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DOSE RATE ANALYSIS
FOR
TANK AZ-101
PROJECT W-151

NOVEMBER 1994

R. A. Schwarz

K. E. Hillesland

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Westinghouse Hanford Company
Hanford operations and Engineering Contractor
for the
U. S. Department of Energy

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1. INTRODUCTION

This report documents calculated dose rates resulting from modifications to tank 101 AZ by project W-151. The scope of the calculational effort was defined in Reference 1 along with subsequent discussions and clarification of details. The thrust of the effort is to determine dose rates from: modification of a steam coil and caisson; the installation of mixer pumps; the installation of temperature probes; and estimates of dose rates that will be encountered while making these changes. Because the dose rates for all of these configurations depend upon the photon source within the supernate and sludge, comparisons were also made between measured dose rates within a drywell and the corresponding calculated dose rates. The calculational tool used is a Monte Carlo (MCNP²) code since complicated three dimensional geometries are involved.

A summary of the most important results of the entire study is given in Section 2. The basic calculational geometry model of the tank is discussed in Section 3, along with a tabulation of the photon sources that were used within the supernate and the sludge, and a discussion of uncertainties. The calculated dose rates around the steam coil and caisson before and after modification are discussed in Section 4. The configuration for the installation of the mixer pumps and the resulting dose rates are given in Section 5. The predicted changes in dose rates due to a possible dilution of the supernate source are given in Section 6. The calculational configuration used to model the installation of temperature probes and the resulting predicted dose rates are discussed in Section 7. Finally, comparisons of measured to calculated dose rates within a drywell are summarized in Section 8. Extended discussions of calculational models and Monte Carlo optimization techniques used are included in Appendix A.

2. SUMMARY

Dose rates were calculated for modifications to a steam coil, installation of a mixer pump, and installation of temperature probes. The most important results are:

- Calculations were compared to some measurements that have been made above the current steam coil. The calculations over predict the dose rates along the top of the caisson, but under predict the dose rate along the 2" condensate line above the top of the caisson. The calculations also predict a dose rate of about 180 mrem/hr at a higher elevation directly above the bend in this line, but this dose rate (calculational predicted to be higher than anywhere else) was not surveyed.
- The calculations for the modified steam coil configuration predict that areas around the caisson where dose rates exceed 1 mrem/hr are very local and less than 2 mrem/hr. Taking into account the conservatism in

the source, (factor of 1.9 discussed below) in the calculations, these maximum local dose rates should actually be about 1 mrem/hr.

- Predicted dose rates radially beyond the base of the mixer pump were substantially less than 2 mrem/hr with the calculational model utilized. However, there must be 11.43cm (4.5") of steel (12.06cm[4.75"] for 2σ upper limit) directly above the extended riser in order to reduce dose rates to 2 mrem/hr. These results are based upon a concrete radiation shield of 41.91cm(16.5") in axial height located near the base of the riser. Calculations were also made for radiation shields of water and steel and for various axial heights.
- Dose rates have been calculated for two types of 6" risers, within which temperature probes potentially could be installed.

All of the dose rates calculated for the final configuration of this equipment are below 2 mrem/hr. After taking into account the conservatism (factor of 1.9 discussed below) in the source, they are below about 1 mrem/hr.

Dose rate contours were also obtained for various stages during some of the modifications to aid in minimizing dose exposure.

A calculational to experimental (C/E) comparison was made for dose rates inside of a drywell in order to better understand the conservatism in the source being used in the calculations. The results indicate the calculational source within the supernate is conservative by about a factor of 1.9 and within the sludge is conservative by a factor of about 3.4.

3. GEOMETRY, SOURCE AND UNCERTAINTIES

3.1 CALCULATIONAL MODEL OF THE TANK

Figure 1 is an elevation view of the tank showing the unmodified steam coil configuration. The scales along the abscissa and ordinate are in centimeters and are with respect to the center of the plot (the + on Figure 1). Certain aspects of the calculational model shown in Figure 1 are related to making the Monte Carlo calculation more efficient. The dashed circle at the bottom of the steam coil riser is a sphere that is used to preferentially scatter random walk photons during collisions within the supernate into the appropriate small solid angle to reach the bottom of the riser for the steam coil. The small cells at the top of the supernate, that are directly under this steam coil riser, are used to preferentially sample the most important portion of the photon source. For each of the other calculations, the geometry model is changed so that these small cells are moved under the riser of interest and the sphere is moved to bottom of the riser of interest.

The geometry model for the tank was formed using information from References 3 and 4 to obtain locations along the top of the tank and the types of risers,

References 5 and 6 for general tank dimensions and contours, Reference 7 for information on risers; and Reference 8 for the steam coil assembly in the tank.

Densities of materials that were used in the Monte Carlo calculations are shown in Table 1.

Table 1. Densities of Materials Used in the Calculations.

<u>Material</u>	<u>Density (g/cm³)</u>
Ordinary Concrete	2.26
Magnetite Concrete	3.28
Iron (most steel)	7.80
Soil	1.67
Supernate (p. 8 Ref. 9)	1.21
Sludge	1.70
Air	0.0012

3.2 SOURCES

ORIGEN calculations were made using radionuclides concentrations from the bottom of Table 1 in Reference 9 for the supernate and the sludge. The resulting spectra used in the Monte Carlo calculations are shown in Table 2. The second column of this table shows the number of photons emitted at the energy indicated in the left hand column per gram of the material per second, where the total number of photons emitted is 1.002×10^8 photons/second per gram of supernate and 2.540×10^9 photons/second per gram of sludge. Even though the emission rate per gram in the sludge is 25 times that of the supernate, the important 0.662 MeV energy line is only 64% greater in the sludge than in the supernate; i.e., the sludge spectrum has a lot more low energy photons that are attenuated rapidly -- mostly within the sludge itself. More importantly, in most of the calculations reported here the supernate attenuates the photons from the sludge, since it is between the sludge and the riser, so in those cases the sludge is a small contributor compared to the supernate.

The right-hand column of Table 2 is proportional to the number of photons that were sampled for each energy line in the Monte Carlo calculation. The calculation actually samples the higher energy photons much more preferentially since these high energy photons have a much higher probability of escaping from the source region and reaching the vicinity of interest. This oversampling of the high energy photons in the random walk is accounted for in the calculation by reducing the weight (future contribution) of these high energy photons to obtain unbiased results; i.e., the statistical uncertainty in the Monte Carlo calculation is reduced by preferentially sampling higher energy photons, but the expected value is an invariant.

Section 8.0 of this report summarizes comparisons of calculations to measurements that were made in two dry wells. The calculated dose rates were generally about 1.9 times higher than measured for the supernate, and 3.4 times higher for the sludge, so there is some built in conservatism for all the calculations reported here. Recently it was discovered that the ORIGEN calculations were made within a source material of UO_2 rather than a lower density source material that would correspond more closely to the effective atomic "Z" of supernate or sludge. This "Z" is used for the production of bremsstrahlung photons from electrons emitted in the decay process. Subsequent ORIGEN calculations indicate that the higher energy portion of the photon source is reduced by about 25% with this change for the supernate. However, we have decided to retain this added conservatism rather than repeating all the calculations that have been made.

3.3 UNCERTAINTIES

Uncertainties in the calculations include:

- the radioisotope concentrations in the supernate that produce the photon source;
- material densities and compositions;
- dimensions and elevations;
- statistical uncertainties in the Monte Carlo random walks.

It is estimated that the above uncertainties, excluding the source, at the 2σ confidence level would increase the calculated nominal dose rates by about 40%. Since the source is conservative (factor of 1.9) by more than this amount, the numbers given in this summary can be considered to be upper limit.

In most cases the one standard deviation statistical uncertainty from the MCNP program, is less than 10%. If the statistical uncertainty is greater than 20%, either a comment is given or a ~ sign is used.

Table 2. Photon Source Spectra Used in the Calculations.

Supernate:		
Energy (MeV)	Number (p/g-s)	Unnormalized Number Sampled in Calculation
1.500E-02	9.844E+06	9.844
2.500E-02	2.298E+06	2.298
3.750E-02	6.188E+06	6.188
5.750E-02	1.508E+06	1.508
8.500E-02	8.045E+05	0.805
1.250E-01	5.830E+05	0.583
2.250E-01	5.463E+05	0.546
3.750E-01	5.572E+05	0.800
6.620E-01*	7.759E+07	160.0
8.500E-01	1.323E+05	0.30
1.250E+00	1.496E+05	0.60
1.750E+00	1.086E+04	0.11
2.250E+00	5.201E+03	0.11
2.750E+00	3.295E+02	0.05
3.500E+00	4.271E+01	0.02
5.000E+00	2.487E-06	0.01
7.000E+00	2.854E-07	0.01
1.100E+01	3.270E-08	0.01
total	1.002+8	photons/gram/second

Sludge:

Energy (MeV)	Number (p/g-s)	Unnormalized Number Sampled in Calculation
1.500E-02	1.211E+09	6.0
2.500E-02	2.656E+08	2.656
3.750E-02	1.913E+08	1.913
5.750E-02	2.456E+08	2.456
8.500E-02	1.520E+08	1.520
1.250E-01	1.176E+08	1.176
2.250E-01	1.359E+08	1.359
3.750E-01	6.789E+07	0.6789
6.620E-01*	1.273E+08	3.0
8.500E-01	1.412E+07	0.30
1.250E+00	9.272E+06	0.40
1.750E+00	8.525E+05	0.09
2.250E+00	1.255E+06	0.13
2.750E+00	1.940E+04	0.05
3.500E+00	2.403E+03	0.02
5.000E+00	6.497E-03	0.01
7.000E+00	7.363E-04	0.01
1.100E+01	8.373E-05	0.01
TOTAL	2.540E+09	photons/gram/second

* This source energy was changed from 0.575 to 0.662 MeV to accurately represent the ^{137}mBa gamma ray.

4. DOSE RATES AROUND STEAM COIL

4.1 SUMMARY

To accommodate the installation of a mixer pump in the tank, the current steam coil in riser 7A needs to be raised three feet so that the bottom of the coil is out of the flow of the pump. Additionally the current steam coil pipes were modified to reduce radiation streaming, while maintaining the same depth of earth covering within the caisson, for shielding.

Dose rates were calculated both for the current steam coil and for the steam coil after modification. Since some measurements were made above the caisson for the current configuration, calculations were made to compare to these measurements. The calculations over predict the dose rates along the top of the caisson, but under predict the dose rate along the 2" condensate line above the top of the caisson. The calculations also predict a dose rate of about 180 mrem/hr at a higher elevation directly above the bend in this line, but this dose rate (calculational predicted to be higher than anywhere else) was not surveyed.

The calculations for the modified steam coil configuration predict that areas around the caisson where dose rates exceed 1 mrem/hr are very local and less than 2 mrem/hr. Taking into account the conservatism in the source, (factor of 1.9) these maximum local dose rates are predicted to be about 1 mrem/hr.

Calculational dose rate contours are also displayed at various states in the modification. This includes dose rates during removal of the caisson and dirt, dose rates during installation of the extended riser and modified pipes, and dose rates during replacement of the new caisson and dirt.

4.2 CALCULATIONAL MODELS OF THE GEOMETRIES

The geometry model for tank 241-AZ-101 was discussed in Section 3.1. References 10 and 11 were utilized to change the geometry model to that after the modification of the steam coil and caisson.

The elevation view of Figure 2 (prior to modification) shows the 2" condensate pipe, with termination in this elevation view by the bend in the pipe near the top of the riser, and the 4" steam inlet pipe. The three dimensional view of Figure 3 shows all three pipes before modification and the view of Figure 4 shows the pipes after modification. The two-dimensional elevation view of Figure 5 shows the 4" steam inlet pipe after modification.

4.3 DISCUSSION AND RESULTS BEFORE AND AFTER MODIFICATION

The Monte Carlo calculations before and after the steam coil modification are summarized in Table 3 (each calculation was executed for 28.3 hours on an HP), where some of these dose rates are shown on the elevation views of Figures 2 and 5 before and after modification, respectively. The only results shown in Figure 2 around the pipes are for a radial distance of 3.81cm (1.5") from each pipe since this would correspond closely to what would be measured -- Table 3 also shows the dose rates at the surface of each pipe and 1.27cm (0.5") away. The only dose rates shown at the top of the caisson in Figure 5 after modification are averages along the top of the caisson above the riser since there is very little streaming up the pipes after modification because of the bends.

The most important results are:

- The average dose rate along the top of the caisson before modification, within the projected radius of the riser, is 2.6 mrem/hr. This compares to experimental measurements of 1 mrem/hr or less. An ISOSHL D calculation gives about 5 mrem/hr.
- The corresponding average dose rate along the top of the caisson after modification is 1.7 mrem/hr. This decreases to 0.98 mrem/hr at an elevation of 15.24cm (6") above the top of the pipes (about 39.37cm [15.5"] above the top of the caisson).
- The calculation predicts essentially no streaming up the pipes for the modified geometry because of the bends in the pipes.
- The "unmodified" calculation only predicts about 5 mrem/hr around the 2" condensate line compared to measured values of 25 mrem/hr. Possible explanations include: (1) the supernate source may have some time dependence -- although a factor of five seems unlikely; (2) there may have been voids in the soil around the pipe near the top of the caisson; (3) perhaps the radial dimensions of the pipe at the top of the caisson are different than the inner radius of 2.625 cm and the outer radius of 3.016 cm; or (4) perhaps there is some source material lodged inside the pipe at an elevation near the top of the caisson.
- The "unmodified" calculation predicts a high field of about 180 mrem/hr vertically above the bend (above the caisson) in the 2" condensate line, while measurements apparently gave low dose rates. The high calculated dose rate is because a small portion of the source is directly viewable from this location above the bend, except for a small amount of attenuation through the walls of the pipe at the top bend and at the bend below the top of the riser. Either there is something else between the source and this viewpoint or else measurements were not made directly above this pipe. This remains an unresolved question, but it

is not important to the revised design due to the added bends in the pipes.

- Calculated dose rates at the radial edge of the modified caisson, averaged over the first foot above grade, are 1.6 mrem/hr. For higher elevations it rapidly drops to below 1 mrem/hr.

The "modified" calculations predict that areas where dose rates exceed 1 mrem/hr are very local. For example, the dose rate along the top of the caisson is predicted to be 1.7 mrem/hr, but 30.48cm (1') or so higher it is only 1 mrem/hr. Similarly, the dose rate at the outer edge of the caisson exceeds 1 mrem/hr right above grade, but rapidly decreases to below 1 mrem/hr at higher elevations or larger radii. Even these maximum dose rates should decrease to about 1 mrem/hr if allowance is made for the conservatism in the source that was discussed in Section 3.3 on uncertainties.

4.4 DOSE RATE CONTOURS DURING MODIFICATION

Dose rate calculations were made at various times during the modifications: during removal of the caisson and dirt; at installation of the riser extension and pipe modification; and during replacement of the new caisson and dirt. The seven plots in Figures 6 to 12 show the resulting contours in mrem/hr, where the following describes the point in each sequence for which the contour was generated and how they relate to the sequences as described by drawing H-2-79249 in sec 9.0, reference 12.

To modify the steam coil, the existing caisson will need to be removed. Figure 6 shows the existing shielding caisson removed with the dirt assumed to have spread into a cone shape (Sequence 1, Task 1).

In Figure 7, the dirt has been partially removed from around the riser, the dirt was removed by reducing the size of the dirt cone (Sequence 1, Task 1).

In Figure 8 all of the dirt has been removed down to the riser flange. It is at this point the remaining piping will be removed, the interim coil purge installed, and the steam coil flange bolts removed in preparation to lift the flange and coil assembly (Sequence 1, Tasks 2-6).

In Figure 9 the steam coil has been raised above the riser flange. This will allow for the removal of the asbestos gasket and installation of a new gasket and riser extension (Sequence 1, Tasks 7-9, Sequence 2, Tasks 1-3, Sequence 3, Tasks 1-2).

In Figure 10 the 91.44cm (3 ft) riser extension has been installed and secured to the riser flange (Sequence 3, Task 3).

In Figure 11 the steam coil has been lowered onto the riser extension and secured. This is the condition where the new piping is attached to the coil

and interim purge is removed (Sequence 3, Tasks 4-7, Sequence 4, Tasks 1-4, 8).

In Figure 12 the shielding caisson is installed and filled with dirt. This completes the modification procedure (Sequence 4).

It is important to note that with no caisson there are relatively high dose rate fields radially beyond the riser.

Table 3. CALCULATED TISSUE DOSE RATES AROUND THE CAISSON BEFORE AND AFTER MODIFICATION.

<u>Location</u>	<u>Before Modification (mrem/hr)</u>	<u>After Modification (mrem/hr)</u>
Above top of caisson		
Radially beyond 2" condensate ^a	9.5, 6.9, 5.0	0.44*, 0.46, 0.44
Vertically above 2" condensate	83 ^b	0.9*
Radially beyond 4" steam inlet ^a	2.9, 2.8, 2.7	0.39*, 0.47, 0.53
Vertically above 4" steam inlet	7.1	0.4
Radially beyond 1.5" steam vent ^a	1.9, 2.1, 2.5	1.25, 1.3, 1.4
Vertically above 1.5" steam vent	11*	0.9
Inside 2" condensate	405	0.26
Inside 4" steam inlet	18*	0.42
Inside 1.5" steam vent	23*	4.2
Along top of caisson		
Radially beyond pipes, inside projected riser, average	2.56	1.69
Dose along radial edge of caisson Average, 1st foot above ground	1.24	1.59
Dose at bottom of flange Top of riser or extended riser	15,700	10,200
Dose at top of model		
15.24cm (6") above top of pipes above caisson 1.8 (average inside projected riser)		0.98
projected 2" condensate	~180 ^b	0.90*
projected 4" steam	7*	0.41
projected 1.5" steam vent	11*	0.94

(a) Radially beyond gives three numbers, all averaged over 15.24cm (6") length vertically starting at 5.08cm (2") above top of caisson. The first number is at outer surface of pipe, next is 1.27cm (0.5") from pipe, and last is 3.81cm (1.5") from pipe. Large statistical uncertainties for modified, but

for some reason larger calculated values were obtained beyond the 3.81cm (1.5") steam vent.

(b) Calculation made with a point detector treating only the portion of the source within the viewing angle of the top of the pipe. The point detector value of 180 mrem/hr is larger than the surface tally of 83 mrem/hr, but the statistical uncertainty in this surface tally is 20% and is apparently an underestimate.

* Statistical uncertainties greater than 20% were involved in these results, so they should only be taken as order-of-magnitude numbers.

5. DOSE RATES FOR DESIGN OF MIXER PUMP SHIELDING

5.1 SUMMARY

One of the modifications of the AZ-101 tank is the installation of mixer pumps in risers 01D and 01E. The predicted dose rates radially beyond the base of the mixer pump were substantially less than 2 mrem/hr with the calculational model utilized. However, there must be 11.43cm (4.5") of steel (12.065cm [4.75"] for 2σ upper limit) directly above the extended riser in order to reduce dose rates to 2 mrem/hr. These results are based upon a concrete radiation shield of 41.91cm (16.5") in axial height. Increasing the axial height to 60.96cm (24") only decreases dose rates by about 30%, whereas decreasing the axial height to 20.32cm (8") increases dose rates by about a factor of three.

The same mass of an alternate material for the radiation shield should produce roughly the same attenuation through the shield. However, increasing the axial height of the shield also reduces the solid angle of the source as seen from the gap at the top of the shield, so a low density shield of the same mass is actually more effective. For example, dose rates increased by about 40% with a 12.166cm (4.79") high steel shield and decreased by about 40% for a 94.742cm (37.3") high water shield, where these shields are equivalent in mass to the 41.19cm (16.5") concrete shield and the bottom of all these shields are at the same elevation.

The radiation shield is also more effective if it is located at higher elevations in the riser. For example, raising the 12.166cm (4.79") axially thick steel radiation shield by 60.960cm (2ft) reduces the dose rate so its now approximately as effective as the 41.190cm (16.5") concrete shield.

Dose rate predictions are also shown within an excavated hole for preparation for the mixer pump installation.

5.2 CALCULATIONAL MODEL

The important features of tank AZ-101 were modeled as discussed previously in Section 3.1. References 13 to 16 were used to obtain a calculational model of the riser and base of the pump.

Figure 13 shows an elevation view of the calculational model of the entire tank for the final configuration after installation of the mixer pump, and includes the streaming path up the riser to the base of the mixer pump. The additional geometry lines surrounding the pump pipe at the top of the supernate and the dashed sphere at the bottom of the riser were utilized to optimize the calculation.

5.3 DOSE RATES BELOW PUMP AND RADially OUTWARD

Figure 14 shows an elevation view of the calculational model of the riser vicinity at the base of the pump. Most of the calculations used concrete for the radiation shield near the bottom of the riser, but calculations were also made for radiation shields of steel and water. Also shown in Figure 14 are the steel plates that support the pump. These steel plates are included in the model since they represent important shielding for reducing the dose rates. The steel plates were all initially modeled as 5.08cm (2") thick. The pump was conservatively not included in the model, but it would also provide shielding in certain directions.

The base calculation utilized a concrete radiation shield that was 41.91cm (16.5") high with an outer radius of 49.53cm (19.5"); i.e., a 3.81cm (1.5") radial gap between the outside of the radiation shield and the inner wall of the riser. Dose rates are summarized on Figure 14 for this base case. The dose rates radially outward below the top plates have large statistical uncertainties in the calculation, but are clearly less than 1 mrem/hr as shown in Fig 14 to be less than 1 mrem/hr. However, the dose rate on top of the flange, directly above the streaming path along the outer radial portion of the riser, is 34 mrem/hr. Even with 10.16cm (4") of shielding, closer to the inner radial portion of the riser, this dose rate is still 2.0 mrem/hr. If the criterion for the maximum dose rate beyond the steel plates is 2.0 mrem/hr, then approximately 11.43cm (4.5") of steel should be utilized for all points directly above the streaming path. The dose rates with 11.43cm (4.5") of steel over the full radius are shown in Figure 15.

Calculations were also made for various axial thicknesses of the concrete radiation shield. These dose rates are tabulated in the first four lines of Table 4, where the locations for the dose rate tabulation are shown on Figure 14 -- this figure is specifically for the 41.91cm (16.5") axial shield thickness.

Table 4. Calculated Dose Rates (mrem/hr) For Various Axial Thicknesses and Materials of Radiation Shield.

<u>Radiation Shield Description</u>	<u>Bottom of Extended Riser</u>	<u>Under Steel</u>	<u>Above 5.08cm(2") Plates</u>	<u>Above 10.16cm(4") of Plate</u>	<u>of Plates</u>
Concrete, 41.91cm (16.5") axial thickness	730	236	34	2.0	
Concrete, 60.96cm (24") axial thickness	511	166	28	1.3	
Concrete, 20.32cm (8") axial thickness	2,500	630	66	7.0	
None, 0cm (0") axial thickness	34,000	7,300	623	68	
Steel, 12.166cm (4.79") axial thickness	1,320	435	47	~3	
Water, 94.74cm (37.3") axial thickness	450	130	28	~1	
Steel, 12.166cm (4.79") axial thickness*	1,205	230	36	1.9	

*Radiation shield raised 60.96cm (2 ft.)

The last three lines of Table 4 summarize the calculated dose rates for shields of steel and water, respectively, instead of concrete. Important insights for the radial shield, as inferred from this table, include:

- As the axial thickness of the concrete radiation shield is increased from zero (no shield) to 20.32cm (8"), there is a substantial reduction in dose rates above it --- about an order of magnitude. An increase in thickness of another 21.59cm (8.5"), to a total thickness of 41.91cm (16.5"), reduces the dose rate by another factor of about three. This factor of three reduction is a combination of both more attenuation, because of the thicker shield, and a solid angle reduction since the axially thicker shield reduces the view of the source as seen from the gap at the top of the shield. Finally, increasing the shield thickness to 60.96cm (24") only reduces dose rates by about 30% compared to the 41.91cm (16.5") case. The latter reduction is probably mostly due to a further reduction in solid angle rather than attenuation. The 41.19cm (16.5") axially thick concrete shield may be near optimum since the payoff with thicker shields is small in reducing dose rates considering the shield mass being added to the system.
- The 12.166cm (4.79") (axial thickness) steel shield is equal in total mass to the 41.19cm (16.5") concrete shield, as is the 94.742cm (37.3") thick water shield. These shields should all be similar in

effectiveness for attenuation. However, the steel shield (third line from bottom of Table 4) is the least effective in reducing dose rates because this thinner shield allows a much larger viewing angle of the source from the gap at the top of the shield. The 94.742cm (37.3") thick water shield is actually similar in dose reduction effectiveness to the 60.96cm (24") thick concrete shield because its length substantially reduces the solid angle even though its dose attenuation properties are not as good.

- An additional reduction in dose rates could be obtained by locating the radiation shield at a higher elevation in the riser, because the bottom of the riser further restricts the source angle as the radiation shield is raised. This could be particularly advantageous for the thinner steel shield. The last line of Table 4 shows the result of raising the steel shield 60.96cm (2ft). It then becomes approximately as effective as the 41.91cm (16.5") concrete shield. All other calculations for Table 4 were for the bottom of the radiation shield at the elevation shown in Figure 14.

5.4 DOSE RATES WITHIN EXCAVATION HOLE

Dose rates were also predicted after excavation around the riser, using a calculational model of the excavation hole for performing the installation field work. References 17 and 18 were utilized for the model of the concrete shield in the riser. Figure 16 shows the calculational model and the calculated dose rates at the bottom of the excavation, 60.96cm (2 ft) above the bottom, and at the elevation of the top of the surrounding soil. These dose rates are given for the 60.96cm (2ft) magnetite concrete shield shown in the figure. Dose rates are also given in Figure 16 for the same geometry model except where the axial shield thickness is reduced to 30.48cm (1ft), and for the case with no shield at all.

The dose rates decrease dramatically with the shield in place. The larger dose rates near the extended radius of the riser are due to a 6.35cm (0.25") radial clearance gap between the shield and the riser. Most of the dose rates in the excavation hole with the 60.96cm (2ft) shield are due to streaming up this gap and then attenuation through the 1.905cm (0.75") thick plate above the plug. With the shield thickness reduced to 30.48cm (1ft), attenuation through the shield plug begins to make a contribution to the dose rates within the excavation hole. The calculation with no shield was made without the 1.905cm (0.75") plate and led to very high dose rates.

6. DOSE RATES AT TOP OF RISERS FOR A REDUCED SOURCE

6.1 SUMMARY

To reduce dose rates for tank operations, it has been suggested that the supernate in the tank be diluted. Dose rate calculations were made at the top of a 106.68cm (42") and a 15.24cm (6") riser for a diluted source and compared to the standard source. The diluted source was obtained with the following specified prescription [Written request from C. M. Winkler, February, 1994]:

30.48cm (12") (33,000 gallons) of the supernatant source, above the sludge, was mixed with 600,000 gallons of supernatant from 102-AY. Here the photon source for the 102-AY generic solution was assumed from the information provided for two radio-active isotopes as:

Cs-137 at 16.25 mCi/l

Sr-90 at 2.50 mCi/l.

The density of the diluted solution was still assumed to be 1.21 g/cm³. ORIGIN was used to obtain a source strength of 5.877×10^6 photons/gram-second (compared to the undiluted of 1.002×10^8 photons/gram-second) and the photon source distribution, as was done for the original source.

The dose rates at the top of the risers with the diluted mixture were found to decrease to about 5.5% of that obtained with the original source. This percentage is reasonable since the original source still dominates even after the dilution -- it is diluted by the factor $33,000/633,000 = 5.2\%$, so the factor of 5.5% is reasonable.

The specific dose rates calculated at the top of the risers with the mixture are:

	Diluted Source (mrem/hr)	Non-Diluted Source (mrem/hr)
Top of 106.68cm (42") riser	870	15,400
Top of 15.24cm (6") riser	19.5	360

Dose rate contours for the reduced source with the 106.68cm (42") riser are shown in Figure 17.

7. TEMPERATURE PROBE ANALYSIS

7.1 SUMMARY

Dose rates have been calculated for the 15.24cm (6") risers, where temperature probes will be installed. Some of the 15.24cm (6") risers are drywells that extend almost to the bottom of the tank (risers numbered 14), whereas the others only penetrate into the tank (risers numbered 15). The contour plots of Figures 18 and 19 show predicted dose rates in the vicinity of the two different types of open risers. The existing shielding plugs are out.

Dose rates near the risers with the temperature probes installed were also determined. For the temperature probe designs analyzed, dose rates will be below 2 mrem/hr with the shield plugs in place.

7.2 CALCULATIONAL MODELS

An extended discussion of the geometry models and the Monte Carlo optimization techniques is given in Appendix A. Here we only briefly discuss and show the pertinent figures.

The top of the drywell riser (types 14) is shown in Figure 20 after modification. The intent of the design is to reduce dose rates to below 2 mrem/hr in the vicinity of the riser. A total of 7.62cm (3") of steel was needed to sufficiently attenuate photons streaming up the riser, where a portion of this steel is at the top (labeled "PLUG" on Figure 20) and a portion is down lower in the riser below grade.

The top of the riser (numbered 15) is shown in the elevation view of Figure 21 after modification. It has similarities to the drywell 14 riser of Figure 20 with an important difference being the introduction of a temperature probe that effectively compensates calculational for the lack of a pre-existing drywell.

7.3 RESULTS AND DISCUSSION

7.3.1 OPEN DRYWELL RISER, (BEFORE MODIFICATION):

The contour plot of Figure 18 shows dose rates in the vicinity of a drywell riser (numbered 14) before modification, but after all shields within the riser have been removed. This contour plot shows the dose rates to be around 78 mrem/hr at the top of the riser. To the sides of the riser, the dose rate is under 2 mrem/hr. If, however, a scattering object is introduced above the riser, the dose rates to the sides of the riser will increase considerably.

7.3.2 DRYWELL RISER WITH TEMPERATURE MEASUREMENT, (AFTER MODIFICATION):

Dose rates were calculated at the top of the drywell riser, with the temperature measurement installed. Dose rates were calculated along the top of the shielding plug within a number of annuli. These results are summarized in Table 5.

Table 5. Dose Rates at The Top of Drywell Riser After Modification
(with shield plug installed)

Radial Distance from Center of Riser (cm)	Dose Rate in mrem/hr (1 std. dev. uncer. in per cent)
0 to 2	0.93 (21%)
2 to 4	0.94 (11%)
4 to 5.986	0.97 (5%)
5.986 to 6.350	1.28 (12%)
6.350 to 6.509 1/16 inch gap	1.81 (9%)
6.509 to 6.873	0.84 (10%)
6.873 to 7.414 to inside radius of riser	0.64 (6%)
7.414 to 8.414 to outside radius of riser	0.10 (7%)

All of the above dose rates are below 2 mrem/hr. Its important to note that the higher dose rates are only for small cross sectional areas so the average over larger areas will reduce these values even farther.

Calculations were also made along the radial side of the riser as summarized in Table 6, and these dose rates are also below 2 mrem/hr.

Table 6. Dose Rates at The Radial Side of Drywell Riser, After Temperature Measurement Installed. (With Shield Plug Installed)

Height above ground level in cm	Dose Rate in mrem/hr (relative error)
0 to 5	1.46 (5%)
5 to 10	1.06 (5%)
10 to 15	0.77 (7%)
15 to 20	0.59 (8%)
20 to 25	0.38 (7%)
25 to 30	0.34 (10%)
30 to 35	0.25 (10%)
35 to 40	0.20 (7%)
40 to 45.72 (to bottom of flange)	0.25 (17%)

7.3.3 OPEN 6" RISER, (BEFORE INSTALLATION OF TEMPERATURE PROBE):

The contour plot of Figure 19 shows dose rates in the vicinity of an open 6" riser (numbered 15) before the installation of the temperature probe. This contour plot shows the dose rate to be around 370 mrem/hr at the top of the riser. To the sides of the riser, the dose rate drops off very rapidly from about 50 mrem/hr. As with drywell risers numbered 14, dose rates to the sides of the riser will increase fairly dramatically if a scattering object is introduced above the riser.

7.3.4 OPEN RISER, AFTER INSTALLATION OF TEMPERATURE PROBE:

Dose rates were calculated at the top of the riser, with the probe installed, for a number of different annuli. The results are summarized in Table 7. These dose rates are well under the 2 mrem/hr limit.

Table 7. Dose Rates at The Top of The Temperature Probe in a 6" Riser.

Radial Distance from Center of Riser (cm)	Dose Rate in mrem/hr (1 std. dev. uncer. in per cent)
0 to 2	0.16 (8%)
2 to 4.24	0.16 (5%)
4.24 to 4.60	0.18 (10%)
4.60 to 4.76 1/16" gap between plug and probe	0.55 (10%)
4.76 to 5.13	0.19 (10%)
5.13 to 6.35	0.056 (8%)

Dose rates at the side of the riser and temperature probe assembly were much more difficult to calculate, and so only a preliminary estimate was completed. The primary source of photon radiation will come from streaming through the 1.27cm (1/2") gap between the riser and the probe. The photons would scatter off of either the wall of the riser or the wall of the probe in order to leave through the side of the riser.

Only the contribution from photons impacting the inner wall of the riser (outer surface of gap) was considered in the calculation, as discussed in Appendix A. The results of these calculations with the line source (see Appendix A) show that dose rates will be less than 0.3 mrem/hr at the side of the riser from this contribution.

The contribution from scattering off of the probe can be assumed to be less than the contribution from scattering on the riser. Using this assumption, the total dose rate at the side of the riser would be less than 0.6 mrem/hr. The dose rate at the side of the temperature probe assembly was not investigated, but should be less than the dose rate at the side of the riser, due to the thicker shielding present.

The contribution through the top of the riser and the side of the aluminum adaptor ring, due to streaming through the 1.27cm (1/2") gap, were calculated to be less than 0.3 mrem.

8. CALCULATED TO MEASURED DOSE RATES FOR A 6 INCH DRYWELL RISER

8.1 Summary

Results of a radiological survey¹⁹ within tank 241-AZ-101 were used to evaluate the accuracy of the source term in MCNP models of the same tank. Dose rates were measured approximately every five feet over the entire length of the riser and drywell within drywells 13-01-68 and 13-01-76 (14c and 14e) for tank 241-AZ-101. Calculations modeling the geometry for these measurements were utilized to make a direct comparison. It was found that calculated dose rates were generally about 1.9 times higher than measured for the supernate, and about 3.4 times higher for the sludge. The calculated dose rate at the top of the riser was 73.5 mrem/hr, whereas the measured value was 40 mR/hr.

8.2 Geometry Models

The geometry model of the drywell starts 7.62cm (3") from the bottom of the tank, and ends 17.78cm (7") above the soil. The drywell is 17.068M (56ft) long, and is made from 6" schedule 40 pipe. The location of the riser was at a 3.81M (12' 6") radius from the center of the tank.

The calculations were divided into two parts. Each part accounted for a different portion of the source so the total dose rate at any point was the sum of the contributions from each of these parts of the source. The first part used a source shown in Figure 22 that consists of the top of the supernate source to a depth of sixty centimeters. The sixty centimeters was chosen based on a mean free path of about seven centimeters, calculated by MCNP, so essentially all of the supernate source below sixty centimeters is attenuated before escaping from the source region. The second part used a source near the drywell, as shown in Figure 23, that began sixty centimeters below the surface of the supernate, and extended to the bottom of the tank. The second part of the source included both supernate and sludge out to a radius of sixty centimeters beyond the outside of the drywell.

8.3 RESULTS AND DISCUSSION

Table 8 gives an axial comparison between measured and calculated values. The depth of the drywell reported by the survey (16.916M, [55.5 ft]) differs slightly from what was modeled (17.068M, [56 ft]) so there is some axial uncertainty in comparisons at locations where dose rates change rapidly.

Table 8. Comparison Between Measured and Calculated Dose Rates in Drywell

Dose point location METERS	Substance just outside of drywell	Measured Dose Rate (kR/hr) Well 13-01-68	Calculated Dose Rate (krem/hr)	Ratio of calculated to measured
0	sludge	0.87	3.06 (.2%)	3.5
.3048 (1')	sludge	1.05	3.45 (.8%)	3.3
1.371 (4' 6")	supernate	0.92	1.71 (.4%)	1.9
2.895 (9' 6")	supernate	0.90	1.68 (.4%)	1.9
4.419 (14' 6")	supernate	0.91	1.69 (.4%)	1.9
5.943 (19' 6")	supernate	0.88	1.69 (.4%)	1.9
7.467 (24' 6")	supernate	0.85	1.67 (.4%)	2.0
8.991 (29' 6")	supernate/air	0.45	1.28 (1%)	2.8*
10.515 (34' 6")	air	0.37	0.704 (3%)	1.9
12.039 (39' 6")	air	0.30	0.618 (3%)	2.1
13.563 (44' 6")	air	0.23	0.506 (2%)	2.2
15.087 (49' 6")	soil	too low for probe	0.0935 (5%)	-
16.611 (54' 6")	soil	too low for probe	0.0919 (4%)	-
Top of riser	air	40 mR/hr	73.5 mrem/hr (2%)	1.8

This higher ratio may be a result of a discrepancy between where the measurement was taken and where the calculation was made in relation to the top of the supernate.

The calculated dose rate along the sludge region (first two entries in Table 8) is 3.3 and 3.5 times higher than measured. The ratio along the supernate is consistently about 1.9. Hence, the source terms are quite conservative, especially in the case of the sludge. The contribution from the sludge to dose rates at the top of the riser is under 5% so this is also dominated by the supernate.

Sometime after this comparison of calculational predictions of dose rates to the experimental measurements within the drywell, it was discovered that the calculation of the photon source with ORIGEN utilized a library that would over predict the contribution of bremsstrahlung photons -- see discussion of sources in Section II. This over prediction for the supernate is estimated to

be 25%. Hence, the above C/E ratios along and above the supernate would decrease from the values of about 1.9 to about 1.4. In the interest of keeping consistency between the calculations, it was decided to not modify the source but rather retain this conservatism.

9. REFERENCES

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APPENDIX A

DETAILS REGARDING CALCULATIONAL MODELS AND OPTIMIZATION TECHNIQUES

A.1 INTRODUCTION

Additional details on the calculations are given in this appendix including the archival storage of the input files. The calculation involved is identified in each heading.

A.2 ARCHIVAL INPUT FILES FOR THE STEAM COIL CALCULATIONS

The important MCNP input files for these calculations are stored in cfs in directory /v93586/w151/coil/. These files are:

<u>File name</u>	<u>Description</u>
i2l	The unmodified steam coil geometry.
i2la	The modified steam coil geometry.

For the contours and animation:

coil.pro.pk	PV-WAVE program file for point kernel sequence.
coil.pro.tpk	PV-WAVE program file for Monte Carlo transport sequence.
inpmaster.tar	Tar file containing inpmaster files for each sequence. Monte Carlo transport files have names ending with a letter.
maketal.new.c	C source code to create maketal executable. Compiled using "cc -o maketal maketal.new.c -lm".
makeinp.tar	Tar file containing makeinp files corresponding to each inpmaster file. Compiled with command of the form, "cc -o makeinp makeinp.new.c".
readtal.new.c	C source code to create readtal executable. Compiled using "cc -o readtal readtal.new.c".
tal.dat.seq5	Tal.dat file used for sequence 5.
tal.dat.tank	Tal.dat file used for all sequences except sequence 5.

These latter files for doing the contours and animation are in the subdirectory contour/.

A.2.1 ANIMATION SEQUENCE

Numbers have been assigned to various stages in the sequence. These numbers are specific to the animation, and are not identical to the sequences listed in drawing H-2-79247.

1. Animation as dirt is removed. The sequence for the Monte Carlo transport calculation is further split into two parts, 1a and 1b.
2. Animation as flange is raised 91.44cm (3 ft).

3. Animation as the sides of the riser extension are brought in and put in place.
4. Animation of the coil assembly being lowered onto the riser extension.
5. The coil assembly has been rotated 45 degrees. Pipes coming out of the riser have been modified. Steel siding used for the new caisson are already in place. The animation shows the filling of the caisson.

Creating an animated sequence involves five basic steps:

1. Maketal is run. Maketal uses an input file called *tal.dat* that describes how the point detectors will be set up. Maketal creates the file *talout* that is appended to the end of the MCNP input file, and *tallog*, which is used later.
2. Makeinp is run. Makeinp reads the appropriate *inpmaster* file and creates the sequence of input files. A file called *stream* is created that can be used to create the run stream for the MCNPH runs.
3. MCNPH is run for each of the input files.
4. Readtal is run. It is executed by typing, "readtal mctal", where mctal is the name of the MCNP mctal file. The output file will have the same name as the mctal file, but with an "o" appended to the beginning e.g. omctal is created from mctal. Readtal also makes use of the file tallog.
5. PV-WAVE is used to create and view the animated sequence. The PV-WAVE program is called *coil.pro.pk* for the point kernel sequence, and *coil.pro.tpk* for the Monte Carlo transport sequence. The PV-WAVE programs use the omctal files previously created. The PV-WAVE program is changed for each sequence (see program comments).

A.3 ARCHIVAL INPUT FILES FOR THE MIXER PUMP

The most important MCNP input files have been saved for archival purposes in cfs in the directory /v93586/w151/pump/. These input files are:

<u>File Name</u>	<u>Description</u>
i2	Base case with 16.5" concrete radiation shield to obtain the dose rates in Figure 3.
i2.8	Like i2, but with 8" concrete radiation shield.
i2.24	Like i2, but with 24" concrete radiation shield.
i2.top	Like i2, but with top plate 2.5" thick and radially extended, to obtain the dose rates of Figure 4.
i2h2o	Like i2, but 37.3" water radiation shield.
i2ss	Like i2, but 4.79" steel radiation shield.
i2ssh	Like i2ss, but steel shield raised 24".
i2nop1	Excavation hole and 2' shield
i2nop2	Excavation hole and 1' shield
i2nodirt	Excavation hole with no shield

A.4 ARCHIVAL INPUT FILES FOR A REDUCED SOURCE

The most important MCNP input files have been saved for archival purposes in cfs in the directory /v93586/w151/rsource/. These input files are:

<u>File Name</u>	<u>Description</u>
i2lw1	42" riser model with original source.
i2lw2	42" riser model with diluted source.
i2lw3	6" riser model with original source.
i2lw4	6" riser model with diluted source.

A.5 GEOMETRY FOR TEMPERATURE PROBE

A.5.1 DRYWELL RISER, BEFORE MODIFICATION:

The drywell riser (numbered 14 series) extends almost to the bottom of the tank. A representative calculational model of a riser at a radius of 3.81M (12' 6") from the center of the tank was used. The results from this calculation will be conservative for risers at a larger radius of 10.59M (34' 9"), since for the larger radius a shorter portion of the drywell is inside the tank for scattering the photons up and a longer portion above. The riser is made of 6" schedule 40 pipe. The bottom of the drywell is assumed to be 7.62cm (3") from the bottom of the tank in the calculational model. The top of the riser was set at 17.78cm (7") above ground level, based on the ground level used for the steam coil riser and the elevation listed in the drawing of Reference 7 for the top of the riser.

A.5.2 MCNP OPTIMIZATION: DRYWELL RISER, BEFORE INSTALLATION OF TEMPERATURE MEASUREMENT:

The source was split into two segments -- identical to the way the source was optimized in the C/E comparisons discussed in the next section. A DXTRAN sphere, importance splitting, and the DXC card were also used in the same manner to optimize the calculation as is discussed in the C/E comparison.

A few hundred point detectors (so-called "point detectors" are used in MCNP to determine flux, or dose rate, at a point) were used to obtain calculated dose rates at a sufficient number of points to generate the contour plots by smooth curve fitting. The PD card was set up similar to the DXC card, except it also included contributions from collisions above the DXTRAN sphere as well. The PD card requires an entry for each cell. For cells near the point detectors, the entry is set to unity and each collision in the cell contributes to each point detector. For cells far away, lower entries are utilized to save computer time: for example, with an entry of 0.1, the point detector tally is only made 10% of the time using a multiplier of 10 (1/0.1) to obtain unbiased results. Another statistical problem is that collisions very near a point detector will contribute large amounts to the tally. For these calculations,

an average contribution within a sphere of 10 cm was used whenever the collision point was less than 10 cm from the point detector.

A.5.3 GEOMETRY: DRYWELL RISER, AFTER INSTALLATION OF TEMPERATURE MEASUREMENT PROBE:

The top of the riser is shown in Figure 20 after installation of equipment. In this calculational model, the length of the riser was extended so that the top of the riser was 45.72cm (18") above grade. Although the new overall length of the riser may be slightly in error, the change allows the bottom of the plug to be 15.24cm (6") below grade after including the correct internal dimensions of the plug, consistent with drawings. The existing riser has a 2.54cm (1") thick flange annulus at the top. A 13.175cm (1 1/4") aluminum adapter plate annulus rests on this flange in the modified configuration. Then is an 3.175mm (1/8") steel cover plate annulus with a smaller radius that rests on the adapter plate. Attached to the inside radius of this cover plate is a steel sleeve that extends for a distance of 64.45cm (25 3/8") down into the riser -- thus the bottom of this sleeve is 15.24cm (6") below grade. There is a 7.93mm (5/16") gap between the outside of this sleeve and the inside of the riser. To reduce streaming through this 7.93mm (5/16") gap, a 2.54cm (1") steel ring is placed above the steel cover plate up at the top of the plug so that it covers the gap.

The intent of the design is to reduce dose rates below 2 mrem/hr in the vicinity of the riser. A total of 7.62cm (3") of steel was needed to sufficiently attenuate photons streaming up the riser and obtain a dose rate of below 2 mrem/hr at the top of the riser. The 7.62cm (3") total steel thickness is split into three portions: (1) the top of the plug is 27.94cm (11") in diameter, and 2.54cm (1") thick, where its outer radial portion rests on top of the 2.54cm (1") steel ring; (2) just below the 2.54cm (1") top of the plug is a 1.905cm (3/4") thick steel slice that is 12.70cm (5") in diameter, where there is a 1.57mm (1/16") radial gap between this 12.70cm (5") diameter section and the steel sleeve; and (3) the bottom portion of the shield is 3.175cm (1 1/4") thick, 12.700cm (5") in diameter, and is located 15.240cm (6") below grade. This bottom steel portion is suspended with a 1" schedule 40 pipe. By lowering the bottom part of the shield as shown in Figure 20, streaming through the 1.575mm (1/16") gap and dose rates at the side of the riser are reduced.

A 6.35cm (2.5") thick, 12.70cm (5") in diameter, cylindrical steel weight was added to the bottom of the drywell which has the temperature measurement device attached to it. The temperature measurement is taken on the bottom of the drywell.

A.5.4 MCNP OPTIMIZATION: DRYWELL RISER, AFTER INSTALLATION OF TEMPERATURE MEASUREMENT PROBE:

The source optimization remained identical to the one used for the drywell riser before its modification.

The hundreds of point detectors were replaced with a surface tally at the top of the riser since the purpose of the calculation is to verify that the shielding is sufficient to reduce dose rates to desired levels beyond the riser. An FS card was used to split the tally surface at the top of the riser radially in order to get a detailed radial dose profile, especially directly over the streaming gaps. Another surface tally was used on the side of the riser and split axially to obtain axial information along the side of the riser.

Importance splitting was utilized to improve the efficiency by transporting more random walk particles through the shield plug. This calculational model used the same DXTRAN sphere and importance splitting in the drywell as was used for the riser before modification.

A.5.5 GEOMETRY: OPEN RISER, BEFORE INSTALLATION OF TEMPERATURE PROFILE PROBE:

Open risers (numbered 15 series) (not drywells) do not extend down to the bottom of the tank, but instead extend only about a 30.48cm (12") below the tank dome and are open to the tank. A representative calculational model was once again chosen to be at a radius of 3.810M (12' 6") from the center of the tank. The riser is made of 6" schedule 40 pipe. The model used 3.429M (11'3") for the total length of the riser. The top of the riser is 17.78cm (7") above ground, like the calculational model of the drywell riser before equipment installation.

A.5.6 MCNP OPTIMIZATION: OPEN RISER, BEFORE INSTALLATION OF TEMPERATURE PROFILE PROBE:

Three different sources were used to simulate the source, and optimize the MCNP calculation. The first input file utilized a cylindrical source 3.657M (12') in radius, and about 60.96cm (2') deep. The contribution beyond the 3.657M (12') radius has previously been shown to be small for similar types of problems. Similarly, it was assumed that contributions would be negligible beyond the 60.96cm depth due to attenuation through the supernate.

The second input file consisted of a similar cylindrical source, but only out to a radius of 35 cm. This radius is somewhat greater than the area of the source where particles can have a direct line of flight to the top of the riser. After preliminary calculations with these two input files, the final input file was created to model the source as follows. The source of the second input file was used, except the source strength was multiplied by the ratio of dose rate obtained at the top of the riser from the first model to the dose rate at the top of the riser with the second model in order to approximately account for source particles beyond the direct line of sight to the top of the riser. This ratio was 1.185, indicating, as expected, that most of the dose rate was a result of particles having a direct flight to the top of the riser. This final calculational model was used for creating the contour plots. The reason for using this approximation is to improve the efficiency and make it practical to do the calculation.

A DXTRAN sphere was used to further optimize each of the three calculational models described above. The DXTRAN sphere of the first model was placed at the bottom of the riser, with an outside radius of 50 cm, in order to improve the efficiency for photons to reach the vicinity of the bottom of the riser. For the second and third models, the DXTRAN sphere was placed closer to the top of the riser, with an outside radius equal to the inside radius of the riser, since we can now optimize line of sight photons from the supernate by dramatically increasing their efficiency of reaching the top of the riser.

A.5.7 GEOMETRY: OPEN RISER, AFTER INSTALLATION OF TEMPERATURE PROFILE PROBE:

Changes in the geometry model for the open risers are more extensive than for drywell risers, due to the introduction of a temperature probe that effectively compensates for the lack of a pre-existing drywell. The calculational model at the top resembles the model used for the modified drywell riser. The length of the riser has also been extended so that the top of the riser is 18" above ground level.

A profile temperature probe is inserted into the existing 6" schedule 40 riser. The temperature probe is a tube 13.970cm (5 1/2") in diameter with a 2.22cm (7/8") thick wall. [The calculation was made with a 1.59cm (5/8") thick wall]. This leaves approximately a 7.137mm (.281") gap [the calculation was made with a 1.27cm (1/2") gap] between the inside radius of the riser and the outside radius of the temperature probe -- see Figure 21. The probe's cylindrical bottom is 6.35cm (2.5") thick. The top of the probe includes facilities for adjusting the height of the probe, thus controlling the distance between the bottom of the probe and the tank bottom. The bottom of the temperature probe in the calculational model is 10.16cm (4") above the tank bottom. The probe assembly is bolted to the existing 6" riser flange.

There is a 2.54cm (1") steel ring at the top of the probe positioned above the 1.27cm (1/2") gap between the probe and the riser. On top of this steel ring is a 3.175cm (1 1/4") aluminum adapter annular ring with a 9.525cm (3 3/4") inner radius and a 3.175mm (1/8") thick annular steel plate. The outer radial portion of the shielding plug rests on the steel plate. This part of the shield plug resting on the steel plate was modeled as being 3.810cm (1 1/2") thick. Hanging from this top piece is another 3.810cm (1 1/2") thick cylindrical disk that is 9.207cm (3 5/8") in diameter, thus giving a total axial thickness of 7.620cm (3"). This leaves a 1.575mm (1/16") gap between the lower part of the plug, and the wall of the probe.

A.5.8 MCNP OPTIMIZATION: OPEN RISER, AFTER INSTALLATION OF TEMPERATURE PROFILE PROBE:

The source for calculating dose rates through the shield plug was optimized in the same manner as was done for the drywell riser. In fact, the source treatment was identical, with the exception that the diameter of the probe penetrating the sludge is 12.700cm (5"), as opposed to the 16.827cm (6 5/8") diameter (6" schedule 40 pipe) in the previous calculation. A DXTRAN sphere

inside the probe and importance splitting both in the probe's wall and the plug, similar to the method for the drywell riser, was used. Also, a surface tally with radial splits was used to calculate the dose rate in a similar manner. Particles that left the probe and riser through the side were killed, as they would contribute insignificantly to the dose rate through the top.

Optimization for finding dose rates to the side of the riser consisted mainly in the use of the line source as described in the following.

A different approach was used to verify dose rates through the sides of the riser would be less than 2 mrem/hr. These dose rates would primarily arise from photon streaming through the 3.810cm (1/2") gap between the riser and the probe. A three stage calculational procedure was used. The source for the first stage consisted of a 23 cm (9.055") outer radius cylinder surrounding the portion of the probe submerged in the supernate, to a depth of 60 cm (23.622") -- the 23 cm was chosen based on a direct line of sight to the top of the riser through the gap. Point detectors were put on the outer radial surface of the gap (inside wall of the riser) at elevations from 60.96cm (2') below grade to the top of the existing riser. These point detectors were used to determine the flux as a function of energy and axial height on the inside wall of the riser. Random walk particles actually entering the probe or riser wall at these elevations were terminated.

The second calculational stage used a line source. The line source extended from 60.960cm (2') below the soil to the top of the existing riser and was positioned radially at the inner surface of the riser. The energy distribution of this photon line source was obtained from a representative point detector, since the shape of the energy distributions from the tallies in the first calculational stage were essentially independent of height. The direction of flight for the photons of this line source was set to be the closest to the direction normal to the riser surface possible from direct line of sight (still nearly parallel to the axis of the riser). Furthermore, the azimuthal direction was set to be normal to the riser surface. The axial dependent strength of the line source was set to correspond with that obtained from the point detectors, where the strength of the line source over a particular axial segment (about the location of a point detector in the first calculational stage) was proportional to the flux obtained by that point detector. This line source current is related to the point detector flux as:

$$J = \Phi A |\mu|,$$

where J is photon current, Φ is the total flux measured by the point detectors, A is the area of the axial segment along the inside surface of the riser integrated over the 2π azimuth, and μ is the cosine of the angle between the assumed direction of flight and the surface normal. A very thin cell tally (approaching a surface tally) was set up to verify that the flux using this line source in a void calculation was approximately the same as that obtained by the point detectors.

This line source was then used with a surface tally to calculate the dose rate outside the riser as a function of height.

Dose rates at the top of the riser from streaming through the same 1.270cm (1/2") gap must also be determined. A similar scheme was developed to calculate this contribution. The first stage of the calculation was modified to include point detectors at the top of the gap, just underneath the 2.540cm (1") steel ring. The second stage of this calculation then used a surface source just underneath the 2.540cm (1") steel ring. The photon current and energy were for this source were obtained in a similar fashion to that described above for the line source. After verifying this surface source for this second stage, a non-void calculation was made with surface tallies on the top of the shield plug, and on the outside radius of the aluminum adaptor ring.

A.5.9 ARCHIVAL OF INPUT FILES

The following files are all stored in a tar file with name probe in cfs in the directory /v93586/w151/tempp/.

DRYWELL RISER BEFORE MODIFICATIONS

<u>Files</u>	<u>Description</u>
itherm.brute	Surface tally at top of riser. Top 60 cm of supernate for source.
itherm.ax	Surface tally at top of riser. Source along length of drywell.
itherm.tf	Field of point detectors. Top 60 cm of supernate for source.
itherm.af	Field of point detectors. Source along length of drywell.

DRYWELL RISER AFTER MODIFICATIONS

<u>Files</u>	<u>Description</u>
il.3t	Top 60 cm of supernate for source.
il.3b	Source along length of drywell.

OPEN RISER BEFORE MODIFICATIONS

<u>Files</u>	<u>Description</u>
itherm.open.base	Surface tally at top of riser. 12' radius source.
itherm.open.cone	Surface tally at top of riser. 35 cm radius source.
itherm.open.field	Field of point detectors. 35 cm radius source.

OPEN RISER AFTER MODIFICATIONS

<u>Files</u>	<u>Description</u>
i2.40t	Dose rate at top of riser. Top 60 cm of supernate for source.
i2.40b	Dose rate at top of riser. Top 60 cm of supernate for source.
i2.71	Dose rate at side of riser. First stage - find line source.
i2.81	Dose rate at side of riser. Second stage - verify line source.
i2.91	Dose rate at side of riser. Final calculation.
i2.73	Dose rate at top of riser due to streaming through 1/2" gap. First stage - find source.
i2.83	Dose rate at top of riser due to streaming through 1/2" gap. Second stage - verify source.
i2.93	Dose rate at top of riser due to streaming through 1/2" gap. Final calculation.

CREATING CONTOUR PLOTS

Contour plots are created in a manner similar to the method used for creating the animated sequence for the steam coil. In this case, only single frames need to be made rather than entire sequences. As a consequence, the step involving the use of makeinp is not necessary.

<u>Files</u>	<u>Description</u>
maketal.new2.c	C source code to create maketal executable. Compiled using "cc -o maketal maketal.new2.c -lm".
readerr.new.c	C source code to create readerr executable. Readerr is similar to readtal, but will create an additional file. The additional file is similar to the omctal file, but is named with an "e" instead of an "o". This emctal file contains information for printing a contour plot of the relative error. It is compiled using "cc -o readerr readerr.new.c".
therm.pro	PV-WAVE program similar to coil.pro.tpk from the animated sequence that reads the omctal file to create a contour plot.

A.6 Calculational Model for Measurements in Drywell

A.6.1 GEOMETRY

The geometry model of the drywell starts 7.60cm (3") inches from the bottom of the tank, and ends 17.78cm (7") above the soil. The drywell is 17.069M (56 ft) long, and is made from 6" schedule 40 pipe. The location of the riser was at a 3.81M (12' 6") radius from the center of the tank.

A.6.2 SOURCE AND MCNP OPTIMIZATION

Photons reaching the top of the riser come from either direct flight from the source, or from scattering on the steel wall of the drywell. Of those that can make a direct flight to the top of the riser, the photons originating in the 7.62cm (3") sludge region below the bottom of the drywell are the most important. Photons outside of the 7.62cm (3") sludge region will have to pass through the side of the drywell, which amounts to quite a bit of attenuation at the steep angle required to reach the top of the riser.

The calculations were divided into two parts. Each part accounted for a different portion of the source so the total dose rate at any point was the sum of the contributions from each of these parts of the source. The first part used a source shown in Figure 22 that consists of the top of the supernate source to a depth of 60 cm (23.622"). The sixty centimeters was chosen based on a mean free path of about seven centimeters, calculated by MCNP, so essentially all of the supernate source below sixty centimeters is attenuated before escaping from the source region. The second part used a source near the drywell, as shown in Figure 23, that began sixty centimeters below the surface of the supernate, and extended to the bottom of the tank. The second part of the source included both supernate and sludge out to a radius of sixty centimeters beyond the outside of the drywell.

The source was further optimized by splitting it both radially and axially. The segment consisting of the top 60 cm (23.622) of supernate was split axially into six 10 cm (3.937") thick layers. Source biasing [sampling random walk particles more frequently in the more important region of the source nearer the dose points of interest, and adjusting for this with a reduced weight to obtain correct expected values] and importances [used to split random walk particles into two or more particles of reduced weight as they are travelling in the direction toward the dose points of interest, or to play Russian roulette with increased weight for the survivors in the other direction] were used to optimize the calculation by focusing the random walks towards the top of the supernate. The second segment was also biased in a similar manner, but was split into six ten centimeter radial layers. The first source segment, consisting of the top sixty centimeters of supernate, was split also radially into four segments in order to further optimize by including the smaller solid angle of the drywell as one moves further away.

A DXTRAN sphere [a DXTRAN sphere is used in MCNP for problems where random walk particles must scatter through a very small solid angle to reach the dose rate point of interest -- at a collision a direction of flight is selected within the angle subtended by the sphere and a pseudo-particle is advanced to the sphere with weight (future scoring contribution) decreased to account for the small solid angle and attenuation between collision (or source point) and sphere] was placed inside the riser for those measurements that were taken above the top of the tank. The outer radius of the sphere was set to be the same as the inner radius of the riser. A DXC card was used to allow contributions only from the drywell below the DXTRAN sphere and the 7.62cm (3") sludge region below the drywell. Particles scattering near the inner surface of the drywell wall are much more likely to reach the sphere, as they will attenuate through much less steel, considering the steep angle of flight. Therefore, further optimization was obtained by splitting the side of the drywell into four separate cells of increasing importance and increasing probabilities of contributing to the DXTRAN sphere.

Cell tallies within the drywell were used such that each cell was axially centered where a measurement was taken. Point detectors were used for 0, 30.48cm (1'), and 8.99M (29' 6") above the bottom of the drywell in order to more precisely determine the dose rate at these locations where dose rates are changing rapidly; i.e., along the sludge and the top of the supernate.

A.6.3 CONSISTENCY CHECK

As a check on the consistency of these calculations, the dose rate within the six inch drywell along the supernate was compared to the dose rate within the supernate itself -- this was done using the input file that was used for analysis of the steam coil riser on the same tank (see section III) and using the radial source of the 2nd part of this study. We would expect to calculate a somewhat higher dose rate within the supernate since the photons don't have to attenuate through the pipe of the dry well. The steam coil riser uses a 91.44cm (3 ft) foot deep, 3.65M (12 ft) radius source at the top of the supernate. The tally was put in the center cell, which extends from 30.48cm (1 ft) deep to 60.96cm (2 ft) deep below the surface of the supernate and has a radius of 91.44cm (3 ft). The source used from the analysis of the steam coil riser yielded a dose rate of 3.3 krem/hr (2%), which is higher than the ~1.70 krem/hr obtained within the drywell as we expected.

The drywell model has a sludge source from elevation 0 to 50.8 cm (20.000") and a supernate source from elevation 50.8 cm to elevation 854.4. Tallies were made in the source cells for the supernate, between elevations 220.98 cm (87.000") and 678.18 cm (22' 1/3"). Results for the 6" riser source are shown in Table 9 for each source cell in the supernate. These peak dose rates within the supernate of 3.14 (krem/hr) are about 4% lower than those obtained from the steam coil model, but that is apparently due to the tally in the drywell model being nearer boundaries. We assume this difference would decrease as the radius of the source in the drywell model was increased.

Table 9. Dose Rate Within Supernate In Drywell Model

Radius from riser	0 to 10 cm (0 to 3.94")	10 to 20 cm (3.94 to 7.87")	20 to 30 cm (7.87 to 11.81")	30 to 40 cm (11.81 to 15.75")	40 to 50 cm (15.75 to 19.69")	50 to 60 cm (19.69 to 23.62")
Dose rate (krem/hr)	2.90 (2%)	3.09 (2%)	3.14 (2%)	3.06 (2%)	2.78 (2%)	2.05 (2%)

A.6.4 ARCHIVAL OF INPUT FILES

The following table shows the MCNP input files that were used for comparing to the various measurements. These files have been saved in cfs in directory /v93586/w151/dry/

Dose Point Location	File Names
0	imeas103b
30.48cm (1')	imeas103
1.372M (4' 6")	imeas1 + imeas10
2.895M (9' 6")	imeas1 + imeas10
4.450M (14' 6")	imeas1 + imeas10
5.943M (19' 6")	imeas1 + imeas10
7.467M (24' 6")	imeas1 + imeas10
8.991M (29' 6")	imeas104
10.515M (34' 6")	imeas1 + imeas10
12.039M (39' 6")	imeas1 + imeas10
13.563M (44' 6")	imeas102
15.087M (49' 6")	imeas11
16.611M (54' 6")	imeas11

File itherm.ax was used for calculating the dose rate at the top of the riser due to the source along the length of the drywell. File itherm.brute was used for calculating the dose rate at the top of the riser due to the top sixty centimeters of the supernate.

File imeas2 was used to calculate the dose rate within the supernate source for the drywell. File imeas4 was used to calculate the dose rate within the supernate source for the steam coil riser.

Figure 1. Elevation View Showing Tank and Unmodified Steam Coil.

05/24/94 08:10:27

task W-151, tank AZ-101, file
121

probid = 05/24/94 08:08:40

basis:

(1.000000, 0.000000, 0.000000)

(0.000000, 0.000000, 1.000000)

origin:

(0.00, 431.05, 800.00)

extent = (1300.00, 1300.00)

Figure 2. Elevation View of modified Steam Coil Showing Dose Rates in mrem/hr.

05/24/94 08:22:08
 task W-151, tank AZ-101, file
 121
 probid = 05/24/94 08:20:36
 basis:
 (1.000000, 0.000000, 0.000000)
 (0.000000, 0.000000, 1.000000)
 origin:
 (-431.05, 431.05, 1700.00)
 extent = (150.00, 150.00)

Figure 3. Steam Coil Prior to Modification

Figure 4. Steam Coil After Modification

Figure 5. Elevation View of 4" Steam Inlet Pipe After Modification Showing Dose Rates in mrem/hr.

05/24/94 11:06:36

task W-151, tank AZ-101, file
121a

probid = 05/24/94 09:50:09

ba818:

(0.707107, 0.707107, 0.000000)

```
( 0.000000, 0.000000, 1.000000)
```

origin:

(	-398.00,	398.00,	1777.00)
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extent = (200.00, 200.00)

Figure 6. Shielding Caisson Removed, Dose Rates (mrem/hr)

Figure 7. Earth Partially Removed, Dose Rates (mrem/hr)

Figure 8. Earth Removed, Piping Removed, Dose Rates (mrem/hr)

Figure 9. Steam Coil Raised, Dose Rates (mrem/hr)

Figure 10. Steam Coil Raised, Riser Extension Installed, Dose Rates (mrem/hr)

Figure 11. Steam Coil Lowered Onto Riser Extension, Dose Rates (mrem/hr)

Figure 12. Caisson in Place, Earth Filled, Modification Complete, Dose Rates (mrem/hr)

Figure 13. Elevation View of Entire Tank Showing Riser to Pump.

05/24/94 14:45:37

task W-151, pump for tank
AZ-101, file 12

probid = 05/24/94 14:44:49

basis:

(1.000000, 0.000000, 0.000000)

(0.000000, 0.000000, 1.000000)

origin:

(0.00, 670.00, 1200.00)

extent = (1300.00, 1300.00)

Figure 14. Elevation View Showing Riser for Pump and Dose Rates (mrem/hr) at Base of Pump.

05/24/94 14:46:58
 task W-151, pump for tank
 AZ-101, file 12

probid = 05/24/94 14:44:49
 basis:
 (1.000000, 0.000000, 0.000000)
 (0.000000, 0.000000, 1.000000)
 origin:
 (0.00, 670.00, 1520.00)
 extent = (250.00, 250.00)

Figure 15. Dose Rates (mrem./hr) at Base of Pump with Thicker Steel Plate.

05/25/94 13:37:29
 task W-151, pump for tank
 AZ-101, thicker top plate,
 12.top
 probid = 05/25/94 13:36:36
 basis:
 (1.000000, 0.000000, 0.000000)
 (0.000000, 0.000000, 1.000000)
 origin:
 (0.00, 670.00, 1520.00)
 extent = (250.00, 250.00)

Figure 16. Dose Rates (mrem/hr) within Excavation Hole for Various Plug Thicknesses

05/25/94 14:33:18
 task W-151, pump for tank
 AZ-101, no dirt, 2' plug, file
 12noplt
 probid = 05/25/94 14:32:48
 basis:
 (1.000000, 0.000000, 0.000000)
 (0.000000, 0.000000, 1.000000)
 origin:
 (0.00, 670.00, 1520.00)
 extent = (230.00, 230.00)

Figure 17. Diluted Source, Steam Coil Raised, Dose Rates (mrem/hr)

Figure 18. Dose Rates (mrem/hr) in the Vicinity of Drywell Risers

Figure 20. Top of Drywell Riser After Modification

05/27/94 11:55:09
task W-151, tank AZ-101, file 4
11.3t

probid = 05/27/94 11:52:56
basis:
(1.000000, 0.000000, 0.000000) 3
(0.000000, 0.000000, 1.000000) 0
origin:
(0.00, 381.00, 1715.00)
extent = (40.00, 40.00)

Figure 21. Top of Open Riser After Modification

05/27/94 14:28:59

task W-151, tank AZ-101, file 6
12.40t

probid = 05/27/94 14:25:51

basis:

(1.000000, 0.000000, 0.000000)

(0.000000, 0.000000, 1.000000)

origin:

(0.00, 381.00, 1750.00)

extent = (60.00, 60.00)

Figure 22. Source Along Top of Supernate.

05/17/94 08:57:18
task W-151, tank AZ-101, file
itherm.brute

probid= 05/17/94 08:54:10
basis:
(0.000000, 1.000000, 0.000000)
(0.000000, 0.000000, 1.000000)
origin:
(0.00, 0.00, 914.40)
extent = (1300.00, 1300.00)

Figure 23: Source Along Drywell

05/17/94 09:03:21
 task W-151, tank AX-101, file
 itherm.ta

probid = 05/17/94 09:00:03
 basis:
 (0.000000, 1.000000, 0.000000)
 (0.000000, 0.000000, 1.000000)
 origin:
 (0.00, 381.00, 500.00)
 extent = (600.00, 600.00)

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SUPPORTING DOCUMENT		1. Total Pages 58 ⁵⁰ _{W78}
2. Title Dose Rate Analysis for Tank 101 AZ (Project W151)	3. Number WHC-SD-W151-TI-002	4. Rev No. 0
5. Key Words Tank 101 AZ Project W-151	6. Author Name: L. L. Carter <i>L. L. Carter</i> Signature Organization/Charge Code 8D530/ J8D53	
7. Abstract This document describes the expected dose rates for modification to tank 101 AZ including modifications to the steam coil, mixer pump, and temperature probes.		
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9. Impact Level SQ		