10%	3369
Upper 20%	4492	Upper 10%	4117

4.4 A review of the data indicates that all individual data results are within the acceptance criteria of ±20% of the CTV. In addition, no measurement results exceed ±10% of the CTV indicating good agreement among all detectors.

4.5 Based upon the acceptance criteria stipulated in ANSI N323A, each detector combination analyzed responds within the range of acceptable count rates. Any calibrated probe/count rate meter combination is therefore acceptable for use in surveys without preference.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 All net measurement results were well within the acceptance criteria of ANSI N323A.

5.2 Any calibrated 3" x ½" NaI probe and Ludlum count rate meter combination may be utilized for surveys without preference to a particular instrument.

3. METHODS

3.1 Eight shielded detector combinations were exposed face on to an ~8 μCi Cs-137 source at a source to probe distance of 0.3 meters. All instruments were in calibration and were operated in window out mode with a lower threshold set at 50 mV. Each detector combination was exposed to the source in identical configurations and 10 one-minute counts were obtained and recorded[4].

3.2 Four, one-minute background measurements were also recorded for each detector combination in the same configuration as the source measurements were obtained.

3.3 The gross individual measurements results were corrected by subtracting the detector specific average background to obtain net measurement results. The ten net individual results for each detector were then averaged and the sample standard deviation was computed.

3.4 Those eight detector averages were then averaged and applied as the CTV in a comparison of results. Using the criteria presented in ANSI N323A (and included in Section 2.2), an upper and lower bound on the data is estimated by adding and subtracting 20% to the CTV.

4. RESULTS AND DISCUSSION

4.1 The individual background results and calculated averages are provided in Table 1.

Table 1

Background Measurements and Average Background for Each Detector (cpm)

Scaler Model/SN	**L-2221/ 144880**	**L-2221/ 146344**	**L-2221/ 197779**	**L-2221/ 117646**	**L-2221/ 144890**	**L-2221/ 126535**	**L-2221/ 202350**	**L-2220/ 50058**
Detector Model/SN	**L-44-82/ 408231**	**L-44-82/ 403155**	**L-44-82/ 312319**	**L-44-82/ 405103**	**L-44-82/ 403267**	**L-44-82/ 408232**	**L-44-82/ 403268**	**L-44-82/ CI - 129**
Bkg # 1	2019	2034	2191	2420	2367	2324	2166	2396
Bkg # 2	1981	2134	2123	2168	2061	2202	2110	2178
Bkg # 3	1840	2073	2054	2177	2161	2214	2022	2099
Bkg # 4	2011	2102	2080	2113	2217	2277	2078	2190
Avg Bkg	**1963**	**2086**	**2112**	**2220**	**2202**	**2254**	**2094**	**2216**

4.2 The net individual measurement results, average and standard deviation are included in Table 2.

[4] Data collected at the Cushing Facility Laboratory by Irving Powell and Terry Keane on November 12, 2004.

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TECHNICAL MEMORANDUM 04-29

December 2, 2004

Originator: A.H. Thatcher, CHP, Senior HP Scientist

Subject: ***Derivation of Embedded Piping DCGLs for Renovation and Occupational Exposure Scenarios at KMTC***

Revision: 0

ENDORSEMENT: This document contains the results of research and technical analysis which have been reviewed and approved for publication by the Technical Director, NEXTEP Environmental, Inc.

H.J. Newman 12/2/2004

Harry J. Newman, CHP, Technical Director Date

1 INTRODUCTION

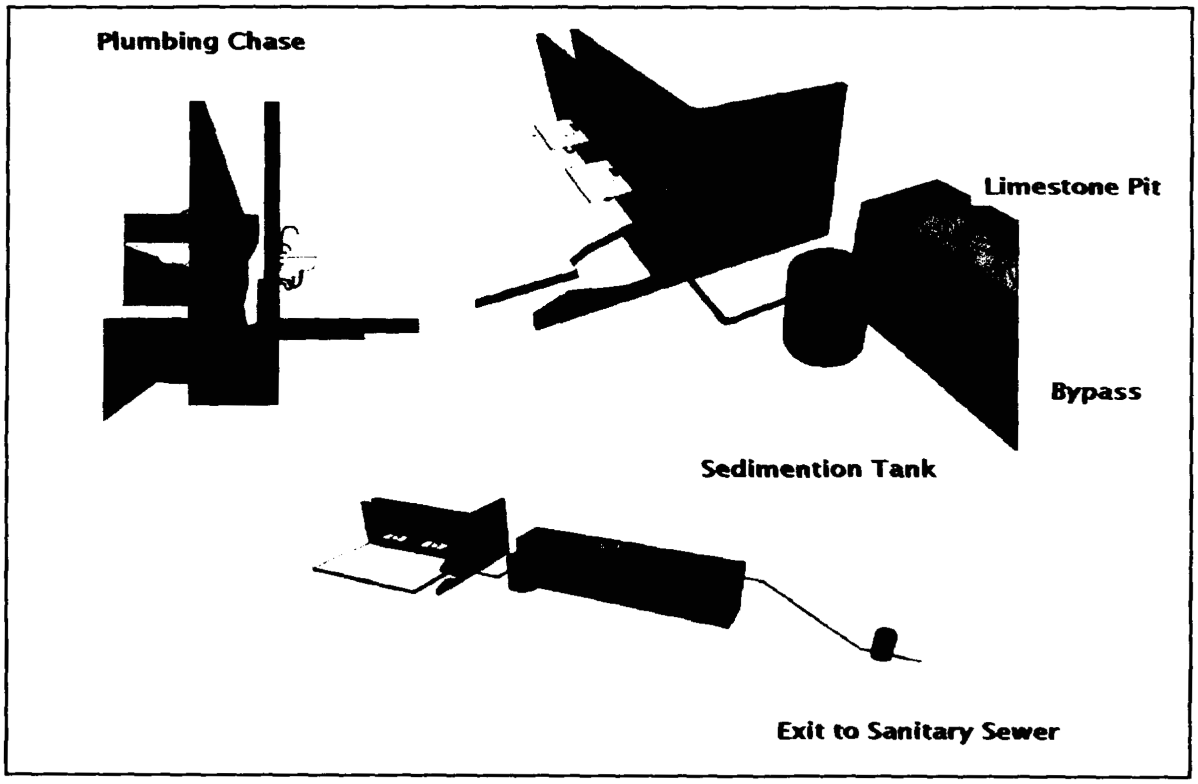
1.1 This Technical Memorandum (TM) develops the Derived Concentration Guideline Level (DCGL) for two scenarios, a renovation and an occupational exposure scenario as applied to exposure from embedded piping at the Kerr McGee Technical Center (KMTC) Facility. This TM explains the technical basis and assumptions used in developing the DCGLs for each scenario and defines what piping at the facility the derived release limit applies to. Following the development and discussion of the two scenarios, a comparison is made to the DCGLs developed in TM 04-03[1] in order to determine which scenario is most limiting. The most limiting scenario results will be recommended as the embedded pipeline release limit.

2 SCOPE

2.1 The chemical drain system at the facility includes the piping from the laboratories into the plumbing chase running underground out of the building and into a sedimentation tank and limestone pipe as shown in Figure 1. The exposed portions of piping located within the laboratories (traps, drains, etc) are not considered to be embedded and are subject to the building surface release criteria[2]. This TM and resulting DCGLs specifically apply to the embedded portions of the system within the plumbing chase and underground.

[1] NEXTEP TM 04-03, *Derivation of Embedded Piping DCGLs from KMTC*, A.H. Thatcher

[2] NEXTEP TM 04-01, *Chemical Drain System Addendum for the KMTC FSSR Indoor Survey Units*, R. Newman.



Schematic Diagrams of Plumbing System
Figure 1

2.2 In TM 04-03[3], a building renovation scenario was developed that essentially assumed that the embedded piping was removed, stockpiled, and crushed with external and inhalation exposures resulting from the piping stockpile. The building renovation scenario in this TM uses a more traditional 500 hour, one time exposure setting with an assumed individual spending a considerable fraction of his/her time cutting and removing the embedded piping in the chaseways within the facility. Exposure pathways include both external and inhalation exposure. This building renovation scenario assumes that the building will no longer be used as a laboratory but instead is being converted to an office building.

2.3 The building occupational exposure scenario uses a 2000 hour per year exposure setting. The exposures are based upon the continued use of the building as a laboratory. In this scenario, no inhalation exposure exists as the piping is assumed to remain in place without modification. External gamma exposure is therefore the only mode of exposure to personnel.

[3] NEXTEP TM 04-03, *Derivation of Embedded Piping DCGLs for KMTC*, A.H. Thatcher, CHP.

3 METHODS

3.1 General Assumptions

3.1.1 NUREG 5512[4] serves as the basis for the two exposure scenarios used in deriving the DCGLs. In developing the occupational and renovation scenarios, the following assumptions are jointly applied:

3.1.1.1 A unit uniform contamination on all buried surfaces is assumed to be 1 dpm/100 cm^2 for the uranium series to uranium 234, Radium 226 and progeny (includes contribution from Th-230), and Thorium 232 and progeny.

3.1.1.2 30 years of ingrowth are assumed.

3.1.1.3 The thickness of the contamination is assumed to be 1/32" (0.0008 m).

3.1.1.4 Regardless of the composition of the pipe material, no shielding is taken into consideration in the calculations.

3.1.1.5 There is no external contamination on the pipes.

3.1.1.6 A rotational geometry is assumed for all external exposures[5].

3.1.1.7 Buried piping outside of the building is not considered. If the piping were removed the exposure would be limited due to the following:

3.1.1.7.1 The soil surrounding the piping would provide significant shielding except for short periods of time

3.1.1.7.2 The work would likely be performed using a track hoe or similar equipment, further reducing potential exposures.

3.1.1.7.3 Any inhalation exposures would be small due to the increased diffusion outdoors and the presumed greater distances of exposure as compared to indoor cutting.

3.2 The Building Renovation Scenario

3.2.1 The goal of the building renovation used in this scenario is to remove all piping from the chaseways in the buildings. This renovation scenario maximizes the time that an individual must spend near the embedded piping as well as maximizes the inhalation potential through the cutting and subsequent removal of the piping. Unlike the crushing and stockpiling assumed in the renovation scenario used in TM 04-03, the removed piping is simply placed in roll-offs and transported for disposal[6]. Assumptions that apply specifically to this building scenario are as follows:

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4 Kennedy, W.E. and Strenge, D.L. *Residual Radioactive Contamination from Decommissioning.*

5 In reality this would seldom be the case as non-uniform exposures from the various line sources would dominate and would result in doses less than those predicted from a rotational geometry.

6 If crushing or volume reduction were to occur, the common construction practice is to simply use a track hoe or similar device to smash the material in the roll-off. No significant exposure would exist in this instance as the closest individual is in the track hoe, a significant distance away in terms of both inhalation and external exposure.

3.2.1.1 The exposed individual spends a significant amount of time working on or near the embedded piping as opposed to working a majority of time in the laboratories.

3.2.1.2 Two individuals are assumed to work in the chaseways removing piping. The two individuals spend over 440 man-hours in the chaseways, almost 6 weeks of full time work. This type of time commitment for a few individuals is considered quite conservative.

3.2.1.3 No shielding is considered from the non affected piping above the drain lines in the chaseways.

3.2.1.4 Figure 1 shows that a number of vertical and horizontal piping runs dominate the chaseways. The majority of these pipes are 2" in diameter with the exception of the single 4" drain pipe running at the bottom of the chaseway. All chaseway exposures, however, were modeled as two 4" pipes running in each chaseway. This conservative assumption provides uniformity to the external exposure in the chaseways as opposed to assuming a given amount of time spent near the vertical drain lines that run from each lab into the chase approximately every ~6 meters. Additional conservatism is also built into the model as the 2" pipe only contains ½ the activity (per pipe length) of a 4" pipe[7].

3.2.1.5 There are a total of 3,270 feet (~997 m) of vertical and horizontal piping contained within the facility[8]. This piping is both glass and PVC, 2" and 4". The modeling assumes all piping is 4" in order to maximize the inhalation potential for a greater surface area of contamination.

3.2.1.6 For exposure considerations, the piping is assumed to be cut (or severed) in 10' lengths for a total of 327 breaks in the piping. Piping cuts are assumed to take two minutes each with the affected area for each break being 1/8" wide over a 4" diameter pipe for a surface area of 0.001013 m^2 per cut. Inhalation exposures are assumed to occur during the two minutes of cutting per pipe section and the sections are assumed to be cut in sequence such that an individual is exposed continuously to airborne contamination[9].

3.2.1.7 Following the active cutting, the contaminated material is assumed to uniformly deposit on the chaseway flooring and result in an inhalation potential through the resuspension of material.

3.2.1.8 3.2 E-5 of the material is available for resuspension[10] from pipe cutting activities.

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[7] A two inch pipe contains only 50% of the activity of a 4" pipe per unit area. This directly translates into a smaller external dose contribution while cutting, carrying, and working near the pipe. Since ½ of the piping is 2" in size, the combined conservatism is approximately 25%.

[8] Bensinger, J. KMTC facilities manager. Email to A. H. Thatcher 11/1/2004.

[9] While cutting a PVC pipe, very little internal contamination would be available for release as the only opening is the blade width of the cut until the pipe is removed thereby significantly limiting the potential for re-suspension of contaminants within the pipe. Glass piping contains junctures at 10 ft. intervals that allow for ease of removal and replacement. No inhalation potential should exist from removal of the glass piping but the same exposure is nevertheless assumed.

[10] See NEXTEP TM 04-03. *Derivation of Embedded Piping DCGLs for KMTC*, Thatcher, A.H., for calculations of the re-suspended fraction.

3.2.1.9 For the renovation worker's time spent in the labs, two 2" piping runs are assumed to run in the chaseway at heights that would allow for a possible exposure to individuals in the lab. It is important to emphasis that an individual in the lab cannot be exposed to the 4" piping on the chaseway flooring due to the depth below grade and the extensive concrete shielding of the sides of the chaseway.

3.2.1.10 The width of the chaseways is 5 feet (1.524 m). The diffusion is conservatively assumed to only reach a height of 3 meters in the chaseway[11], thereby limiting the diffusion to the longitudinal travel of the chaseway in either direction.

3.2.1.11 The diffusion is assumed to spread at a rate of 0.5 ft/s with no ventilation[12]. This diffusion rate is potentially important in the event the initial exposure is significant and would otherwise be underestimated.

3.2.1.12 Chaseway CW-2 (59' x 5' x 13') is used as the model for the inhalation calculations. A total of 14 piping cuts on affect piping are assumed to be made in this chaseway. All inhalation and resuspension calculations are based upon the results for this chaseway.

3.2.1.13 An individual is assumed to carry two 10' pipe sections at a time, carrying them under the arm and against the chest. The dose point on interest for these calculations is not the on contact dose rate (which would be a skin dose in effect), but a dose 3" in depth to the torso in order to approximate a whole body dose[13].

3.2.1.14 The time spent near the roll-offs is negligible compared to the hours spent in close proximity to the piping in the chaseway.

3.2.2 Exposure (both inhalation and external) is segregated into a series of stages with exposure times (in hours) assigned to each stage.

3.2.3 External Exposure Calculations

3.2.3.1 The general formula used for calculating the external dose equivalent for outdoor exposure is as follows:

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[11] As opposed to the full 13' height of the chaseway.

[12] This diffusion rate is based upon lateral diffusion measurements of smoke in a calm environment. Smoke is used as a visible indicator of particulate movement and face velocity. While the vertical diffusion rate of smoke would be artificially high due to temperature differentials, lateral diffusion would not be affected by temperature and is therefore used as the basis for the mixing environment. The experimental diffusion measurement setup can be found at http://www.osha.gov/SLTC/indoorairquality/evaluation.html, then select ventilation investigation, then investigation guidelines. This experimental setup was performed multiple times by A.H. Thatcher on 11/10/04 in an outdoor, protected, calm environment. The 0.5 ft/s measurements were measured on both sides of the smoke plume.

[13] A dose point 3" in depth to the torso is very conservative for a whole body dose. For reference, a whole body dose would include the head, trunk (including male gonads), arms above the elbow, or legs above the knee. A dose point at the centroid of the torso (about 8" for reference man) would be more appropriate without being conservative.

Equation 1

$$D_{ext} = C * DCF * ED * 100$$

Where:

D_{ext} = *Dose (mrem)*
C = *Concentration (dpm/100 cm²)*
DCF = *Dose conversion factor, nuclide specific (mSv/hr/dpm/100 cm²)*
ED = *Exposure duration (hours/year or hours)*
100 = *Conversion from mSv to mrem*

3.2.3.2 The external dose conversion factors used in this TM are calculated by the Microshield computer code[14] based upon a unit contaminant concentration contained within a PVC pipe. All piping lengths modeled are infinite in length (10 meters) with the exception of the10' piping lengths carried by personnel for disposal.

3.2.4 Inhalation Exposure Calculations

3.2.4.1 Inhalation Exposure calculations involve two separate calculations for the renovation scenario.

3.2.4.1.1 The first calculation is performed for the time exposed while cutting the piping.

3.2.4.1.2 The second calculation is for exposure time spent in the chaseway removing brackets and piping from the chaseways.

3.2.4.2 In order to more accurately calculate the inhalation exposure while cutting the pipe in the chaseway, the contamination is modeled as a continuous release over the time period of interest. Chaseway CW-2 is used as the reference example for inhalation exposure (chaseway dimensions 59'x13'x5') with a total effective volume (assuming a 3m effective height) of 83.4 m^3.

3.2.4.3 The airborne activity at any time during the cutting of a single pipe[15] is described in equation 2.

Equation 2

$$C_{air} = \frac{\frac{C * A_{cont}}{T_{total}} * F_{released} * T_i}{V_i}$$

Where:

C_{air} = *Airborne Concentration (Bq/m³)*
C = *Contaminant activity of 1.67 Bq/m²(equivalent to 1 dpm/100 cm²)*
A_{cont} = *Cut area of pipe susceptable to resuspension (4" diameter pipe, 1/8" length)*
T_{total} = *The total assumed time per cut (120 seconds)*
$F_{released}$ = *Fraction Released (3.2E-05)*[16]
T_i = *The time period of interest (from 0 to 120 seconds)*
V_i = *The air volume at T_i based upon the 3 dimensional diffusion parameters.*

[14] Grove Engineering, Microshield, Version 5.03, Rockville, MD. 1998.
[15] An assumed 2 minute period.
[16] Details provided in TM 04-03.

3.2.4.4 The average concentration during the first pipe cut is a time weighted average of the 120 second exposure (*air1*). Air concentrations in CW-2 for subsequent cuts are calculated as follows:

Equation 3

$$C_{air} = air_1 + \left[\frac{A_{released}}{V_{total}}\right]_2 + \left[\frac{A_{released}}{V_{total}}\right]_3 + \ldots$$

Where:

V_{total} = *The total air volume in the chaseway (83.4 m^3)*

$A_{released}$ = *Activity released during the pipe cut operation. (= C^*A_{cont})*

3.2.4.5 The air concentration over time approximates an exponential buildup, particularly since no loss terms are included in the calculation over the 5.4 hour exposure period of affected pipe cutting.

3.2.4.6 There are a total of 14 pipes cut in CW-2 given that a pipe is cut every 10' and the pipes are assumed to run in parallel. The equation for estimating this exposure is:

Equation 4

$$D_{int} = C * B_{rate} * ED * DCF * 10^5$$

Where:

B_{rate} = *Worker breathing rate (1.2 m^3/hr)*

ED = *Time of exposure in 1 year (5.4 hours)*

DCF = *Dose conversion factor (Sv/Bq)*[17]

10^5 = *Conversion factor (mrem/Sv)*

D_{int} = *Dose rate normalized to 1 dpm/100 cm^2* $\left(\frac{mrem/yr}{dpm/100cm^2}\right)$

3.2.4.7 Following the initial inhalation exposure, the airborne contaminated material is assumed to settle and the individuals are exposed to re-suspended material that has deposited out on the chaseway surfaces. The equation for calculating this exposure is as follows:

Equation 5

$$D_{int} = * R_f * B_{rate} * ED * DCF * 10^5$$

Where:

Concentration = *Total activity released from 14 pipes in CW-2 divided by the 27.9 m^2 area of the chaseway. (Bq/m^2)*

R_f = *indoor resuspension factor (5 E-05/m)*[18]

ED = *time spent removing affected brackets and piping (16.8 hours)*

[17] ICRP, Age-Dependent Doses to Members of the Public From Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients, ICRP Publication 72, Oxford, Pergamon Press, 1995.

[18] Kennedy, W.E. and Strenge, D.L. Residual Radioactive Contamination from Decommissioning. NUREG/CR-5512. 1992.

3.3 Occupational Exposure Scenario

3.3.1 The occupational scenario is intended to represent a worst-case exposure to individuals working in the facility. The individual is chosen as someone who works in the labs and at various locations within the building. The occupational exposure scenario involves only external exposures as no piping replacement work is assumed to occur that would result in any meaningful exposure[19]. Assumptions for the occupational scenario include:

3.3.1.1 The chaseway walls are the equivalent of 1" of concrete in thickness[20] and that this is the only shielding between the individual working in the lab and the embedded piping[21].

3.3.1.2 Two 2" piping runs are assumed to run in the chaseway at heights that would allow for a possible exposure to individuals in the lab. The time that the occupational individual spends in the chaseways however, is modeled using the same 4" pipes used in the renovation scenario. It is important to emphasize that an individual in the lab cannot be exposed to the 4" piping on the chaseway flooring due to the depth below grade and the extensive concrete shielding of the sides of the chaseway.

3.3.2 Exposure is segregated into a series of stages with exposure times (in hours) assigned to each stage. External exposure calculations are performed in the same manner as detailed in the renovation scenario.

3.4 Individual Release Limits

3.4.1 The internal and external dose contributions may be combined and applied to the 25 mrem/y proposed release limit in the following manner:

Equation 6

$$DCGL = \frac{25(mrem/yr)}{D_{\text{int}} + D_{ext}}$$

Where:

D_{int} = *Normalized exposure rate due to inhalation* $\left(\frac{mrem/yr}{dpm/100cm^2}\right)$

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19 Assume that three sections of piping are replaced in any given year and the occupational individual is involved in the replacement and that resuspension values considered in the renovation scenario occur. Further assume that the total exposure time is 15 minutes for the pipe replacement and that the average concentration is 2.6E-09 $Bq/m^3/dpm/100cm^2$ (see attachment on air concentration calculations for three pipe breaks), the resulting exposure is approximately 50 times less than that of the renovation exposure calculations. This impact is less than 0.2% of the final occupational release limit. Any reasonable inhalation exposures for the occupational scenario may therefore be neglected.

20 The walls are actually made of a clay brick. Each brick is comprised of an inner and outer wall of approximately 1.5 cm thickness each and an inner wall of approximately 1 cm in thickness.

21 Glass piping exits the lab as floor level and immediately drops into the piping trench in the chaseway, thereby limiting the exposure to individuals within a laboratory to exposures shielded not only by the chaseway walls but also by the concrete on the sidewalls of the chaseways beneath lab floor levels. It is likely that little if any exposure would occur to an individual in the lab for the piping in the chaseways.

D_{ext} = *Normalized exposure rate due to external dose contribution* $\left(\dfrac{mrem/yr}{dpm/100cm^2}\right)$

$DCGL$ = *Release limit based upon 25 mrem/yr exposure standard* $(dpm/100cm^2)$

3.4.2 The limits may be calculated for U-238 to U-234, the thorium series, and Ra-226 and progeny (plus Th-230).

3.5 Combining Individual Release Limits

3.5.1 An overall release limit for embedded piping may be determined by combined the individual release limits in the following manner:

Equation 7

$$DCGL_{comp} = \frac{\sum_i F_i}{\sum \frac{F_i}{Lm_i}}$$

Where:

$DCGL_{comp}$ = *Composite DCGL for Uranium, Radium and Thorium parents combined,* $(dpm/100\ cm^2)$

Lm_i = *maximum concentration of U, Ra, or Th in radioactive equilibrium*[22]

F_i = *fraction of radioactivity represented by Uranium, Radium and Thorium*

4 RESULTS

4.1 Renovation Scenario results

4.1.1 The stages assumed and links to supporting documentation for U-238 to U-234 calculations are included in Table 1. Attachment 1 documents U-238 to U-234 calculations, Attachment 2 documents the thorium series calculations, and Attachment 3 documents the radium and progeny calculations (including Th-230). The Tables identified in the Supporting Calculations in Table 1 apply to all three attachments.

[22] Equilibrium for both series with the progeny at the same concentration as the parent.

Table 1
Renovation Stages, exposure pathways, and time estimates

Stage	Activity	Exposure Pathway	Estimated Time Required (hours)	Supporting Calculations[23]
1	Removing non affected piping @ 1 meter	External	108.8[24]	Attachment 1, Table 1
2	Carrying away non affected piping @ 2 meters	External	40.8[25]	Attachment 1, Table 2
3	Cutting affected piping @ 0.5 meters	External and Inhalation	5.4[26]	Attachment 1, Table 3, 4, 5, and 6
4	Removing other impediment (brackets, etc) from affected piping @ 0.5 meters	External and Inhalation	10[27]	Attachment 1, Table 7[28]
5	Carrying away affected piping (on contact – effective distance 0.127 meters)	External and Inhalation	6.8[29]	Attachment 1, Table 8[30]
6	Work in renovation projects at an average distance in the laboratories @ 3 meters	External	328.2[31]	Attachment 1, Table 9
Total			**500**	

4.1.3 Table 2 summarizes the external dose contributions for U-238 to U-234 for the renovation scenario based upon the exposure estimates and the calculated Microshield

[23] Note that the Microshield calculations provided in the Attachments are for a single pipe. Results are simply doubled for the external exposure calculations. The rotational geometry results with buildup are used.

[24] Based upon the time to cut and remove approximately 10 times the affected piping (includes hot and cold water, chilled water, deionized water, compressed gas, natural gas, argon, nitrogen, steam (no longer used), and vacuum lines) plus an inefficiency factor of two due to the large amount of piping.

[25] Once cut and cleared, the piping is assumed to take about six times that of the drain line piping to remove, due mostly to smaller diameter piping.

[26] The operating assumption is that it takes two minutes to cut open or break open a pipe and that inhalation exposure only occurs during this time period. There is 3,270 feet of piping, assumed to be cut into 10' sections. Two individuals area assumed to cut the piping. (3,270/10*2 minutes*1 hour/60 minutes)/2 persons=5.44 hours.

[27] Additional time spent near the piping prior to removal.

[28] Note that the Microshield calculations in Figure 3 also apply to the external calculations in Stage 4.

[29] 3,270 feet of piping cut into 10 foot sections, carried in bundles of two for 5 minutes while dumping. Also assumes that two people will be performing the work. 327/2 people* 5 minutes*1 hour/60 minutes = 6.8 hours.

[30] Note that the inhalation exposure times are combined in Figure 7 for calculational ease.

[31] 500 hours minus the time spent in the chaseways. Exposure is modeled using 2" piping with wall shielding.

results. The external dose contribution for U-238 to U-234 is 2.71 E-07 mrem/1 dpm/100 cm^2.

Table 2
Renovation Stages, exposure pathways, and time estimates

Exposure Stage	Conversion to Rem from Sv	Hours of Exposure (hours)	External Exposure Rate (mSv/hr)	Estimated External dose (mrem/1 dpm/100cm^2)	Estimated Internal dose (mrem/dpm/100cm^2)
1	100	108.8	9.97E-12	1.08E-07	NA
2	100	40.8	4.45 E-12	1.81E-08	NA
3	100	5.4	2.04 E-11	1.11 E-08	3.71E-07
4	100	10	2.04 E-11	2.04 E-08	2.95E-10*
5	100	6.8	1.00 E-10	3.80 E-08	
6	100	328.2	1.36 E-12	4.46 E-08	NA
Total				2.71 E-07	3.71E-07

* *Attachment 1, Figures 4 and 7 (Stages 4&5 combined).*

4.1.4 Inhalation contributions for the uranium series are calculated in Figure 4 with supporting air concentration calculations provided in Figures 5 and 6. The contribution from the uranium series is 3.71 E-07 mrem/1 dpm/100 cm^2.

4.1.5 The internal and external dose contributions for uranium 238 to uranium 234 may be combined and applied to the 25 mrem/y release limit in the following manner:

Equation 8

$$\frac{25 mrem/y}{3.71E^{-07}\frac{mrem/y}{dpm/100cm^2}+2.71E^{-07}\frac{mrem/y}{dpm/100cm^2}}=3.90E^{+07}dpm/100cm^2$$

4.1.6 The release limit for all three radionuclide groups are shown in Table 3.

Table 3
Calculated Embedded Piping DCGLs

Nuclide	$DCGL_w$ (dpm/100cm^2)*
Radium-226 and progeny (including Th-230)	1,600,000
Th-232 and progeny	1,070,000
U-238 to U-234	39,000,000

*The units of the calculated DCGLw are dpm/100cm^2 for the parent nuclide.

4.1.7 Combining Individual Release Limits

4.1.7.1 The three individual release limits may be combined using Equation assuming all three radionuclides were present in equal proportions.

Equation 9

$$DCGL_{comp} = \frac{1}{\frac{0.33}{39,000,000} + \frac{0.33}{1,070,000} + \frac{0.33}{1,600,000}} = 1,910,000 \frac{dpm}{100cm^2}$$

4.2 Occupational Scenario Results

4.2.1 The stages assumed and links to supporting documentation for U-238 to U-234 are included in Table 4 for the occupational scenario. Attachment 4 documents the U-238 to U-234 calculations, Attachment 5 documents the thorium series calculations, and Attachment 6 documents the radium and progeny (and Th-230) calculations. The Tables identified in the Supporting Calculations in Table 4 apply to all three attachments.

Table 4
Occupational Stages, exposure pathways, and time estimates

Stage	Activity	Exposure Pathway	Estimated Time Required (hours)	Supporting Calculations[32]
1	Exposure while working at a lab counter or sink @ 1.5 meters	External	500	Attachment 4, Table 1
2	Exposure while working in the lab but away from the sinks or immediate embedded piping @ 3 meters	External	1,000	Attachment 4, Table 2
3	Exposure from other locations within the building (i.e. meetings, etc) @ 5 meters	External	400	Attachment 4, Table 3
4	Exposure during time spent in causeways (no shielding) @ 1.5 meters	External	100[33]	Attachment 4, Table 4
Total			**2,000**	

4.2.2 Table 5 summarizes the external dose contributions for U-238 to U-234 for the renovation scenario based upon the exposure estimates and the calculated Microshield results.

[32] Note that the Microshield calculations are for a single pipe. Results are simply doubled for final results. The rotational geometry results with buildup are used.

[33] Bensinger, J. Email to A.H. Thatcher 11/8/04. Considered 100 hours of time in the chaseways "highly unlikely".

Table 5
Occupational Stages, exposure pathways, and time estimates

Exposure Step	Exposure rate (mSv/hr)	Conversion to Rem from Sv	Hours of Exposure (hours)	Estimated dose (mrem/1 dpm/100 cm^2)
1	3.13E-12	100	500	1.57E-07
2	1.36E-12	100	1000	1.36E-07
3	6.41E-13	100	400	2.56E-08
4	6.31E-12	100	100	6.31E-08
Total				3.81E-07

4.2.3 The external dose contributions for uranium 238 to uranium 234 may be applied to the 25 mrem/y release limit in the following manner:

Equation 10

$$\frac{25mrem/y}{3.81E^{-07}\frac{mrem/y}{dpm/100cm^2}} = 6.56E^{+07}dpm/100cm^2$$

4.2.4 The release limit for all three radionuclide groups are shown in Table 6.

Table 6
Calculated Embedded Piping DCGLs

Nuclide	$DCGL_W$ (dpm/100cm^2)*
Radium-226 and progeny (including Th-230)	1,300,000
Th-232 and progeny	920,000
U-238 to U-234	65,600,000

*The Unit of the calculated DCGLw are dpm/100cm^2 for the parent nuclide.

4.2.5 **Combining of Individual Release Limits**

4.2.5.1 The three individual release limits may be combined using Equation 11 assuming all three radionuclides were present in equal proportions.

Equation 11

$$\text{DCGL} = \frac{1}{\frac{0.33}{65,600,000}+\frac{0.33}{1,300,000}+\frac{0.33}{920,000}} = 1,620,000\frac{dpm}{100cm^2}$$

5 DISCUSSION

5.1 Combining the individual external gamma exposures and converting this to an allowable release limit based upon a 25 mrem/y standard results in the calculated release limits provided in Table 3 and Table 6. Embedded piping release may be performed by assuming a conservative mix of contaminants and determining the external on contact counts from a NaI detector for that radionuclide mix.

5.2 Multiple layers of conservatism are intentionally built into the calculations. Areas of conservatism within the document are:

5.2.1 All piping for the renovation scenario was modeled as 4" in diameter when in fact a majority of the piping is 2" in diameter.

5.2.2 The extent and placement of the 2" piping was modified for the occupational scenario in order to maximize the dose to an individual. Glass piping actually exits the lab near floor level and immediately drops into the piping trench in the chaseway, thereby limiting the exposure to individuals within a laboratory to exposures shielded not only by the chaseway walls but also by the concrete on the sidewalls of the chaseways beneath lab floor levels.

5.2.3 Contaminant resuspension from cut piping is assumed to present an inhalation potential. In practice, glass piping can easily be removed without any breakage thereby preventing any resuspension hazard. PVC piping, if cut, would present a minimal resuspension potential due to the limited area within which contamination could escape during cutting operations. In addition, deposited material on the internals of piping is readily attached to the walls and not readily susceptible to removal (or resuspension)[34].

5.2.4 The rotational geometry is the assumed external exposure geometry. It is likely that external exposures would not be uniform and represent some form of an anisotropic exposure situation that would not be equivalent to an effective dose.

5.2.5 The exposure time estimates for the renovation scenario are quite conservative as only two individuals are assumed to work in the chaseways to remove old piping. It is likely that a number of individuals would be present for removal operations.

5.2.6 The time that an occupational individual spends in the chaseways is likewise conservative.

5.3 The conservatism is left in the model in order to clearly indicate that the potential exposures from the occupational and renovation scenarios in this TM do not approach the release level in TM 04-03.

5.4 In both scenarios presented in this TM, the calculated release limits are greater than that derived in TM 04-03. Table 7 provides a comparison of the three scenarios.

[34] Bensinger, J. Personal communication with A. H. Thatcher and R. Callahan on 11/16/04.

Table 7
Scenario Release Limit Comparison

Nuclide	Renovation Scenario $DCGL_w$ (dpm/100cm^2)	Occupational Scenario $DCGL_w$ (dpm/100cm^2)	TM 04-03 Renovation Scenario $DCGL_w$ (dpm/100cm^2)
Radium-226 and progeny (including Th-230)	1,600,000	1,300,000	1,150,000
Th-232 and progeny	1,070,000	920,000	487,000
U-238 to U-234	39,000,000	65,600,000	4,350,000

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Tables 3 and 6 provide a summary of the individual release limits calculated for both the renovation and the occupational scenarios.

6.2 The release limits calculated under this TM result in a greater release limit than that calculated under TM 04-03.

6.3 The embedded piping should be released to the proposed limits published under TM-04-03.

ATTACHMENT 1

Calculations for the Renovation Scenario

(U-238 to U-234)

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1U.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 10:33:02 PM
Dose Point # 2 - (105.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.840e-006	1.939e-006
Photon Energy Fluence Rate	MeV/cm²/sec	3.330e-007	3.439e-007
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	6.062e-010	6.262e-010
Absorbed Dose Rate in Air	mGy/hr	5.292e-012	5.467e-012
"	mrad/hr	5.292e-010	5.467e-010
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.179e-012	7.441e-012
o Opposed	"	4.873e-012	5.028e-012
o Rotational	"	4.834e-012	4.986e-012
o Isotropic	"	4.437e-012	4.581e-012
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.389e-012	7.654e-012
o Opposed	"	6.376e-012	6.587e-012
o Rotational	"	6.376e-012	6.587e-012
o Isotropic	"	4.760e-012	4.915e-012

Microshield External Exposure Calculations at 1 meter for U-238 to U-234
Table 1

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1U.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 10:33:02 PM
Dose Point # 6 - (205.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	8.006e-007	8.712e-007
Photon Energy Fluence Rate	MeV/cm²/sec	1.457e-007	1.534e-007
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.650e-010	2.793e-010
Absorbed Dose Rate in Air	mGy/hr	2.313e-012	2.438e-012
"	mrad/hr	2.313e-010	2.438e-010
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.136e-012	3.324e-012
o Opposed	"	2.132e-012	2.242e-012
o Rotational	"	2.115e-012	2.224e-012
o Isotropic	"	1.941e-012	2.043e-012
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.228e-012	3.418e-012
o Opposed	"	2.788e-012	2.939e-012
o Rotational	"	2.788e-012	2.939e-012
o Isotropic	"	2.082e-012	2.192e-012

Microshield External Exposure Calculations at 2 meters for U-238 to U-234
Table 2

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1U.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 10:33:02 PM
Dose Point # 5 - (55.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	3.814e-006	3.941e-006
Photon Energy Fluence Rate	MeV/cm²/sec	6.878e-007	7.017e-007
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	1.253e-009	1.278e-009
Absorbed Dose Rate in Air	mGy/hr	1.093e-011	1.116e-011
"	mrad/hr	1.093e-009	1.116e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.484e-011	1.518e-011
o Opposed	"	1.006e-011	1.026e-011
o Rotational	"	9.983e-012	1.018e-011
o Isotropic	"	9.164e-012	9.349e-012
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.527e-011	1.561e-011
o Opposed	"	1.317e-011	1.344e-011
o Rotational	"	1.317e-011	1.344e-011
o Isotropic	"	9.833e-012	1.003e-011

Microshield External Exposure Calculations at 0.5 meters for U-238 to U-234
Table 3

Isotope	Concentration (Bq/m²)	Affected Contaminated area (m^2)	Dose conversion factor (Sv/Bq)	Time spent cutting piping (hours)	Breathing rate for time cutting piping (m^3/hr)	Air Concentration (Bq/m^3)	fraction of material available for resuspended from cutting disburbance	Dose Estimate (CED) (Sv)	Dose Estimate (CED) (mrem)/1dpm/100 cm²
U-235	0.077	0.001013	1.97E-06	5.44	1.2	2.53E-10	3.20E-05	3.25E-15	3.25E-10
U-238	1.667	0.001013	1.90E-06	5.44	1.2	5.51E-09	3.20E-05	6.83E-14	6.83E-09
U-234	1.667	0.001013	2.13E-06	5.44	1.2	5.51E-09	3.20E-05	7.66E-14	7.66E-09
Pa-231	0.08	0.001013	3.47E-04	5.44	1.2	2.53E-10	3.20E-05	5.73E-13	5.73E-08
Ac-227	0.08	0.001013	1.81E-03	5.44	1.2	2.53E-10	3.20E-05	2.99E-12	2.99E-07
Th-230	0.00	0.001013	8.80E-05	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Ra-226	0.00	0.001013	2.32E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Pb-210	0.00	0.001013	3.67E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Th-232	0.00	0.001013	4.43E-04	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Ra-228	0.00	0.001013	1.29E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Th-228	0.00	0.001013	6.75E-05	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Reference			[ICRP, 1995]	[Kennedy, W.E.Jr., and Strenge, D.L., 1992]	[USNRC, 1994]		[Kennedy, W.E.Jr., and Strenge, D.L., 1992]		3.71E-07

Inhalation Calculations[35] for U-238 to U-234
Table 4

[35]Note that [USNRC, 1994] is U.S. NRC. Policy and Guidance Directive PG-8-08: Scenario s for Assessing Potential Doses Associated with Residual Radioactivity. 1994; and [ICRP, 1995] is ICRP 72.

Time (seconds)	Release rate (Bq/s)	Total Activity (Bq)	Diffusion distance travelled in x direction (m)	Diffusion distance travelled in y direction (m)	Diffusion distance travelled in z direction (m)	Affected air volume (m^3)	Air Concentration (Bq/m^3)
1	4.51E-10	4.51E-10	3.05E-01	1.52E-01	3.05E-01	1.42E-02	3.19E-08
2	4.51E-10	9.02E-10	6.10E-01	3.04E-01	6.10E-01	1.13E-01	7.97E-09
3	4.51E-10	1.35E-09	9.15E-01	4.56E-01	9.15E-01	3.82E-01	3.54E-09
4	4.51E-10	1.80E-09	1.22E+00	6.08E-01	1.22E+00	9.05E-01	1.99E-09
5	4.51E-10	2.26E-09	1.52E+00	7.60E-01	1.52E+00	1.76E+00	1.28E-09
6	4.51E-10	2.71E-09	1.52E+00	9.12E-01	1.83E+00	2.54E+00	1.07E-09
7	4.51E-10	3.16E-09	1.52E+00	1.06E+00	2.13E+00	3.45E+00	9.14E-10
8	4.51E-10	3.61E-09	1.52E+00	1.22E+00	2.44E+00	4.51E+00	8.00E-10
9	4.51E-10	4.06E-09	1.52E+00	1.37E+00	2.74E+00	5.71E+00	7.11E-10
10	4.51E-10	4.51E-09	1.52E+00	1.52E+00	3.05E+00	7.05E+00	6.40E-10
11	4.51E-10	4.96E-09	1.52E+00	1.67E+00	3.05E-01	7.75E-01	6.41E-09
12	4.51E-10	5.41E-09	1.52E+00	1.82E+00	4.57E-01	1.27E+00	4.27E-09
13	4.51E-10	5.87E-09	1.52E+00	1.98E+00	6.10E-01	1.83E+00	3.20E-09
14	4.51E-10	6.32E-09	1.52E+00	2.13E+00	7.62E-01	2.47E+00	2.56E-09
15	4.51E-10	6.77E-09	1.52E+00	2.28E+00	9.14E-01	3.17E+00	2.14E-09
16	4.51E-10	7.22E-09	1.52E+00	2.43E+00	1.07E+00	3.94E+00	1.83E-09
17	4.51E-10	7.67E-09	1.52E+00	2.58E+00	1.22E+00	4.79E+00	1.60E-09
18	4.51E-10	8.12E-09	1.52E+00	2.74E+00	1.37E+00	5.70E+00	1.42E-09
19	4.51E-10	8.57E-09	1.52E+00	2.89E+00	1.52E+00	6.69E+00	1.28E-09
20	4.51E-10	9.02E-09	1.52E+00	3.00E+00	1.68E+00	7.64E+00	1.18E-09
21	4.51E-10	9.48E-09	1.52E+00	3.00E+00	1.83E+00	8.34E+00	1.14E-09
22	4.51E-10	9.93E-09	1.52E+00	3.00E+00	1.98E+00	9.03E+00	1.10E-09
23	4.51E-10	1.04E-08	1.52E+00	3.00E+00	2.13E+00	9.73E+00	1.07E-09

Figure abbreviated and continued below

102	4.51E-10	4.60E-08	1.52E+00	3.00E+00	1.42E+01	6.46E+01	7.12E-10
103	4.51E-10	4.65E-08	1.52E+00	3.00E+00	1.43E+01	6.53E+01	7.11E-10
104	4.51E-10	4.69E-08	1.52E+00	3.00E+00	1.45E+01	6.60E+01	7.11E-10
105	4.51E-10	4.74E-08	1.52E+00	3.00E+00	1.46E+01	6.67E+01	7.10E-10
106	4.51E-10	4.78E-08	1.52E+00	3.00E+00	1.48E+01	6.74E+01	7.10E-10
107	4.51E-10	4.83E-08	1.52E+00	3.00E+00	1.49E+01	6.81E+01	7.09E-10
108	4.51E-10	4.87E-08	1.52E+00	3.00E+00	1.51E+01	6.88E+01	7.08E-10
109	4.51E-10	4.92E-08	1.52E+00	3.00E+00	1.52E+01	6.95E+01	7.08E-10
110	4.51E-10	4.96E-08	1.52E+00	3.00E+00	1.54E+01	7.02E+01	7.07E-10
111	4.51E-10	5.01E-08	1.52E+00	3.00E+00	1.55E+01	7.09E+01	7.07E-10
112	4.51E-10	5.05E-08	1.52E+00	3.00E+00	1.57E+01	7.16E+01	7.06E-10
113	4.51E-10	5.10E-08	1.52E+00	3.00E+00	1.58E+01	7.23E+01	7.05E-10
114	4.51E-10	5.14E-08	1.52E+00	3.00E+00	1.60E+01	7.30E+01	7.05E-10
115	4.51E-10	5.19E-08	1.52E+00	3.00E+00	1.62E+01	7.37E+01	7.04E-10
116	4.51E-10	5.23E-08	1.52E+00	3.00E+00	1.63E+01	7.44E+01	7.04E-10
117	4.51E-10	5.28E-08	1.52E+00	3.00E+00	1.65E+01	7.51E+01	7.03E-10
118	4.51E-10	5.32E-08	1.52E+00	3.00E+00	1.66E+01	7.57E+01	7.03E-10
119	4.51E-10	5.37E-08	1.52E+00	3.00E+00	1.68E+01	7.64E+01	7.02E-10
120	4.51E-10	5.41E-08	1.52E+00	3.00E+00	1.69E+01	7.71E+01	7.02E-10
						Average	1.29E-09

***Air Concentration for a Single Release*[36]**

Table 5

[36] Only a portion of all 120 seconds of a single release was included for basic space considerations. One can observe the progression of airborne activity over time with the beginning and ending times shown. The average represents the average over 120 seconds of exposure.

Cut #	Concentration buildup in Chaseway from subsequent cuts (Bq/m^3)
1	1.29E-09
2	1.94E-09
3	2.59E-09
4	3.24E-09
5	3.89E-09
6	4.54E-09
7	5.19E-09
8	5.84E-09
9	6.48E-09
10	7.13E-09
11	7.78E-09
12	8.43E-09
13	9.08E-09
14	9.73E-09
Average	5.51E-09

Average air concentration in CW-2
Table 6

Isotope	Concentration (Bq/m^2)	Dose conversion factor (Sv/Bq)	Time spent cleaning up and removing piping (hours)	Breathing rate (m^3/hr)	Indoor resuspension factor (per meter)	Dose Estimate (CED) (Sv/y)	Dose Estimate (CED) (mrem/y)
U-235	1.30E-09	1.97E-06	16.8	1.2	0.00005	2.59E-18	2.59E-13
U-238	2.72E-08	1.90E-06	16.8	1.2	0.00005	5.21E-17	5.21E-12
U-234	2.72E-08	2.13E-06	16.8	1.2	0.00005	5.84E-17	5.84E-12
Pa-231	1.30E-09	3.47E-04	16.8	1.2	0.00005	4.56E-16	4.56E-11
Ac-227	1.30E-09	1.81E-03	16.8	1.2	0.00005	2.38E-15	2.38E-10
Th-230	0.00E+00	8.80E-05	16.8	1.2	0.00005	0.00E+00	0.00E+00
Ra-226	0.00E+00	2.32E-06	16.8	1.2	0.00005	0.00E+00	0.00E+00
Pb-210	0.00E+00	3.67E-06	16.8	1.2	0.00005	0.00E+00	0.00E+00
Th-232	0.00E+00	4.43E-04	16.8	1.2	0.00005	0.00E+00	0.00E+00
Ra-228	0.00E+00	1.29E-06	16.8	1.2	0.00005	0.00E+00	0.00E+00
Th-228	0.00E+00	6.75E-05	16.8	1.2	0.00005	0.00E+00	0.00E+00
Reference		[ICRP, 1995]		[USNRC, 1994]	[Kennedy, W.E.Jr., and Strenge, D.L., 1992]		2.95E-10

Inhalation Resuspension Calculations for U-238 to U-234

(stages 4 & 5 combined)
Table 7

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1U.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 10:33:02 PM
Dose Point # 1 - (12.7,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm^2/sec	1.910e-005	1.929e-005
Photon Energy Fluence Rate	MeV/cm^2/sec	3.430e-006	3.451e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	6.250e-009	6.289e-009
Absorbed Dose Rate in Air	mGy/hr	5.457e-011	5.491e-011
"	mrad/hr	5.457e-009	5.491e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.407e-011	7.458e-011
o Opposed	"	5.019e-011	5.049e-011
o Rotational	"	4.978e-011	5.008e-011
o Isotropic	"	4.571e-011	4.599e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.624e-011	7.676e-011
o Opposed	"	6.572e-011	6.613e-011
o Rotational	"	6.571e-011	6.613e-011
o Isotropic	"	4.905e-011	4.936e-011

Microshield External Exposure Calculations at 0.0076 meters for U-238 to U-234
Table 8

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AU2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:41:15 AM
Dose Point # 2 - (302.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm^2/sec	4.599e-008	3.024e-007
Photon Energy Fluence Rate	MeV/cm^2/sec	1.472e-008	4.858e-008
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.645e-011	8.408e-011
Absorbed Dose Rate in Air	mGy/hr	2.309e-013	7.340e-013
"	mrad/hr	2.309e-011	7.340e-011
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.908e-013	1.041e-012
o Opposed	"	2.187e-013	6.824e-013
o Rotational	"	2.185e-013	6.793e-013
o Isotropic	"	1.969e-013	6.289e-013
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.035e-013	1.060e-012
o Opposed	"	2.776e-013	9.036e-013
o Rotational	"	2.776e-013	9.036e-013
o Isotropic	"	2.103e-013	6.695e-013

Microshield External Calculations at 3 meters for U-238 to U-234
Table 9

ATTACHMENT 2

Calculations for the Renovation Scenario

(Thorium Series)

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1T.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 11:26:43 PM
Dose Point # 2 - (105.08,500,0) cm

Results [Summed over energies]	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	3.502e-005	3.589e-005
Photon Energy Fluence Rate	MeV/cm²/sec	2.856e-005	2.887e-005
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	4.687e-008	4.741e-008
Absorbed Dose Rate in Air	mGy/hr	4.092e-010	4.139e-010
"	mrad/hr	4.092e-008	4.139e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	4.800e-010	4.859e-010
o Opposed	"	4.002e-010	4.047e-010
o Rotational	"	4.001e-010	4.046e-010
o Isotropic	"	3.608e-010	3.649e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	5.034e-010	5.095e-010
o Opposed	"	4.796e-010	4.852e-010
o Rotational	"	4.796e-010	4.852e-010
o Isotropic	"	3.800e-010	3.843e-010

Microshield External Exposure Calculations at 1 meter for the Thorium Series
Table 1

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1T.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 11:26:43 PM
Dose Point # 6 - (205.08,500,0) cm

Results [Summed over energies]	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.535e-005	1.597e-005
Photon Energy Fluence Rate	MeV/cm²/sec	1.258e-005	1.280e-005
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.063e-008	2.102e-008
Absorbed Dose Rate in Air	mGy/hr	1.801e-010	1.835e-010
"	mrad/hr	1.801e-008	1.835e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.112e-010	2.155e-010
o Opposed	"	1.762e-010	1.794e-010
o Rotational	"	1.761e-010	1.793e-010
o Isotropic	"	1.588e-010	1.617e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.215e-010	2.259e-010
o Opposed	"	2.111e-010	2.151e-010
o Rotational	"	2.111e-010	2.151e-010
o Isotropic	"	1.673e-010	1.703e-010

Microshield External Exposure Calculations at 2 meters for the Thorium Series
Table 2

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1T.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 11:26:43 PM
Dose Point # 5 - (55.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	7.224e-005	7.336e-005
Photon Energy Fluence Rate	MeV/cm²/sec	5.876e-005	5.915e-005
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	9.644e-008	9.714e-008
Absorbed Dose Rate in Air	mGy/hr	8.420e-010	8.480e-010
"	mrad/hr	8.420e-008	8.480e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	9.878e-010	9.954e-010
o Opposed	"	8.234e-010	8.292e-010
o Rotational	"	8.231e-010	8.289e-010
o Isotropic	"	7.423e-010	7.475e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.036e-009	1.044e-009
o Opposed	"	9.868e-010	9.941e-010
o Rotational	"	9.868e-010	9.941e-010
o Isotropic	"	7.817e-010	7.873e-010

Microshield External Exposure Calculations at 0.5 meters for the Thorium Series
Table 3

Isotope	Dose conversion factor (Sv/Bq)	Time spent cutting piping (hours)	Breathing rate for time cutting piping (m^3/hr)	Air Concentration (Bq/m^3)	fraction of material available for resuspended from cutting disburbance	Dose Estimate (CED) (Sv)	Dose Estimate (CED) (mrem)/1dpm/100 cm²
U-235	1.97E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
U-238	1.90E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
U-234	2.13E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Pa-231	3.47E-04	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Ac-227	1.81E-03	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Th-230	8.80E-05	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Ra-226	2.32E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Pb-210	3.67E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Th-232	4.43E-04	5.44	1.2	5.51E-09	3.20E-05	1.59E-11	1.59E-06
Ra-228	1.29E-06	5.44	1.2	5.51E-09	3.20E-05	4.64E-14	4.64E-09
Th-228	6.75E-05	5.44	1.2	5.51E-09	3.20E-05	2.43E-12	2.43E-07
Reference	[ICRP, 1995]	[Kennedy, W.E.Jr., and Strenge, D.L., 1992]	[USNRC, 1994]		[Kennedy, W.E.Jr., and Strenge, D.L., 1992]		1.84E-06

Inhalation Calculations[37] for the Thorium Series
Table 4

[37]Note that [USNRC, 1994] is U.S. NRC. Policy and Guidance Directive PG-8-08: Scenario s for Assessing Potential Doses Associated with Residual Radioactivity. 1994; and [ICRP, 1995] is ICRP 72.

Time (seconds)	Release rate (Bq/s)	Total Activity (Bq)	Diffusion distance travelled in x direction (m)	Diffusion distance travelled in y direction (m)	Diffusion distance travelled in z direction (m)	Affected air volume (m^3)	Air Concentration (Bq/m^3)
1	4.51E-10	4.51E-10	3.05E-01	1.52E-01	3.05E-01	1.42E-02	3.19E-08
2	4.51E-10	9.02E-10	6.10E-01	3.04E-01	6.10E-01	1.13E-01	7.97E-09
3	4.51E-10	1.35E-09	9.15E-01	4.56E-01	9.15E-01	3.82E-01	3.54E-09
4	4.51E-10	1.80E-09	1.22E+00	6.08E-01	1.22E+00	9.05E-01	1.99E-09
5	4.51E-10	2.26E-09	1.52E+00	7.60E-01	1.52E+00	1.76E+00	1.28E-09
6	4.51E-10	2.71E-09	1.52E+00	9.12E-01	1.83E+00	2.54E+00	1.07E-09
7	4.51E-10	3.16E-09	1.52E+00	1.06E+00	2.13E+00	3.45E+00	9.14E-10
8	4.51E-10	3.61E-09	1.52E+00	1.22E+00	2.44E+00	4.51E+00	8.00E-10
9	4.51E-10	4.06E-09	1.52E+00	1.37E+00	2.74E+00	5.71E+00	7.11E-10
10	4.51E-10	4.51E-09	1.52E+00	1.52E+00	3.05E+00	7.05E+00	6.40E-10
11	4.51E-10	4.96E-09	1.52E+00	1.67E+00	3.05E-01	7.75E-01	6.41E-09
12	4.51E-10	5.41E-09	1.52E+00	1.82E+00	4.57E-01	1.27E+00	4.27E-09
13	4.51E-10	5.87E-09	1.52E+00	1.98E+00	6.10E-01	1.83E+00	3.20E-09
14	4.51E-10	6.32E-09	1.52E+00	2.13E+00	7.62E-01	2.47E+00	2.56E-09
15	4.51E-10	6.77E-09	1.52E+00	2.28E+00	9.14E-01	3.17E+00	2.14E-09
16	4.51E-10	7.22E-09	1.52E+00	2.43E+00	1.07E+00	3.94E+00	1.83E-09
17	4.51E-10	7.67E-09	1.52E+00	2.58E+00	1.22E+00	4.79E+00	1.60E-09
18	4.51E-10	8.12E-09	1.52E+00	2.74E+00	1.37E+00	5.70E+00	1.42E-09
19	4.51E-10	8.57E-09	1.52E+00	2.89E+00	1.52E+00	6.69E+00	1.28E-09
20	4.51E-10	9.02E-09	1.52E+00	3.00E+00	1.68E+00	7.64E+00	1.18E-09
21	4.51E-10	9.48E-09	1.52E+00	3.00E+00	1.83E+00	8.34E+00	1.14E-09
22	4.51E-10	9.93E-09	1.52E+00	3.00E+00	1.98E+00	9.03E+00	1.10E-09
23	4.51E-10	1.04E-08	1.52E+00	3.00E+00	2.13E+00	9.73E+00	1.07E-09

Table abbreviated and continued below

102	4.51E-10	4.60E-08	1.52E+00	3.00E+00	1.42E+01	6.46E+01	7.12E-10
103	4.51E-10	4.65E-08	1.52E+00	3.00E+00	1.43E+01	6.53E+01	7.11E-10
104	4.51E-10	4.69E-08	1.52E+00	3.00E+00	1.45E+01	6.60E+01	7.11E-10
105	4.51E-10	4.74E-08	1.52E+00	3.00E+00	1.46E+01	6.67E+01	7.10E-10
106	4.51E-10	4.78E-08	1.52E+00	3.00E+00	1.48E+01	6.74E+01	7.10E-10
107	4.51E-10	4.83E-08	1.52E+00	3.00E+00	1.49E+01	6.81E+01	7.09E-10
108	4.51E-10	4.87E-08	1.52E+00	3.00E+00	1.51E+01	6.88E+01	7.08E-10
109	4.51E-10	4.92E-08	1.52E+00	3.00E+00	1.52E+01	6.95E+01	7.08E-10
110	4.51E-10	4.96E-08	1.52E+00	3.00E+00	1.54E+01	7.02E+01	7.07E-10
111	4.51E-10	5.01E-08	1.52E+00	3.00E+00	1.55E+01	7.09E+01	7.07E-10
112	4.51E-10	5.05E-08	1.52E+00	3.00E+00	1.57E+01	7.16E+01	7.06E-10
113	4.51E-10	5.10E-08	1.52E+00	3.00E+00	1.58E+01	7.23E+01	7.05E-10
114	4.51E-10	5.14E-08	1.52E+00	3.00E+00	1.60E+01	7.30E+01	7.05E-10
115	4.51E-10	5.19E-08	1.52E+00	3.00E+00	1.62E+01	7.37E+01	7.04E-10
116	4.51E-10	5.23E-08	1.52E+00	3.00E+00	1.63E+01	7.44E+01	7.04E-10
117	4.51E-10	5.28E-08	1.52E+00	3.00E+00	1.65E+01	7.51E+01	7.03E-10
118	4.51E-10	5.32E-08	1.52E+00	3.00E+00	1.66E+01	7.57E+01	7.03E-10
119	4.51E-10	5.37E-08	1.52E+00	3.00E+00	1.68E+01	7.64E+01	7.02E-10
120	4.51E-10	5.41E-08	1.52E+00	3.00E+00	1.69E+01	7.71E+01	7.02E-10
						Average	1.29E-09

***Air Concentration for a Single Release*[38]**

Table 5

[38] Only a portion of all 120 seconds of a single release was included for basic space considerations. One can observe the progression of airborne activity over time with the beginning and ending times shown. The average represents the average over 120 seconds of exposure.

Cut #	Concentration buildup in Chaseway from subsequent cuts (Bq/m^3)
1	1.29E-09
2	1.94E-09
3	2.59E-09
4	3.24E-09
5	3.89E-09
6	4.54E-09
7	5.19E-09
8	5.84E-09
9	6.48E-09
10	7.13E-09
11	7.78E-09
12	8.43E-09
13	9.08E-09
14	9.73E-09
Average	5.51E-09

Average air concentration in CW-2

Table 6

Isotope	Concentration (Bq/m^2)	Dose conversion factor (Sv/Bq)	Time spent cleaning up and removing piping (hours)	Breathing rate (m^3/hr)	Indoor resuspension factor (per meter)	Dose Estimate (CED) (Sv/y)	Dose Estimate (CED) (mrem/y)
U-235	0.00E+00	1.97E-06	16.8	1.2	0.00005	0.00E+00	0
U-238	0.00E+00	1.90E-06	16.8	1.2	0.00005	0.00E+00	0
U-234	0.00E+00	2.13E-06	16.8	1.2	0.00005	0.00E+00	0
Pa-231	0.00E+00	3.47E-04	16.8	1.2	0.00005	0.00E+00	0
Ac-227	0.00E+00	1.81E-03	16.8	1.2	0.00005	0.00E+00	0
Th-230	0.00E+00	8.80E-05	16.8	1.2	0.00005	0.00E+00	0
Ra-226	0.00E+00	2.32E-06	16.8	1.2	0.00005	0.00E+00	0
Pb-210	0.00E+00	3.67E-06	16.8	1.2	0.00005	0.00E+00	0
Th-232	2.72E-08	4.43E-04	16.8	1.2	0.00005	1.21E-14	1.21E-09
Ra-228	2.72E-08	1.29E-06	16.8	1.2	0.00005	3.54E-17	3.54E-12
Th-228	2.72E-08	6.75E-05	16.8	1.2	0.00005	1.85E-15	1.85E-10
Reference		[ICRP, 1995]		[USNRC, 1994]	[Kennedy, W.E.Jr., and Strenge, D.L., 1992]		1.40E-09

Inhalation Resuspension Calculations for the Thorium Series

Table 7

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1T.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 11:26:43 PM
Dose Point # 1 - (12.7,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	3.597e-004	3.614e-004
Photon Energy Fluence Rate	MeV/cm²/sec	2.917e-004	2.923e-004
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	4.789e-007	4.800e-007
Absorbed Dose Rate in Air	mGy/hr	4.181e-009	4.190e-009
"	mrad/hr	4.181e-007	4.190e-007
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	4.906e-009	4.917e-009
o Opposed	"	4.088e-009	4.097e-009
o Rotational	"	4.087e-009	4.095e-009
o Isotropic	"	3.686e-009	3.693e-009
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	5.145e-009	5.157e-009
o Opposed	"	4.900e-009	4.911e-009
o Rotational	"	4.900e-009	4.911e-009
o Isotropic	"	3.882e-009	3.890e-009

Microshield External Exposure Calculations at 0.0076 meters for the Thorium Series
Table 8

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AT2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:59 AM
Dose Point # 2 - (302.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.827e-006	4.792e-006
Photon Energy Fluence Rate	MeV/cm²/sec	2.057e-006	3.319e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	3.280e-009	5.461e-009
Absorbed Dose Rate in Air	mGy/hr	2.864e-011	4.767e-011
"	mrad/hr	2.864e-009	4.767e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.307e-011	5.649e-011
o Opposed	"	2.826e-011	4.650e-011
o Rotational	"	2.826e-011	4.647e-011
o Isotropic	"	2.552e-011	4.196e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.471e-011	5.912e-011
o Opposed	"	3.332e-011	5.604e-011
o Rotational	"	3.332e-011	5.604e-011
o Isotropic	"	2.679e-011	4.421e-011

Microshield External Calculations at 3 meters for the Thorium Series
Table 9

ATTACHMENT 3

Calculations for the Renovation Scenario

(Radium & Progeny)

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1R.MS5
Case Title: Embedded piping
This case was run on Thursday, November 18, 2004 at 12:08:09 PM
Dose Point # 2 - (105.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	2.534e-005	2.589e-005
Photon Energy Fluence Rate	MeV/cm²/sec	1.918e-005	1.941e-005
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	3.368e-008	3.409e-008
Absorbed Dose Rate in Air	mGy/hr	2.940e-010	2.976e-010
"	mrad/hr	2.940e-008	2.976e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.459e-010	3.503e-010
o Opposed	"	2.854e-010	2.889e-010
o Rotational	"	2.853e-010	2.888e-010
o Isotropic	"	2.551e-010	2.582e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.636e-010	3.682e-010
o Opposed	"	3.468e-010	3.512e-010
o Rotational	"	3.468e-010	3.512e-010
o Isotropic	"	2.696e-010	2.729e-010

Microshield External Exposure Calculations at 1 meter for Radium and Progeny
Table 1

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1R.MS5
Case Title: Embedded piping
This case was run on Thursday, November 18, 2004 at 12:08:09 PM
Dose Point # 6 - (205.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.112e-005	1.151e-005
Photon Energy Fluence Rate	MeV/cm²/sec	8.438e-006	8.602e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	1.481e-008	1.511e-008
Absorbed Dose Rate in Air	mGy/hr	1.293e-010	1.319e-010
"	mrad/hr	1.293e-008	1.319e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.521e-010	1.553e-010
o Opposed	"	1.256e-010	1.280e-010
o Rotational	"	1.255e-010	1.280e-010
o Isotropic	"	1.122e-010	1.144e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.599e-010	1.632e-010
o Opposed	"	1.526e-010	1.557e-010
o Rotational	"	1.526e-010	1.557e-010
o Isotropic	"	1.186e-010	1.210e-010

Microshield External Exposure Calculations at 2 meters for Radium and Progeny
Table 2

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1R.MS5
Case Title: Embedded piping
This case was run on Thursday, November 18, 2004 at 12:08:09 PM
Dose Point # 5 - (55.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	5.224e-005	5.295e-005
Photon Energy Fluence Rate	MeV/cm²/sec	3.947e-005	3.976e-005
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	6.932e-008	6.985e-008
Absorbed Dose Rate in Air	mGy/hr	6.051e-010	6.098e-010
"	mrad/hr	6.051e-008	6.098e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.120e-010	7.177e-010
o Opposed	"	5.874e-010	5.919e-010
o Rotational	"	5.872e-010	5.917e-010
o Isotropic	"	5.250e-010	5.290e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.484e-010	7.544e-010
o Opposed	"	7.139e-010	7.195e-010
o Rotational	"	7.139e-010	7.195e-010
o Isotropic	"	5.550e-010	5.592e-010

Microshield External Exposure Calculations at 0.5 meters for Radium and Progeny
Table 3

Isotope	Dose conversion factor (Sv/Bq)	Time spent cutting piping (hours)	Breathing rate for time cutting piping (m^3/hr)	Air Concentration (Bq/m^3)	fraction of material available for resuspended from cutting disburbance	Dose Estimate (CED) (Sv)	Dose Estimate (CED) (mrem)/1dpm/100 cm²
U-235	1.97E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
U-238	1.90E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
U-234	2.13E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Pa-231	3.47E-04	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Ac-227	1.81E-03	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Th-230	8.80E-05	5.44	1.2	5.51E-09	3.20E-05	3.16E-12	3.16E-07
Ra-226	2.32E-06	5.44	1.2	5.51E-09	3.20E-05	8.34E-14	8.34E-09
Pb-210	3.67E-06	5.44	1.2	5.51E-09	3.20E-05	1.32E-13	1.32E-08
Th-232	4.43E-04	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Ra-228	1.29E-06	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Th-228	6.75E-05	5.44	1.2		3.20E-05	0.00E+00	0.00E+00
Reference	[ICRP, 1995]	[Kennedy, W.E.Jr., and Strenge, D.L., 1992]	[USNRC, 1994]		[Kennedy, W.E.Jr., and Strenge, D.L., 1992]		3.38E-07

Inhalation Calculations[39] for Radium and Progeny
Table 4

[39]Note that [USNRC, 1994] is U.S. NRC. Policy and Guidance Directive PG-8-08: Scenario s for Assessing Potential Doses Associated with Residual Radioactivity. 1994; and [ICRP, 1995] is ICRP 72.

Time (seconds)	Release rate (Bq/s)	Total Activity (Bq)	Diffusion distance travelled in x direction (m)	Diffusion distance travelled in y direction (m)	Diffusion distance travelled in z direction (m)	Affected air volume (m^3)	Air Concentration (Bq/m^3)
1	4.51E-10	4.51E-10	3.05E-01	1.52E-01	3.05E-01	1.42E-02	3.19E-08
2	4.51E-10	9.02E-10	6.10E-01	3.04E-01	6.10E-01	1.13E-01	7.97E-09
3	4.51E-10	1.35E-09	9.15E-01	4.56E-01	9.15E-01	3.82E-01	3.54E-09
4	4.51E-10	1.80E-09	1.22E+00	6.08E-01	1.22E+00	9.05E-01	1.99E-09
5	4.51E-10	2.26E-09	1.52E+00	7.60E-01	1.52E+00	1.76E+00	1.28E-09
6	4.51E-10	2.71E-09	1.52E+00	9.12E-01	1.83E+00	2.54E+00	1.07E-09
7	4.51E-10	3.16E-09	1.52E+00	1.06E+00	2.13E+00	3.45E+00	9.14E-10
8	4.51E-10	3.61E-09	1.52E+00	1.22E+00	2.44E+00	4.51E+00	8.00E-10
9	4.51E-10	4.06E-09	1.52E+00	1.37E+00	2.74E+00	5.71E+00	7.11E-10
10	4.51E-10	4.51E-09	1.52E+00	1.52E+00	3.05E+00	7.05E+00	6.40E-10
11	4.51E-10	4.96E-09	1.52E+00	1.67E+00	3.05E-01	7.75E-01	6.41E-09
12	4.51E-10	5.41E-09	1.52E+00	1.82E+00	4.57E-01	1.27E+00	4.27E-09
13	4.51E-10	5.87E-09	1.52E+00	1.98E+00	6.10E-01	1.83E+00	3.20E-09
14	4.51E-10	6.32E-09	1.52E+00	2.13E+00	7.62E-01	2.47E+00	2.56E-09
15	4.51E-10	6.77E-09	1.52E+00	2.28E+00	9.14E-01	3.17E+00	2.14E-09
16	4.51E-10	7.22E-09	1.52E+00	2.43E+00	1.07E+00	3.94E+00	1.83E-09
17	4.51E-10	7.67E-09	1.52E+00	2.58E+00	1.22E+00	4.79E+00	1.60E-09
18	4.51E-10	8.12E-09	1.52E+00	2.74E+00	1.37E+00	5.70E+00	1.42E-09
19	4.51E-10	8.57E-09	1.52E+00	2.89E+00	1.52E+00	6.69E+00	1.28E-09
20	4.51E-10	9.02E-09	1.52E+00	3.00E+00	1.68E+00	7.64E+00	1.18E-09
21	4.51E-10	9.48E-09	1.52E+00	3.00E+00	1.83E+00	8.34E+00	1.14E-09
22	4.51E-10	9.93E-09	1.52E+00	3.00E+00	1.98E+00	9.03E+00	1.10E-09
23	4.51E-10	1.04E-08	1.52E+00	3.00E+00	2.13E+00	9.73E+00	1.07E-09

Table abbreviated and continued below

102	4.51E-10	4.60E-08	1.52E+00	3.00E+00	1.42E+01	6.46E+01	7.12E-10
103	4.51E-10	4.65E-08	1.52E+00	3.00E+00	1.43E+01	6.53E+01	7.11E-10
104	4.51E-10	4.69E-08	1.52E+00	3.00E+00	1.45E+01	6.60E+01	7.11E-10
105	4.51E-10	4.74E-08	1.52E+00	3.00E+00	1.46E+01	6.67E+01	7.10E-10
106	4.51E-10	4.78E-08	1.52E+00	3.00E+00	1.48E+01	6.74E+01	7.10E-10
107	4.51E-10	4.83E-08	1.52E+00	3.00E+00	1.49E+01	6.81E+01	7.09E-10
108	4.51E-10	4.87E-08	1.52E+00	3.00E+00	1.51E+01	6.88E+01	7.08E-10
109	4.51E-10	4.92E-08	1.52E+00	3.00E+00	1.52E+01	6.95E+01	7.08E-10
110	4.51E-10	4.96E-08	1.52E+00	3.00E+00	1.54E+01	7.02E+01	7.07E-10
111	4.51E-10	5.01E-08	1.52E+00	3.00E+00	1.55E+01	7.09E+01	7.07E-10
112	4.51E-10	5.05E-08	1.52E+00	3.00E+00	1.57E+01	7.16E+01	7.06E-10
113	4.51E-10	5.10E-08	1.52E+00	3.00E+00	1.58E+01	7.23E+01	7.05E-10
114	4.51E-10	5.14E-08	1.52E+00	3.00E+00	1.60E+01	7.30E+01	7.05E-10
115	4.51E-10	5.19E-08	1.52E+00	3.00E+00	1.62E+01	7.37E+01	7.04E-10
116	4.51E-10	5.23E-08	1.52E+00	3.00E+00	1.63E+01	7.44E+01	7.04E-10
117	4.51E-10	5.28E-08	1.52E+00	3.00E+00	1.65E+01	7.51E+01	7.03E-10
118	4.51E-10	5.32E-08	1.52E+00	3.00E+00	1.66E+01	7.57E+01	7.03E-10
119	4.51E-10	5.37E-08	1.52E+00	3.00E+00	1.68E+01	7.64E+01	7.02E-10
120	4.51E-10	5.41E-08	1.52E+00	3.00E+00	1.69E+01	7.71E+01	7.02E-10
						Average	1.29E-09

Air Concentration for a Single Release[40]

Table 5

[40] Only a portion of all 120 seconds of a single release was included for basic space considerations. One can observe the progression of airborne activity over time with the beginning and ending times shown. The average represents the average over 120 seconds of exposure.

Cut #	Concentration buildup in Chaseway from subsequent cuts (Bq/m^3)
1	1.29E-09
2	1.94E-09
3	2.59E-09
4	3.24E-09
5	3.89E-09
6	4.54E-09
7	5.19E-09
8	5.84E-09
9	6.48E-09
10	7.13E-09
11	7.78E-09
12	8.43E-09
13	9.08E-09
14	9.73E-09
Average	5.51E-09

Average air concentration in CW-2

Table 6

Isotope	Concentration (Bq/m^2)	Dose conversion factor (Sv/Bq)	Time spent cleaning up and removing piping (hours)	Breathing rate (m^3/hr)	Indoor resuspension factor (per meter)	Dose Estimate (CED) (Sv/y)	Dose Estimate (CED) (mrem/y)
U-235	0.00E+00	1.97E-06	16.8	1.2	0.00005	0.00E+00	0
U-238	0.00E+00	1.90E-06	16.8	1.2	0.00005	0.00E+00	0
U-234	0.00E+00	2.13E-06	16.8	1.2	0.00005	0.00E+00	0
Pa-231	0.00E+00	3.47E-04	16.8	1.2	0.00005	0.00E+00	0
Ac-227	0.00E+00	1.81E-03	16.8	1.2	0.00005	0.00E+00	0
Th-230	2.72E-08	8.80E-05	16.8	1.2	0.00005	2.41E-15	2.41E-10
Ra-226	2.72E-08	2.32E-06	16.8	1.2	0.00005	6.36E-17	6.36E-12
Pb-210	2.72E-08	3.67E-06	16.8	1.2	0.00005	1.01E-16	1.01E-11
Th-232	0.00E+00	4.43E-04	16.8	1.2	0.00005	0.00E+00	0.00E+00
Ra-228	0.00E+00	1.29E-06	16.8	1.2	0.00005	0.00E+00	0.00E+00
Th-228	0.00E+00	6.75E-05	16.8	1.2	0.00005	0.00E+00	0.00E+00
Reference		[ICRP, 1995]		[USNRC, 1994]	[Kennedy, W.E.Jr., and Strenge, D.L., 1992]		2.58E-10

Inhalation Resuspension Calculations for Radium and Progeny

Table 7

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1R.MS5
Case Title: Embedded piping
This case was run on Thursday, November 18, 2004 at 12:08:09 PM
Dose Point # 1 - (12.7,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	2.600e-004	2.611e-004
Photon Energy Fluence Rate	MeV/cm²/sec	1.960e-004	1.965e-004
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	3.443e-007	3.452e-007
Absorbed Dose Rate in Air	mGy/hr	3.006e-009	3.013e-009
"	mrad/hr	3.006e-007	3.013e-007
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.537e-009	3.546e-009
o Opposed	"	2.918e-009	2.925e-009
o Rotational	"	2.917e-009	2.924e-009
o Isotropic	"	2.608e-009	2.614e-009
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.718e-009	3.727e-009
o Opposed	"	3.547e-009	3.555e-009
o Rotational	"	3.547e-009	3.555e-009
o Isotropic	"	2.757e-009	2.763e-009

Microshield External Exposure Calculations at 0.0076 meters for Radium and Progeny
Table 8

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AR2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:41 AM
Dose Point # 2 - (302.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.371e-006	3.217e-006
Photon Energy Fluence Rate	MeV/cm²/sec	1.289e-006	2.212e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.229e-009	3.890e-009
Absorbed Dose Rate in Air	mGy/hr	1.946e-011	3.396e-011
"	mrad/hr	1.946e-009	3.396e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.261e-011	4.020e-011
o Opposed	"	1.901e-011	3.291e-011
o Rotational	"	1.901e-011	3.290e-011
o Isotropic	"	1.700e-011	2.943e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.380e-011	4.221e-011
o Opposed	"	2.284e-011	4.015e-011
o Rotational	"	2.284e-011	4.015e-011
o Isotropic	"	1.793e-011	3.112e-011

Microshield External Calculations at 3 meters for Radium and Progeny
Table 9

ATTACHMENT 4

Calculations for the Occupational Scenario

(U-238 through U-234)

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AU2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:41:15 AM
Dose Point # 3 - (152.54,500.0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	9.983e-008	6.796e-007
Photon Energy Fluence Rate	MeV/cm²/sec	3.273e-008	1.117e-007
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	5.886e-011	1.935e-010
Absorbed Dose Rate in Air	mGy/hr	5.139e-013	1.689e-012
"	mrad/hr	5.139e-011	1.689e-010
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	6.451e-013	2.384e-012
o Opposed	"	4.870e-013	1.571e-012
o Rotational	"	4.866e-013	1.565e-012
o Isotropic	"	4.383e-013	1.447e-012
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	6.738e-013	2.430e-012
o Opposed	"	6.174e-013	2.078e-012
o Rotational	"	6.174e-013	2.078e-012
o Isotropic	"	4.680e-013	1.541e-012

Microshield External Exposure Calculations at 1.5 meters for U-238 to U-234
Table 1

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AU2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:41:15 AM
Dose Point # 2 - (302.54,500.0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	4.599e-008	3.024e-007
Photon Energy Fluence Rate	MeV/cm²/sec	1.472e-008	4.858e-008
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.645e-011	8.408e-011
Absorbed Dose Rate in Air	mGy/hr	2.309e-013	7.340e-013
"	mrad/hr	2.309e-011	7.340e-011
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.908e-013	1.041e-012
o Opposed	"	2.187e-013	6.824e-013
o Rotational	"	2.185e-013	6.793e-013
o Isotropic	"	1.969e-013	6.289e-013
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.035e-013	1.060e-012
o Opposed	"	2.776e-013	9.036e-013
o Rotational	"	2.776e-013	9.036e-013
o Isotropic	"	2.103e-013	6.695e-013

Microshield External Exposure Calculations at 3 meters for U-238 to U-234
Table 2

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AU2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:41:15 AM
Dose Point # 4 - (502.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	2.277e-008	1.445e-007
Photon Energy Fluence Rate	MeV/cm²/sec	7.133e-009	2.292e-008
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	1.281e-011	3.968e-011
Absorbed Dose Rate in Air	mGy/hr	1.118e-013	3.464e-013
"	mrad/hr	1.118e-011	3.464e-011
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.412e-013	4.925e-013
o Opposed	"	1.058e-013	3.220e-013
o Rotational	"	1.057e-013	3.204e-013
o Isotropic	"	9.536e-014	2.968e-013
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.472e-013	5.014e-013
o Opposed	"	1.345e-013	4.265e-013
o Rotational	"	1.345e-013	4.265e-013
o Isotropic	"	1.018e-013	3.160e-013

Microshield External Exposure Calculations at 5 meters for U-238 to U-234
Table 3

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1U.MS5
Case Title: Embedded piping
This case was run on Thursday, November 18, 2004 at 4:10:45 PM
Dose Point # 4 - (155.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.149e-006	1.231e-006
Photon Energy Fluence Rate	MeV/cm²/sec	2.086e-007	2.176e-007
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	3.794e-010	3.961e-010
Absorbed Dose Rate in Air	mGy/hr	3.312e-012	3.458e-012
"	mrad/hr	3.312e-010	3.458e-010
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	4.492e-012	4.710e-012
o Opposed	"	3.051e-012	3.180e-012
o Rotational	"	3.027e-012	3.154e-012
o Isotropic	"	2.778e-012	2.898e-012
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	4.623e-012	4.844e-012
o Opposed	"	3.991e-012	4.167e-012
o Rotational	"	3.991e-012	4.167e-012
o Isotropic	"	2.980e-012	3.109e-012

Microshield External Exposure Calculations at 1.5 meters for U-238 to U-234
Table 4

ATTACHMENT 5

Calculations for the Occupational Scenario

(Thorium Series)

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AT2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:59 AM
Dose Point # 3 - (152.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	4.096e-006	1.111e-005
Photon Energy Fluence Rate	MeV/cm²/sec	4.702e-006	7.850e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	7.478e-009	1.290e-008
Absorbed Dose Rate in Air	mGy/hr	6.529e-011	1.127e-010
"	mrad/hr	6.529e-009	1.127e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.532e-011	1.333e-010
o Opposed	"	6.447e-011	1.099e-010
o Rotational	"	6.447e-011	1.099e-010
o Isotropic	"	5.824e-011	9.918e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	7.906e-011	1.396e-010
o Opposed	"	7.593e-011	1.324e-010
o Rotational	"	7.593e-011	1.324e-010
o Isotropic	"	6.111e-011	1.045e-010

Microshield External Exposure Calculations at 1.5 meters for Th-232 and Progeny
Table 1

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AT2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:59 AM
Dose Point # 2 - (302.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.827e-006	4.792e-006
Photon Energy Fluence Rate	MeV/cm²/sec	2.057e-006	3.319e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	3.280e-009	5.461e-009
Absorbed Dose Rate in Air	mGy/hr	2.864e-011	4.767e-011
"	mrad/hr	2.864e-009	4.767e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.307e-011	5.649e-011
o Opposed	"	2.826e-011	4.650e-011
o Rotational	"	2.826e-011	4.647e-011
o Isotropic	"	2.552e-011	4.196e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.471e-011	5.912e-011
o Opposed	"	3.332e-011	5.604e-011
o Rotational	"	3.332e-011	5.604e-011
o Isotropic	"	2.679e-011	4.421e-011

Microshield External Exposure Calculations at 3 meters for Th-232 and Progeny
Table 2

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AT2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:59 AM
Dose Point # 4 - (502.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	8.798e-007	2.251e-006
Photon Energy Fluence Rate	MeV/cm²/sec	9.784e-007	1.547e-006
Exposure and Dose Rates			
Exposure Rate in Air	mR/hr	1.562e-009	2.545e-009
Absorbed Dose Rate in Air	mGy/hr	1.364e-011	2.222e-011
"	mrad/hr	1.364e-009	2.222e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.576e-011	2.635e-011
o Opposed	"	1.345e-011	2.167e-011
o Rotational	"	1.345e-011	2.166e-011
o Isotropic	"	1.215e-011	1.956e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.654e-011	2.757e-011
o Opposed	"	1.588e-011	2.612e-011
o Rotational	"	1.588e-011	2.612e-011
o Isotropic	"	1.275e-011	2.061e-011

Microshield External Exposure Calculations at 5 meters for Th-232 and Progeny
Table 3

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1T.MS5
Case Title: Embedded piping
This case was run on Wednesday, November 17, 2004 at 11:26:43 PM
Dose Point # 4 - (155.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	2.195e-005	2.268e-005
Photon Energy Fluence Rate	MeV/cm²/sec	1.795e-005	1.820e-005
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.945e-008	2.990e-008
Absorbed Dose Rate in Air	mGy/hr	2.571e-010	2.610e-010
"	mrad/hr	2.571e-008	2.610e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.015e-010	3.064e-010
o Opposed	"	2.514e-010	2.552e-010
o Rotational	"	2.513e-010	2.551e-010
o Isotropic	"	2.267e-010	2.300e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	3.162e-010	3.213e-010
o Opposed	"	3.013e-010	3.060e-010
o Rotational	"	3.013e-010	3.060e-010
o Isotropic	"	2.387e-010	2.423e-010

Microshield External Exposure Calculations at 1.5 meters for Th-232 and Progeny
Table 4

ATTACHMENT 6

Calculations for the Occupational Scenario

(Radium and Progeny)

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AR2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:41 AM
Dose Point # 3 - (152.54,500.0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	3.071e-006	7.493e-006
Photon Energy Fluence Rate	MeV/cm²/sec	2.923e-006	5.223e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	5.047e-009	9.185e-009
Absorbed Dose Rate in Air	mGy/hr	4.406e-011	8.018e-011
"	mrad/hr	4.406e-009	8.018e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	5.117e-011	9.483e-011
o Opposed	"	4.308e-011	7.772e-011
o Rotational	"	4.307e-011	7.769e-011
o Isotropic	"	3.652e-011	6.949e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	5.387e-011	9.958e-011
o Opposed	"	5.170e-011	9.477e-011
o Rotational	"	5.170e-011	9.477e-011
o Isotropic	"	4.063e-011	7.347e-011

Microshield External Exposure Calculations at 1.5 meters for Ra-226 and Progeny

Table 1

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AR2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:41 AM
Dose Point # 2 - (302.54,500.0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.371e-006	3.217e-006
Photon Energy Fluence Rate	MeV/cm²/sec	1.289e-006	2.212e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.229e-009	3.890e-009
Absorbed Dose Rate in Air	mGy/hr	1.946e-011	3.396e-011
"	mrad/hr	1.946e-009	3.396e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.261e-011	4.020e-011
o Opposed	"	1.901e-011	3.291e-011
o Rotational	"	1.901e-011	3.290e-011
o Isotropic	"	1.700e-011	2.943e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.380e-011	4.221e-011
o Opposed	"	2.284e-011	4.015e-011
o Rotational	"	2.284e-011	4.015e-011
o Isotropic	"	1.793e-011	3.112e-011

Microshield External Exposure Calculations at 3 meters for Ra-226 and Progeny

Table 2

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPP1AR2.MS5
Case Title: Embedded piping
This case was run on Sunday, November 21, 2004 at 8:40:41 AM
Dose Point # 4 - (502.54,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	6.599e-007	1.510e-006
Photon Energy Fluence Rate	MeV/cm²/sec	6.157e-007	1.031e-006
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	1.065e-009	1.814e-009
Absorbed Dose Rate in Air	mGy/hr	9.300e-012	1.584e-011
"	mrad/hr	9.300e-010	1.584e-009
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.081e-011	1.875e-011
o Opposed	"	9.085e-012	1.535e-011
o Rotational	"	9.084e-012	1.534e-011
o Isotropic	"	8.123e-012	1.372e-011
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	1.138e-011	1.969e-011
o Opposed	"	1.092e-011	1.872e-011
o Rotational	"	1.092e-011	1.872e-011
o Isotropic	"	8.570e-012	1.451e-011

Microshield External Exposure Calculations at 5 meters for Ra-226 and Progeny
Table 3

Conversion of calculated exposure in air to dose
FILE: C:\MS5\DATA\TECHCE~1\TCPIPE1R.MS5
Case Title: Embedded piping
This case was run on Thursday, November 18, 2004 at 12:08:09 PM
Dose Point # 4 - (155.08,500,0) cm

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1.589e-005	1.635e-005
Photon Energy Fluence Rate	MeV/cm²/sec	1.205e-005	1.224e-005
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2.115e-008	2.149e-008
Absorbed Dose Rate in Air	mGy/hr	1.846e-010	1.876e-010
"	mrad/hr	1.846e-008	1.876e-008
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.172e-010	2.209e-010
o Opposed	"	1.793e-010	1.821e-010
o Rotational	"	1.792e-010	1.821e-010
o Isotropic	"	1.602e-010	1.628e-010
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2.283e-010	2.322e-010
o Opposed	"	2.178e-010	2.214e-010
o Rotational	"	2.178e-010	2.214e-010
o Isotropic	"	1.693e-010	1.721e-010

Microshield External Exposure Calculations at 1.5 meters for Ra-226 and Progeny
Table 4