NUCLEAR GROUP

DOCTYPE 061

# CALCULATION COVER SHEET

1. Calculation No. LM-526

Page 1

2. ☒ LGS ☐ PBAPS

3. UNIT(S) 1+2

4. MOD/NCR/ECR No.: N/A
Other:

5. Responsible Branch: SEAQ

6. Last Page No: Att 7 pg 24 / 34

7. ☐ Safety Related ☒ Non-Safety Related

8. Description: Determine worst case radiological impacts of using solids, taken from cooling tower basins, Holding Pond, and Spray Pond, as fill

9. System/Topic No.: 009, 011, 012, 068, 102, 401, 911

Structure: N/A

Component: N/A

## RECORD OF REVISIONS

| 10. Rev. No. | 11. Description of Revision | 12. Vendor Calc. Number | Rev. | 13. Assumptions Yes | No | 14. Signatures Preparer | Reviewer | Approver/Date |
|---|---|---|---|---|---|---|---|---|
| 0 | Original | N/A | 0 | X | | P.T. Reichert (RNI) | [signature] (RNI) | L.R. [signature] (RNI) 1/16/95; IWB JC Basilio; JA Basilio 1/17/95 |
| 1 | Assess actual location, larger area, groundwater transport | N/A | 1 | X | | P.T. Reichert (RNI) | [signature] RNI | L.R. [signature] (RNI) 2/24/95; JC Basilio; IWB JA Basilio |

| 15. Related Calc. Numbers | | | | | | |
|---|---|---|---|---|---|---|
| Provides Info to: | N/A | | | | | |
| Receives Info from: | N/A | | | | | |
| 17. Provides Info to UFSAR/ Tech. Spec.: | NONE | | | | | |

16. ☐ Manual ☒ Computer

Computer program and version GASPAR (MC-011) Rev. 0

18. Total Pages: (DS Use)

CALC. # LM-526 REV. 1

DCD # N/A DATE: 2/23/95

# CALCULATION REVIEW CHECKLIST

| MANUAL CALC. | COMPUTER CALC. | | YES or N/A |
|---|---|---|---|
| X | (X) | CALCULATION IS THE APPROPRIATE BASIS FOR THE ACTIVITY | Yes |
| X | (X) | CALCULATION ASSUMPTIONS, CONSIDERATIONS, AND METHODOLOGY CONFORM TO APPLICABLE DESIGN REQUIREMENTS | Yes |
| X | (X) | SOURCES OF DATA AND FORMULAS WERE REVIEWED AND VERIFIED TO BE CORRECT AND COMPLETE | Yes |
| X | (X) | INPUT ~~DATE~~ DATA IS CORRECT AND USED PROPERLY | Yes |
| X | | THE ANALYTICAL METHOD USED IN THE CALCULATION HAS BEEN CONSIDERED AND IS PROPER FOR THE INTENDED USE | NA |
| X | | MATHEMATICAL ACCURACY HAS BEEN CHECKED AND IS CORRECT (INDICATE METHOD USED) | NA |
| | | A) COMPLETE CHECK OF EACH COMPUTATION | NA |
| | | B) SPOT CHECK OF SELECTED COMPUTATIONS | NA |
| | | C) PERFORMANCE OF ALTERNATE OR APPROXIMATION CALCULATION (ATTACHED) | NA |
| X | (X) | CALCULATION RESULTS WERE CHECKED AGAINST APPLICABLE DESIGN CRITERIA AND WERE FOUND TO BE IN COMPLIANCE | Yes |
| X | (X) | EXISTING CALCULATIONS REQUIRING REVISION AS A RESULT OF THIS CALCULATION HAVE BEEN IDENTIFIED & DOCUMENTED | NA |
| | (X) | THE ANALYTICAL METHODS DESCRIBED IN THE COMPUTER CALCULATION SUMMARY IS PROPER FOR THE INTENDED USE | Yes |
| X | (X) | ALL SYSTEM AND TOPIC NUMBERS ASSOCIATED WITH THE CALCULATION ARE LISTED | Yes |
| | (X) | COMPUTATIONAL ACCURACY HAS BEEN CHECKED AND IS CORRECT (INDICATE METHOD USED) | Yes |
| | | A) CHECK SAMPLE CALCULATION USING DATA OTHER THAN THAT USED IN THE SAMPLE | NA |
| | | B) PERFORMANCE OF ALTERNATE OR APPROXIMATION CALCULATION (ATTACHED) | NA |
| | | C) DESCRIBE OTHER METHOD USED: GASPAR WAS VERIFIED UNDER ~~B~~MEDP-0044 | Yes |
| | (X) | PROGRAM USED IS APPROPRIATE, INPUT IS VALID, AND OUTPUT IS REASONABLE CONSIDERING THE INPUT | Yes |
| X | (X) | BASE CALCULATION HAS BEEN REVIEWED AGAINST CURRENT DRAWING REVISIONS AND POSTED DCDs TO IDENTIFY SIGNIFICANT DIFFERENCES | NA |

The criteria listed above are the minimum criteria to be considered and are not intended to limit the initiative of the reviewer to consider other criteria.

Attributes applicable to manual and computer calculations are noted by an "X" in the appropriate column.

List the documents used to support this review. References 5-9 in section 6.0

REVIEWED BY: [signature] (RNZ) DATE: 2/23/95

FORM 5610 REV. 4/91

**Raytheon**
**Engineers & Constructors**
A Consolidation of Badger and UE&C

# CALCULATION SUMMARY & CONTROL SHEET



CALCULATION SET NO. LM-526

| PRELIM | FINAL | VOID | REVISION |
|---|---|---|---|
| | X | | 1 |

DISCIPLINE: MECHANICAL

J.O.: 7198.600

PROJECT TITLE: LIMERICK GENERATING STATION UNITS 1 & 2

STRUCTURE OF SYSTEM: 009,011,012,068,102,901 911 OTR

DESIGN CLAS[illegible]: NON-SAFETY RELATED

SUBJECT: DETERMINE WORST CASE RADIOLOGICAL IMPACTS C[illegible]SING SOLIDS, TAKEN FROM COOLING TOWER BASINS, HOLDING POND, AND SPRAY POND, AS FILL

COMPLETED BY: Paul T. Reichert — Paul T. Reichert — DATE: 2/23/95

CHECKED BY: W. R. Brown — W. R. BROWN — DATE: 2/23/95

APPROVED BY: L.R. Scott — L.R. Scott — DATE: 2/24/95 (SDE OR MGR OF STAFF GROUP)

REASON FOR REVISION:

CALCULATION REVISED TO: (1) CALCULATE DOSE IMPACTS WITH INCREASED AMOUNT OF SOLIDS TO BE HANDLED AND INCREASED AREAS TO BE COVERED; (2) REVISE AND DEFEND ASSUMPTIONS FOR EROSION CAUSED DOSES; (3) IDENTIFY RELATIONSHIP BETWEEN ACTIVITY LIMITS AND EFFLUENT LLDs; (4) DELETE ASSESSMENTS FOR ZR-95 & NB-95; AND ASSESS GROUNDWATER TRANSPORT EFFECTS FOR THE SELECTED SITE.

TOTAL NUMBER OF SHEETS IN THIS ISSUE: 141

SHEETS REVISED, ~~ADDED OR DELETED~~: 1, 2, 3, 5-14, 16-22
Att 1 (3 pgs)
Att 6 (3 pgs)
Att 7 (24 pgs) replaced

PROBLEM STATEMENT:

SEE PAGE 5, SECTION 1.0.

SUMMARY/CONCLUSIONS:

SEE PAGE 5, SECTION 2.0.

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CALCULATION SUMMARY
& CONTROL SHEET
Page ~~2 of 2~~ 4 of 22

| CALCULATION SET NO | | | |
|---|---|---|---|
| LM-526 | | | |
| PRELIM | FINAL | VOID | REVISION |
| | X | | 0 |

DISCIPLINE MECHANICAL

J.O. 7198.600

PROJECT TITLE LIMERICK GENERATING STATION UNITS 1 & 2

DESIGN BASIS:

SEE SECTION 3.0.

UNVERIFIED ASSUMPTIONS/OPEN ITEMS:

SEE SECTION 4.2.

REFERENCES: (SPECIFICATIONS, DRAWINGS, CODES, CALCULATIONS, TEXTS, REPORTS, COMPUTER DATA, FSAR, ETC.)

SEE SECTION 6.0.

## 1.0 PROBLEM STATEMENT / PURPOSE OR OBJECTIVE OF CALCULATION

This calculation supports the use of flowable solids taken from the LGS holding pond, cooling tower basins, and spray pond as onsite fill. This material will be monitored to confirm that any radioactivity concentrations are not greater than Solids Activity Limits that are ten (10) times the Effluent Lower Limits of Detectability (LLD). This calculation determines worst case radiological impacts, if the flowable solids radioactivity concentrations were at the Solids Activity Limits.

Radiological impact considered are:

(1) Airborne concentrations and doses due to wind borne erosion of the flowable solids pile. These concentrations will be compared with 10 CFR 20 [Ref.1] limits, and doses compared with 10CFR50 [Ref. 2] limits. It is desirable that these concentrations and doses should be negligible compared with these limits, to support the use of the Solids Activity Limits as screening criteria.

(2) Groundwater transport of activity to the Schuylkill River. No consideration of groundwater transport to well locations is necessary, since all offsite and onsite wells are upgradient from the locations where this flowable solids may be placed.

(3) Evaluation of water caused erosion impacts.

(4) Worst case dose rate to workers directly over the flowable solids, due to direct shine and inhalation.

(5) Worst case dose rate for a hypothetical residential use of the flowable solids placement area. This data will provide an indication of the potential for free release of the areas where these flowable solids are used, after plant decommissioning.

(6) Offsite doses due to airborne releases for pathways other than inhalation.

## 2.0 SUMMARY OF RESULTS AND CONCLUSIONS

This calculation analyzes radiological impacts of a conservatively characterized system for using flowable solids as onsite fill. Radioactivity in solids to be placed onsite will be less than the Solids Activity Limits, as described in Attachment 1.

Wind caused airborne releases from the fill area can cause only a negligible contribution to offsite doses. The calculated inhalation dose commitment to an individual at the site boundary is 1.82E-4 mrem/yr. Doses to other pathways, modeled using GASPAR, are all at or below 0.101 mrem/yr, with a very conservative isotopic mix.

Worst case concentrations in releases from the solids to groundwater will be near (2.93 MPC) the regulatory limits for effluents, even if all isotopes are at the Solids Activity Limits. Concentrations of about 0.021 of the 10CFR20 Maximum Permissable Concentration (MPC) will result at the site boundary when credit for the transit time of 194 years [based on Sr-90] is taken. No onsite or offsite wells will be impacted.

Potential release concentrations due to erosion will be less than an MPC.

Dose rates to operators during handling this material will be far below 10CFR20 restricted area limits. Airborne activity will also be negligible.

Placement of these conservatively characterized flowable solids as fill should not interfere with plant decommissioning and free release. Some decay time may be necessary depending on actual activity levels.

## 3.0 DESIGN BASES / INPUT / CRITERIA

### 3.1 DESIGN BASES / INPUT

(1) The total flowable solids removal rate is conservatively set at 70,000 $ft^3$ per year. A total of 16 placements are assumed for a total of 1,120,000 $ft^3$. This total allowance for the remaining 30 years of plant life is approximately 10 times the solids removed over the first 10 years of plant life. The compressed schedule of placement is used to maximize the calculated groundwater effects and to minimize potential that bases for this calculation could delay solids placement. See Section 5.1.1 for discussion of historical solids removal.

(2) These solids are unlikely to be spread over more than 70,000 $ft^2$ (1.61 acres). [See Section 5.1.3.]

(3) The flowable solids will be monitored to assure that any radioactivity is at concentrations less than the Solids Activity Limits, which are set at ten (10) times the Effluent LLD for potentially expected isotopes. [See Section 5.1.2, and Attachment 1 for Effluent LLD Derivation.]

(4) The area for solids placement will be located down-gradient from any offsite well, or onsite well used for other than groundwater sampling.

### 3.2 DESIGN CRITERIA

(1) Doses to onsite personnel from any radioactivity in the flowable solids shall be within 10CFR20 limits and ALARA.

(2) Offsite airborne concentrations due to dusting from the flowable solids fill area shall be a very small fraction of 10CFR20 unrestricted area concentrations.

(3) Offsite doses due to dusting from the flowable solids area shall be a very small fraction of doses resulting from other sources at LGS.

(4) Groundwater concentrations, due to any radioactivity transport from the flowable solids, shall be less than 10CFR20, Appendix B limits, upon discharge to the Schuylkill River.

(5) Activity in stormwater runoff, as discharged from the holding pond, shall have radioactivity concentration levels less than 10CFR20, Appendix B limits, upon discharge to the Schuylkill River.

(6) It is preferable that the flowable solids not require any additional handling upon LGS decommissioning, to allow free release of the flowable solids use area. Free release criteria published in the USNRC proposed rule on Radiological Criteria for Decommissioning [Ref. 3] shall be used in this determination.

## 4.0 ASSUMPTIONS / UNVERIFIED ASSUMPTIONS

### 4.1 ASSUMPTIONS

None.

## 4.2 UNVERIFIED ASSUMPTIONS

The design inputs (in Section 3.1) and certain other conclusions of this calc. will become design criteria for the flowable solids fill area, or this calculation should be revised. Particularly included are:

(a) The 70,000 sq. ft. fill area size upper bound;

(b) The commitment to control radioactivity concentrations to the proposed Solids Activity Limits;

(c) The groundwater transport calculation basis assumes that the solids are placed in one (1) foot thick layers covering 70,000 sq. ft. Solids place in thicker layers over smaller areas would reduce the diluting infiltering water. Therefore, placements should be evaluated to assure that:

FRACTION OF THE LIMIT FOR THE WORST CASE ISOTOPE *
VOLUME OF SOLIDS PLACEMENT ($ft^3$) /
PLACEMENT AREA ($ft^2$)

is less than one (1).

(d) Total placement of less than 1,120,000 cu. ft, and individual placements are equal to or less than 70,000 cu. ft.

## 5.0 DETAILS OF CALCULATIONS

## 5.1 MATERIALS HANDLED

### 5.1.1 FLOWABLE SOLIDS REMOVAL RATES

Flowable solids may be taken from the cooling tower basins, the holding pond, and the spray pond. Discussion with PECO personnel provided historical solids generation data, as discussed below.

The most recent operation (1994) on the holding pond yielded 7,900 cu. ft. of material. This operation is expected on perhaps an every three year basis.

The cooling tower basins are expected to be the dominant source of material. The only historical operation on a cooling tower basin (Unit 1, 1991) yielded 68,000 cubic feet of dewatered sludge. Another cleaning may be required in 1996. The Unit 2 cooling tower appears less prone to flowable solids buildup and has never required cleaning.

The spray pond has not yet required flowable solids removal. The spray pond has a design margin of 3 inches of flowable solids, displacing 0.68 million gallons of water [UFSAR, Section 9.2.6.4.2.5]. Thus, if cleaning were ever required, and the entire margin were to be restored, approximately 91,000 cu. ft. of material would be removed.

For this analysis an enveloping assumption of 70,000 cubic feet of total material in each placement. To minimize the potential that the calculation could cause a delay in material placement, this amount

is assumed to be deposited each year, for 16 years. This compressed schedule maximizes calculated concentrations in groundwater. The total assumed placement would be 1,120,000 cubic feet, which is more than 10 times that historically observed over the first 10 years of plant life. These values are expected to envelope any cooling tower and holding pond requirements. This is also a more realistic amount for a spray pond cleaning operation.

### 5.1.2 WORST CASE RADIOACTIVITY CONTENT

Little or no radioactivity has been found in these flowable solids in the past, and they have been disposed of as non-radioactive, non-hazardous wastes. To establish a conservative estimate of the amounts and isotopic breakdowns of the postulated radioactive material dispersed within the flowable solids, Table 1 was developed. This table shows (1) Solids Activity Limits which would be used as a screening criteria, for a range of isotopes which have been found in various plant process fluids and waste streams; and (2) the 10CFR20, Appendix B limits on effluent concentrations in air and water.

### 5.1.3 LOCATION AND LAYOUT FOR MATERIAL PLACEMENT

The location for the placement of this material has been selected to be in an area to the northwest of the spray pond and south of the meteorology tower No. 1. A final layout for this material has not been determined. Therefore, for this analysis, the material is assumed to be spread over an area of not greater than 70,000 sq. ft. (6503 sq. meters).

## 5.2 POTENTIAL AIRBORNE RELEASES TO OFFSITE AREAS

### 5.2.1 AIRBORNE RELEASE MECHANISMS FROM FLOWABLE SOLIDS FILL AREA

Any airborne releases from the flowable solids fill area are expected to be due to wind caused dusting of this material. Attachment 2, taken from Reference 6, describes the physical processes involved, and the methods of assessment performed by the USNRC for uranium milling tailing piles.

Additionally, Ref. 7 indicates that an air dust loading of $10^{-4}$ gm/cu. meter can be used for airborne activity above the contaminated soil under normal dusty conditions. A loading of $5x10^{-4}$ gm/cu. meter can be used for soil being worked, such as might be the case for grading, or residential use gardening.

### 5.2.2 OFFSITE AIRBORNE CONCENTRATIONS AND INHALATION DOSES

Table 1A shows the resulting inhalation dose rate to an individual at the nearest site boundary to the solids fill, to be $1.82x10^{-4}$ mrem/yr, based on the above normal dust loading.

The inhalation dose rate above the fill is low enough to be considered a negligible contribution to offsite doses rates resulting from other LGS activities.

### 5.2.3 OFFSITE DOSES DUE TO INGESTION PATHWAYS

Attachment 7 is a GASPAR run output, calculating doses due to various ingestion pathways. X/Q values are based on several factors. Releases are assumed to be 370 gm/yr/sq. meter, conservatively based on uranium mill tailing analyses from Reference 6, and shown in Attachment 2, page 6. This yields a release of $2.406x10^{6}$ gm/yr, or 0.07625 gm/sec. [See Table 1B.]

Using the $10^{-4}$ gm/cu. meter normal dust loading, a X/Q of $1.312 \times 10^{-3}$ sec/cu. meter is calculated. As shown in Table 1A, additional credit can be taken for wind direction frequency toward a location on the nearest site boundary, and for the additional lateral dispersion. No credit is taken for vertical dispersion or for any deposition effects in route to the site boundary. The X/Q is therefore adjusted by 0.103 to account for wind frequency and 0.68 for lateral dispersion, yielding an net X/q of $9.189 \times 10^{-5}$.

Default pathway parameters are used and are conservative for the LGS site.

Doses from the GASPAR analysis in no case exceed 0.101 mrem/yr, and are extremely conservative.

## 5.3 RELEASES THROUGH GROUNDWATER

### 5.3.1 BEHAVIOR OF GROUNDWATER RELEASES

No consideration of groundwater transport to well locations is necessary, since all offsite and onsite wells are up-gradient from the locations where this flowable solids may be placed. Only consideration of groundwater transport to the Schuylkill River is needed.

Removal of any radioactivity from the flowable solids fill to groundwater is the result of radionuclide leaching from the contaminated zone. The leached radioactivity is assumed to be carried by the infiltered water. Attachment 3 [Ref. 8], Equation E.4, is used to determine the infiltration rate. The annual average precipitation rate [$P_r$] used is from UFSAR Table 2.3.1.4, and is 43.9 inches of water. This would be 1.12 m/yr. The standard evapotranspiration and runoff coefficients [$C_e$ and $C_r$] were used. No irrigation was assumed. The resulting infiltration rate is 0.448 m/yr. Over the 70,000 $ft^2$ fill surface, this provided a water flow of 2.91E+09 ml/yr.

Attachment 3, taken from Ref. 8, also provides a basis for assessing this leaching phenomena. Table 2A shows the derivation of leach rates from the solids.

Table 2B shows the ratio of the resulting concentration to 10CFR20, Appendix B Effluent Limits. Assuming that all material placements, for all isotopes, are at the Solids Activity Limits, the calculated releases to underlying groundwater is 2.93 MPC.

To determine the groundwater transport time the same methodology was used as was applied to radwaste tank spillages in UFSAR Section 2.4.13. The information below shows the application for both the radwaste tank and the solids area.

DETERMINATION OF ISOTOPE TRANSPORT TIME TO SCHUYLKILL RIVER FOR GROUNDWATER BORNE ACTIVITY:

| | |
|---|---|
| 130 | Groundwater Elevation below Tank (ft) [UFSAR Analysis] |
| 240 | Groundwater Elevation below Solids Placement Area (ft) [UFSAR Fig. 2.4-15] |
| 800 | Tank Distance to River (ft.) [UFSAR Analysis] |
| 1000 | Solids Placement Area Distance to River (ft.) [UFSAR Figure 2.4-1] |
| 105 | Average River Elevation [UFSAR Analysis] |
| 390 | Permeability of underlying material (ft/yr) [UFSAR Analysis] |

| | gradient | groundwater velocity (ft/yr) | groundwater travel time (yrs) | Sr-90 travel time (yrs) |
|---|---|---|---|---|
| Tank | 0.03125 | 243.75 | 3.28 | 671 |
| Solids | 0.135 | 1053 | 0.950 | 194 |

As shown in Table 2B, it is expected that the additional decay in transit from below the fill area to the Schuylkill River will be sufficient to assure that discharges of groundwater would meet these limits.

It should also be noted that this groundwater flow of 2.91E+09 ml/yr will be diluted by an average of 1.60E+15 ml/yr of river flow (UFSAR Pg. 2.4-2, 1793 cfs * 3.16E+07 sec/yr *2.83E+04 ml/ft$^3$), for an average concentration reduction of 1.8E-06.

For the above reasons, the Groundwater pathway from the flowable solids is considered negligible.

## 5.4 RELEASES THROUGH EROSION

### 5.4.1 NORMAL RAINFALL CONDITIONS

The fill area is expected to be graded and seeded to minimize erosion. Erosion control fencing will also be used as appropriate.

For worst case evaluation purposes, erosion by way of runoff will contain one (1) percent by weight solids. A runoff coefficient of 0.2 is used, consistent with the groundwater assessment above. With the 1.12 m/yr precipitation rate, and a 6503 sq. m. area, the total water runoff would be 1.46E+09 ml/yr. Using the worst case 1 percent solid as a conservative upper bound, 1.46E+07 gm/yr of the fill material would be eroded. Note that this solids loading (10,000 ppm) is on the order of 100 times that typically in estuaries such as the Deleware [Ref 9].

For further illustration purposes, this erosion rate would yield a loss of about 0.38 percent of the nominal 70,000 ft$^3$ fill load each year, or about 1.2 mm average surface loss. Reference 9 estimates of soil loss for the Deleware River basin averages approximately 50 metric tonnes/sq. km, or only about 0.025 mm. The Schuylkill River Basin would be expected to be comparable.

A 1 percent slurry will yield a combined radionuclide concentration within 10CFR20, Appendix B limits, as shown in Table 6.

Given the demonstrated conservatism of runoff loading assumptions, and the resulting acceptability of calculated doses, the standard erosion control measures described above should be ample to assure that regulatory limits are not exceeded.

### 5.4.2 PROBABLE MAXIMUM PRECIPITATION (PMP) CONDITIONS

UFSAR Table 2.4-7 indicates that the initial 6 hour PMP is 26.8 inches of rainfall. Under PMP conditions, virtually all of this rainfall will run off.

The PMP rainfall 3 times the normal 8.8 inches (1.12 meters/yr * 0.2 runoff coef. * 39.4 in./meter) of rainfall runoff that was calculated to "run off with 1 percent" of the nominal fill load over a three year

period as described in Section 5.4.1 above. Thus, concentrations leaving the fill area would be no worse than the condition shown in Table 6, unless significantly more erosion occured. Additionally, this conclusion considers dilution only by rainfall falling directly on the 1.61 acre fill area. Runoff can be expected to actually mix with and be diluted by runoff from surrounding areas before discharging beyond the site boundary. The total site area is 595 acres. Therefore, for this severe event, average discharge concentrations, even with severe erosion, would be unlikely to exceed 10CFR20 Effluent Limits.

## 5.5 OCCUPATIONAL DOSE RATES DURING MATERIAL HANDLING

Table 3 shows external exposure dose rates for contact with the flowable solids fill, modeled as a semi-infinite slab. Also shown are calculated doses due to inhalation, based on suspended airborne activity commensurate with this material being worked.

The worst case external exposure dose rate is less than 0.05 mrem/hr, and therefore this would not be considered a radiation area. The inhalation dose rates are such that respiratory protection would not be required.

## 5.6 RESIDENTIAL USE DOSE ASSESSMENTS

An additional concern with the use of flowable solids, is whether this material might require additional handling during plant decommissioning and eventual site free release.

In order to quantify this, a residential use assessment is performed. The methodology is as Documented in NUREG/CR-5512 "Residual Radioactive Contamination from Decommissioning - Technical Basis for Translating Contamination Levels to Annual Dose" [Ref. 7]. Relevant portions of this reference are in Attachment 7.

Two standardized exposure scenarios are considered, as follows:

(1) The Residential Use (Surface Soil) Scenario, which includes:

(a) External gamma shine to resident, both inside and outside of the residence;

(b) Inhalation doses;

(c) Food ingestion from garden grown in this soil.

(2) The Drinking Water Scenario.

The doses from the surface soil scenario are given in Table 4, and are controlled by the last material deposit. The design criteria for free release is taken from Ref. 3, and requires that doses be less that 15 mrem/yr and ALARA below that level. It is likely that several decades may be required for decommissioning, including an allowance for decay of radioactivity in plant equipment. Table 4 shows that, even for this worst case isotopic mix, that annual doses under this scenario would be below 15 mrem within 20 years.

Table 5 shows doses in the Drinking Water Scenario. The total deposited activity is assumed to be 16 70,000 cu. ft. loads, each deposited one year apart. The dose conversion factors from NUREG/CR-5512 require, as input, the total activity in the contaminated material at free release. Therefore, that

activity over each load is summed, with credit for decay but no other release mechanism. As can be seen, the drinking water scenario doses are less that 1 mrem/yr at 20 years.

Use of this material as onsite fill is not expected to interfere with free release of the site, after plant decommissioning. This is because:

(1) Even with very conservative activity assumptions, the dose rates would be within decommissioning criteria within 20 years;

(2) The residual radioactivity is likely to be substantially less;

(3) The material in its final configuration will be easily surveyed and evaluated to confirm its acceptability for free release.

## 6.0 REFERENCES

(1) 10CFR20, "Standards for Protection Against Radiation", Appendix B.

(2) 10CFR50, Appendix I.

(3) USNRC Proposed Rule on Radiological Criteria for Decommissioning (Federal Register, Vol 59, pages 43200-43232, August 22, 1994.

(4) PECO supplied estimates of material taken from holding pond and cooling tower.

(5) LGS UFSAR, Current as of 11/01/94, as indicated in calculation text.

(6) NUREG-0706, "Final Generic Environmental Impact Statement on Uranium Milling", Volume III, Appendix G, Pages G-7 to G-11, Sept, 1980

(7) NUREG/CR-5512, "Residual Radioactive Contamination from Decommissioning - Technical Basis for Translating Contamination Levels to Annual Dose." Draft Report for Comment, Jan 1990.

(8) ANL/EAD/LD-2, "Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0", September 1993.

(9) <u>Ecology and Restoration of the Deleware River Basin</u>, Pennsylvania Academy of Sciences, 1988

## 7.0 LIST OF ATTACHMENTS

(1) PECO Provided Effluent LLD and Solids Activity Limits Derivations

(2) Reference 6.

(3) Appendix E, "Water Pathway Factors", of Reference 8.

(4) Portions of Reference 7 used in this calculation.

(5) Portions of 10CFR20, Appendix B.

(6) Computer Disclosure Sheet and Spreadsheet Verification

(7) GASPAR Run Output

FORM 5007 REV. 4/91

| **Raytheon** Engineers & Constructors | GENERAL COMPUTATION SHEET | CALCULATION SET NO. LM-526 | REV. | COMP. BY | CHK'D. BY |
|---|---|---|---|---|---|
| | | PRELIM. / FINAL -X / VOID | 1 | PTR DATE 2/23/95 | DATE 2/23/95 |
| | | SHEET 13 OF 22 | | DATE | DATE |
| | | J.O. 7198.600 | | | |

PROJECT LIMERICK GENERATING STATION - UNITS 1 & 2 COOLING TOWER, HOLDING POND AND SPRAY POND

SUBJECT DETERMINE WORST CASE RADIOLOGICAL IMPACTS OF USING SOLIDS, TAKEN FROM THE COOLING TOWER BASINS, HOLDING POND, AND SPRAY POND, AS FILL

TABLE 1A - ASSESSMENT OF INHALATION DOSE RATE ABOVE-SOIL TAKEN FROM COOLING TOWER BASINS, SPRAY POND, & SETTLING POND, ASSUMING ALL ISOTOPES ARE AT THE SOLIDS [illegible] LIMIT

| Nuclide | Solids Activity Limits uCi/g(dry) | 10CFR20 App. B Limits Air uCi/ml | # Fraction of Air Limit | @ Annual Dose mrem |
|---|---|---|---|---|
| Fe-55 | 1E-05 | 3E-09 | 3.3E-07 | 1.7E-05 |
| Mn-54 | 5E-06 | 1E-09 | 5.0E-07 | 2.5E-05 |
| Co-58 | 5E-06 | 1E-09 | 5.0E-07 | 2.5E-05 |
| Fe-59 | 5E-06 | 5E-10 | 1.0E-06 | 5.0E-05 |
| Co-60 | 5E-06 | 5E-11 | 1.0E-05 | 5.0E-04 |
| Zn-65 | 5E-06 | 4E-10 | 1.3E-06 | 6.3E-05 |
| Sr-89 | 5E-07 | 1E-09 | 5.0E-08 | 2.5E-06 |
| Sr-90 | 5E-07 | 6E-12 | 8.3E-06 | 4.2E-04 |
| Mo-99 | 5E-06 | 2E-09 | 2.5E-07 | 1.3E-05 |
| Cs-134 | 5E-06 | 2E-10 | 2.5E-06 | 1.3E-04 |
| Cs-137 | 5E-06 | 2E-10 | 2.5E-06 | 1.3E-04 |
| Ce-141 | 5E-06 | 8E-10 | 6.3E-07 | 3.1E-05 |
| Ce-144 | 5E-06 | 2E-11 | 2.5E-05 | 1.3E-03 |
| | | | 5.3E-05 | 2.6E-03 |

\# Assuming airborne dust loading of 1.0E-04 g/cu. meter, for dusty outside conditions, per NUREG/CR-5512.

@ Given that the 10CFR20 concentration limits are those projected to yield 50 mrem/yr, the air total should correspond to an annual dose commitment of 2.6E-03 mrem/yr.

To credit dispersion to the site boundary the placement area is treated as having a lateral extent of no greater than 100 meters. A virtual source is then determined such that a single 22.5 degree sector would encompass the source. This virtual source would be at 250 meters back from the distributed source. The nearest site boundary to the placement area is approximately 400 ft, (120 M) from the placement area in between the ENE and NNE directions. At this distance winds from the SW and 1/2 of the SSW & WSW Sectors could cross the placement area and impact a receiver at the boundary. Based on UFSAR Table 2.3.2-2, the total wind frequency would be 0.047+0.5*(0.060+0.051) = 0.103. Therefore the dose above the placement area can be adjusted to account for wind frequency and also, additional lateral dispersion [250 / (120 + 250) = 0.68]. The resulting calculated dose rate is 2.6E-03 * 0.103 * 0.68 = 1.82E-04.

TABLE 1B - IDENTIFIECTION OF AIRBORNE RELEASES

370 = (gm/m^2-yr) MASS AREAL RELEASE RATE

6503.2128 = AREA OF STORAGE (m^2)

2.41E+06 = MASS RELEASE RATE (GM/YR)

| Nuclide | Solids Activity Limits uCi/g(dry) | Annual Release (Ci) | |
|---|---|---|---|
| Fe-55 | 1E-05 | 2.4E-05 | |
| Mn-54 | 5E-06 | 1.2E-05 | |
| Co-58 | 5E-06 | 1.2E-05 | |
| Fe-59 | 5E-06 | 1.2E-05 | |
| Co-60 | 5E-06 | 1.2E-05 | |
| Zn-65 | 5E-06 | 1.2E-05 | |
| Sr-89 | 5E-07 | 1.2E-06 | |
| Sr-90 | 5E-07 | 1.2E-06 | |
| Mo-99 | 5E-06 | 1.2E-05 | |
| Cs-134 | 5E-06 | 1.2E-05 | |
| Cs-137 | 5E-06 | 1.2E-05 | |
| Ce-141 | 5E-06 | 1.2E-05 | |
| Ce-144 | 5E-06 | 1.2E-05 | |

Areal release rate is that calculated in the Final Environmental Impact Statement on Uranium Milling. [NUREG-0706] and is considered conservative compared to this application.

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TABLE 2A

APPLICATION OF ATTACHMENT 3, EQUATIONS E.3 - E.8 TO DETERMINE WORST CASE LEACH RATES

0.448 = Infiltration Rate (m/yr)

0.3048 = initial thickness of contamination zone (m)

2.25 = contaminated material nominal bulk density (gm/ml)

| | Tbl. E.2<br>K sat | Tbl. E.2<br>THETA sat | Tbl. E.2<br>b | Eq. E.7<br>R sat | Eq. E.6<br>Theta (cz) | |
|---|---|---|---|---|---|---|
| Sand | 5.55E+03 | 0.395 | 4.05 | 0.428 | 0.169 | used below |
| Loamy sand | 4.93E+03 | 0.410 | 4.38 | 0.453 | 0.186 | |
| Sandy loam | 1.09E+03 | 0.435 | 4.90 | 0.544 | 0.237 | |
| Silty loam | 2.27E+02 | 0.485 | 5.30 | 0.633 | 0.307 | |
| Loam | 2.19E+02 | 0.451 | 5.39 | 0.638 | 0.288 | |
| Sandy clay loam | 1.99E+02 | 0.420 | 7.12 | 0.702 | 0.295 | |
| Silty clay loam | 5.36E+01 | 0.477 | 7.75 | 0.772 | 0.368 | |
| Clay loam | 7.73E+01 | 0.476 | 8.52 | 0.773 | 0.368 | |
| Sandy clay | 6.84E+01 | 0.426 | 10.40 | 0.810 | 0.345 | |
| Silty clay | 3.26E+01 | 0.492 | 10.40 | 0.835 | 0.411 | |
| Clay | 4.05E+01 | 0.482 | 11.40 | 0.840 | 0.405 | used below |

Retardation Factor Determination for Elements of Interest

| Element | Table E.3<br>K d (sand)<br>(ml/g) | Table E.3<br>K d (clay)<br>(ml/g) | Eq. E.8<br>R di<br>(sand) | Eq. E.<br>R di<br>(clay) | Eq. E.3<br>L i<br>(sand)<br>(yr^-1) | Eq. E.3<br>L i<br>(clay)<br>(yr^-1) |
|---|---|---|---|---|---|---|
| Fe | 100 | 1000 | 1332 | 5559 | 6.5E-03 | 6.5E-04 |
| Mn | 20 | 200 | 267 | 1113 | 3.3E-02 | 3.3E-03 |
| Co | 100 | 1000 | 1332 | 5559 | 6.5E-03 | 6.5E-04 |
| Zn | 2 | 20 | 28 | 112 | 3.1E-01 | 3.2E-02 |
| Sr | 3 | 30 | 41 | 168 | 2.1E-01 | 2.2E-02 |
| Zr | 100 | 1000 | 1332 | 5559 | 6.5E-03 | 6.5E-04 |
| Cs | 80 | 500 | 1066 | 2780 | 8.2E-03 | 1.3E-03 |
| Ce | 100 | 1000 | 1332 | 5559 | 6.5E-03 | 6.5E-04 |

Regarding flowable solids densities, the ground below the site is described in the UFSAR, Table 2.4-20, as having a bulk density of 2.65 gm/ml and a 0.05 porosity. The flowable solids are assumed to be similar material, except with a porosity of 0.3. This porosity is identified in Ref. 7, Page B.12, as a value applicable to only partially compacted soils. This value is used for the Ref. 7 waste/soil mixtures in drinking water scenario assessments. The resulting bulk densities for the flowable solids would be 1.95 gm/ml (totally dry), and 2.25 gm/ml (saturated).

TABLE 2B ASSESSMENT OF GROUNDWATER INGESTION DOSE RATE, ASSUMING ACTIVITY IS RELEASED FROM THE CONTAMINATED ZONE TO GROUNDWATER BASED ON APPLICABLE LEACH RATES, WITH CREDIT FOR DECAY, AND MIXED IN THE EXPECTED PRECIPITATION INFILTRATION. SIXTEEN LOADS ARE ASSUMED, WITH CREDIT FOR LOSSES BY DECAY AND LEACHING, UNTIL THE LAST LOAD IS PLACED.

1.95 - Nominal flowable solids density (gm/cc)
70,000 - Volume and Area of solids deposited every year (cu. ft. & sq. ft.)
1.98E+09 - Volume of solids deposited every year (ml)
6.50E+07 - Area of solids deposited (sq. cm.)
0.448 - Infiltration Rate (meters/yr)
2.91E+09 - Total Infiltration (ml/yr)

| Nuclide | Solids Activity Limits uCi/g(dry) | Activity Loss Rates | | Decay + Leach Constant (-yr-1) | Activity at Placement (uCi) | Activity After 16 Placements (uCi) | uCi | Release from Solids to Groundwater Fraction of Water Limit | Percent of MPC Total | Fraction of Water Limit with 194 yr of decay |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Leach Rate (yr-1) # | Half Life (yr) | | | | | | | |
| Fe-55 | 1E-05 | 6.5E-03 | 2.7 | -2.63E-01 | 3.9E+04 | 1.65E+05 | 1E-04 | 3.67E-03 | 0.13% | 8.6E-25 |
| Mn-54 | 5E-06 | 3.3E-02 | 0.856 | -8.43E-01 | 1.9E+04 | 3.39E+04 | 3E-05 | 1.28E-02 | 0.44% | 7.6E-71 |
| Co-58 | 5E-06 | 6.5E-03 | 0.194 | -3.58E+00 | 1.9E+04 | 1.99E+04 | 2E-05 | 2.22E-03 | 0.08% | 2.1E-304 |
| Fe-59 | 5E-06 | 6.5E-03 | 0.122 | -5.69E+00 | 1.9E+04 | 1.94E+04 | 1E-05 | 4.33E-03 | 0.15% | 0.0E+00 |
| Co-60 | 5E-06 | 6.5E-03 | 5.27 | -1.38E-01 | 1.9E+04 | 1.33E+05 | 3E-06 | 9.92E-02 | 3.38% | 8.2E-13 |
| Zn-65 | 5E-06 | 3.1E-01 | 0.688 | -1.32E+00 | 1.9E+04 | 2.64E+04 | 5E-06 | 5.62E-01 | 19.15% | 7.3E-86 |
| Sr-89 | 5E-07 | 2.1E-01 | 0.138 | -5.23E+00 | 1.9E+03 | 1.94E+03 | 8E-06 | 1.75E-02 | 0.60% | 0.0E+00 |
| Sr-90 | 5E-07 | 2.1E-01 | 29.12 | -2.34E-01 | 1.9E+03 | 9.05E+03 | 5E-07 | 1.30E+00 | 44.49% | 1.3E-02 |
| Cs-134 | 5E-06 | 8.2E-03 | 2.06 | -3.45E-01 | 1.9E+04 | 6.60E+04 | 9E-07 | 2.06E-01 | 7.04% | 9.2E-30 |
| Cs-137 | 5E-06 | 8.2E-03 | 30 | -3.13E-02 | 1.9E+04 | 2.47E+05 | 1E-06 | 6.95E-01 | 23.71% | 7.9E-03 |
| Ce-141 | 5E-06 | 6.2E-03 | 0.089 | -7.79E+00 | 1.9E+04 | 1.93E+04 | 3E-05 | 1.37E-03 | 0.05% | 0.0E+00 |
| Ce-144 | 5E-06 | 6.2E-03 | 0.778 | -8.97E-01 | 1.9E+04 | 3.26E+04 | 3E-06 | 2.31E-02 | 0.79% | 2.0E-77 |
| | | | | | | | TOTAL MPC | 2.93 | | 0.021 |

\# Worst case sand leach rate from Table 2A.

SUMMARY OF RESULTS Even with no credit for decay in transit to the site boundary, the activity level leaving the accumulated solids will only be 2.93 MPC. Z-65, Sr-90, and Cs-137 dominated at this point in time.

Based on the calculated transit time to the Schuylkill River of 194 years, the activity at release would be 0.021 MPCs.

At this point in time the activity would be dominated by Sr-90. Cs-137, though shown above as making a noticable contribution at the River, will likely have a much longer transit time than Sr-90, and thus a lower impact.

FORM 5007 REV. 4/91

**Raytheon**
**Engineers & Constructors**

GENERAL COMPUTATION SHEET

| CALCULATION SET NO. | | | REV. | COMP. BY | CHK'D. BY |
|---|---|---|---|---|---|
| LM-526 | | | 1 | PTR | [illegible] |
| PRELIM. | FINAL X | VOID | | DATE 1/21/95 | DATE 2/23/95 |
| SHEET 17 OF 22 | | | | DATE | DATE |
| J.O. 7198.600 | | | | | |

PROJECT LIMERICK GENERATING STATION - UNITS 1 & 2 COOLING TOWER, HOLDING POND AND SPRAY POND

SUBJECT DETERMINE WORST CASE RADIOLOGICAL IMPACTS OF USING SOLIDS, TAKEN FROM THE COOLING TOWER BASINS, HOLDING POND, AND SPRAY POND, AS FILL

TABLE 3 - ASSESSMENT OF DOSE RATE ABOVE SOIL TAKEN FROM THE LGS COOLING TOWER BASIN, SPRAY POND, & HOLDING POND, ASSUMING THAT ALL ISOTOPES ARE AT SOLIDS ACTIVITY LIMIT [OCCUPATIONAL DOSE ASSESSMENT]

| Nuclide | Solids Activity Limits uCi/g(dry) | * | External Dose Rate mrem/hr | # | Inhalation Dose Rate mrem/hr |
|---|---|---|---|---|---|
| Fe-55 | 1E-05 | 3.3E-08 | 3.3E-07 | 1.2E-06 | 6.0E-09 |
| Mn-54 | 5E-06 | 7.9E-04 | 4.0E-03 | 6.1E-06 | 1.5E-08 |
| Co-58 | 5E-06 | 9.6E-04 | 4.8E-03 | 1.0E-05 | 2.5E-08 |
| Fe-59 | 5E-06 | 1.1E-03 | 5.5E-03 | 1.2E-05 | 3.0E-08 |
| Co-60 | 5E-06 | 2.4E-03 | 1.2E-02 | 1.9E-04 | 4.8E-07 |
| Zn-65 | 5E-06 | 6.2E-04 | 3.1E-03 | 1.7E-05 | 4.3E-08 |
| Sr-89 | 5E-07 | 2.1E-06 | 1.1E-06 | 5.3E-06 | 1.3E-09 |
| Sr-90 | 5E-07 | 3.0E-06 | 1.5E-06 | 2.0E-04 | 5.0E-08 |
| Mo-99 | 5E-06 | 1.4E-04 | 7.0E-04 | 1.9E-06 | 4.8E-09 |
| Cs-134 | 5E-06 | 1.6E-03 | 8.0E-03 | 4.0E-05 | 1.0E-07 |
| Cs-137 | 5E-06 | 5.7E-04 | 2.9E-03 | 1.3E-05 | 3.3E-08 |
| Ce-141 | 5E-06 | 3.8E-05 | 1.9E-04 | 8.4E-06 | 2.1E-08 |
| Ce-144 | 5E-06 | 2.5E-05 | 1.3E-04 | 3.6E-04 | 9.0E-07 |
| | | Total = | 4.1E-02 | Total = | 1.7E-06 |

\# Inhalation Committed Effective Dose Conversion Factors from NUREG/CR-5512, Table 2.2. (mrem/hr per pCi/cu. meter) Assumes dust loading over pile of 5E-4 gm/cu. meter. This corresponds to conditions where soil is being worked.

* Soil Volume Source External Dose Rate Conversion Factors from NUREG/CR-5512, Table 2.1. (mrem/hr per pCi/gm)

1 (revision marks)

FORM 5007 REV 4/91

**Raytheon Engineers & Constructors**

GENERAL COMPUTATION SHEET

PROJECT: LIMERICK GENERATING STATION - UNITS 1 & 2 COOLING TOWER, HOLDING POND AND SPRAY POND

SUBJECT: DETERMINE WORST CASE RADIOLOGICAL IMPACTS OF USING SOLIDS, TAKEN FROM THE COOLING TOWER BASINS, HOLDING POND, AND SPRAY POND, AS FILL

| CALCULATION SET NO. | | | REV. | COMP. BY | CHK'D. BY |
|---|---|---|---|---|---|
| LM-526 | | | 1 | PDR | [signature] |
| PRELIM. | FINAL | VOID | | DATE 1/21/95 | DATE 2/23/95 |
| | X | | | DATE | DATE |
| SHEET 18 OF 22 | | | | | |
| J.O. 7198.600 | | | | | |

| TABLE 4 - RESIDENTIAL (SURFACE SOIL) SCENARIO WITH CREDIT FOR DECAY | | | | | | | |
|---|---|---|---|---|---|---|---|
| Nuclide | Solids Activity Limits uCi/g(dry) | T 1/2 (yrs) | Annual TEDE # Factor for Residential Use (mrem/yr/pCi/gm) | Residential Use Doses (mrem/yr) # Decay Time | | | |
| | | | | 0 (yrs) | 10 (yrs) | 20 (yrs) | 30 (yrs) |
| Fe-55 | 1E-05 | 2.7 | 1.4E-04 | 1.4E-03 | 1.1E-04 | 8.2E-06 | 6.3E-07 |
| Mn-54 | 5E-06 | 0.856 | 2.6E+00 | 1.3E+01 | 4.0E-03 | 1.2E-06 | 3.7E-10 |
| Co-58 | 5E-06 | 0.194 | 3.1E+00 | 1.6E+01 | 4.7E-15 | 1.4E-30 | 4.4E-46 |
| Fe-59 | 5E-06 | 0.122 | 3.6E+00 | 1.8E+01 | 3.8E-24 | 8.1E-49 | 1.7E-73 |
| Co-60 | 5E-06 | 5.27 | 7.7E+00 | 3.9E+01 | 1.0E+01 | 2.8E+00 | 7.4E-01 |
| Zn-65 | 5E-06 | 0.688 | 3.0E+00 | 1.5E+01 | 6.3E-04 | 2.7E-08 | 1.1E-12 |
| Sr-89 | 5E-07 | 0.138 | 1.4E-01 | 7.0E-02 | 1.1E-23 | 1.7E-45 | 2.5E-67 |
| Sr-90 | 5E-07 | 29.12 | 1.9E+00 | 9.5E-01 | 7.5E-01 | 5.9E-01 | 4.7E-01 |
| Mo/Tc-99 | 1.8E-13 | 2.13E+05 | 3.0E-01 | 1.9E-15 | 1.9E-15 | 1.9E-15 | 1.9E-15 |
| Cs-134 | 5E-06 | 2.06 | 5.4E+00 | 2.7E+01 | 9.3E-01 | 3.2E-02 | 1.1E-03 |
| Cs-137 | 5E-06 | 30 | 1.9E+00 | 9.5E+00 | 7.5E+00 | 6.0E+00 | 4.8E+00 |
| Ce-141 | 5E-06 | 0.089 | 1.2E-01 | 6.0E-01 | 9.0E-35 | 1.4E-68 | 2.0E-102 |
| Ce-144 | 5E-06 | 0.778 | 8.2E-02 | 4.1E-01 | 5.5E-05 | 7.5E-09 | 1.0E-12 |
| | | | Totals = | 139 | 20 | 9.4 | 6.0 |

# Based on Dose Equivalance Factors for Residential Use (Surface Soil) Scenario supplied in NUREG/CR-5512, Table 3.3. [See Reference 2 and Attachment 1.]

For this scenario, the Mo-99 (measured to LLD) is assumed to have been completely converted to Tc-99 for dose purposes.

TABLE 5 - DRINKING WATER USE SCENARIO WITH CREDIT FOR DECAY

70,000 - Cu. Ft. of material deposited every year
1.95 - gm/ml nominal dry bulk density
3.87E+09 - grams of material deposited with each fill operation
16 - number of solids deposits over remaining plant life

| Nuclide | Solids Activity Limits uCi/g(dry) | T 1/2 (yrs) | Annual TEDE # Factor for Drinking Water Use (mrem/yr/pCi) | Initial Deposit (pCi) | Cumm. Act. at Last Deposit with Decay (pCi) | Drinking Water Use Doses (mrem/yr) # Decay Time 0 (yrs) | 10 (yrs) | 20 (yrs) | 30 (yrs) |
|---|---|---|---|---|---|---|---|---|---|
| Fe-55 | 1E-05 | 2.7 | 2.3E-13 | 3.87E+10 | 1.58E+11 | 3.6E-02 | 2.8E-03 | 2.1E-04 | 1.6E-05 |
| Mn-54 | 5E-06 | 0.856 | 6.8E-14 | 1.93E+10 | 1.51E+11 | 1.0E-02 | 3.1E-06 | 9.5E-10 | 2.9E-13 |
| Co-58 | 5E-06 | 0.194 | 1.9E-13 | 1.93E+10 | 1.36E+11 | 2.6E-02 | 7.8E-18 | 2.4E-33 | 7.3E-49 |
| Fe-59 | 5E-06 | 0.122 | 1.9E-13 | 1.93E+10 | 1.35E+11 | 2.6E-02 | 5.4E-27 | 1.2E-51 | 2.4E-76 |
| Co-60 | 5E-06 | 5.27 | 4.4E-12 | 1.93E+10 | 2.31E+11 | 1.0E+00 | 2.7E-01 | 7.3E-02 | 2.0E-02 |
| Zn-65 | 5E-06 | 0.688 | 3.2E-12 | 1.93E+10 | 1.46E+11 | 4.7E-01 | 2.0E-05 | 8.3E-10 | 3.5E-14 |
| Sr-89 | 5E-07 | 0.138 | 2.1E-13 | 1.93E+09 | 1.35E+10 | 2.8E-03 | 4.4E-25 | 6.7E-47 | 1.0E-68 |
| Sr-90 | 5E-07 | 29.12 | 3.8E-11 | 1.93E+09 | 2.90E+10 | 1.1E+00 | 8.7E-01 | 6.8E-01 | 5.4E-01 |
| Mo/Tc-99 | 1.8E-13 | 2.13E+05 | 1.2E-11 | 6.96E+02 | 1.11E+04 | 1.3E-07 | 1.3E-07 | 1.3E-07 | 1.3E-07 |
| Cs-134 | 5E-06 | 2.06 | 2.8E-13 | 1.93E+10 | 1.81E+11 | 5.1E-02 | 1.8E-03 | 6.1E-05 | 2.1E-06 |
| Cs-137 | 5E-06 | 30 | 1.2E-13 | 1.93E+10 | 2.91E+11 | 3.5E-02 | 2.8E-02 | 2.2E-02 | 1.7E-02 |
| Ce-141 | 5E-06 | 0.089 | 1.4E-15 | 1.93E+10 | 1.35E+11 | 1.9E-04 | 2.8E-38 | 4.3E-72 | 6.4E-106 |
| Ce-144 | 5E-06 | 0.778 | 1.8E-13 | 1.93E+10 | 1.49E+11 | 2.7E-02 | 3.6E-06 | 4.9E-10 | 6.6E-14 |
| | | | | | Totals ~ | 2.8E+00 | 1.2E+00 | 7.8E-01 | 5.8E-01 |

# Based on Dose Equivalance Factors for Residential Use (Drinking Water) Scenario supplied in NUREG/CR-5512, Table 3.4. [See Reference 2 and Attachment 1.]

For this scenario, the Mo-99 (measured to LLD) is assumed to have been completely converted to Tc-99 for dose purposes.

TABLE 6 - RUNOFF BORNE RADIOACTIVITY CONCENTRATIONS

1.46E+07 = SOLIDS IN RUNOFF (gm/yr)

1.46E+09 = RUNOFF (ml/yr)

| Nuclide | Solids Activity Limits uCi/g(dry) | 10CFR20 APP. B Water uCi/ml | Runoff Activity Conc. uCi/ml | Fraction of Limit |
|---|---|---|---|---|
| Fe-55 | 1E-05 | 1E-04 | 1.0E-07 | 1.0E-03 |
| Mn-54 | 5E-06 | 3E-05 | 5.0E-08 | 1.7E-03 |
| Co-58 | 5E-06 | 2E-05 | 5.0E-08 | 2.5E-03 |
| Fe-59 | 5E-06 | 1E-05 | 5.0E-08 | 5.0E-03 |
| Co-60 | 5E-06 | 3E-06 | 5.0E-08 | 1.7E-02 |
| Zn-65 | 5E-06 | 5E-06 | 5.0E-08 | 1.0E-02 |
| Sr-89 | 5E-07 | 8E-06 | 5.0E-09 | 6.3E-04 |
| Sr-90 | 5E-07 | 5E-07 | 5.0E-09 | 1.0E-02 |
| Mo-99 | 5E-06 | 2E-05 | 5.0E-08 | 2.5E-03 |
| Cs-134 | 5E-06 | 9E-07 | 5.0E-08 | 5.6E-02 |
| Cs-137 | 5E-06 | 1E-06 | 5.0E-08 | 5.0E-02 |
| Ce-141 | 5E-06 | 3E-05 | 5.0E-08 | 1.7E-03 |
| Ce-144 | 5E-06 | 3E-06 | 5.0E-08 | 1.7E-02 |
| | | | Total = | 1.7E-01 |

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## EQUATIONS FOR TABLES (SPREADSHEETS) 1A-6

**Table 1A**

Column 5: $$\frac{\text{Solids Act. Lmt}\left[\frac{\mu Ci}{gm}\right] * \text{Airborne } 1\times10^{-4}\ \frac{gm}{m^3} * 10^{-6}\left[\frac{m^3}{ml}\right]}{\text{Air Limit (Col. 3)}\left[\frac{\mu Ci}{ml}\right]}$$

**Table 1B**

Column 3: $\text{Solids Act Lmt}\left[\frac{\mu Ci}{gm}\right] * 2.41\times10^{6}\left[\frac{gm}{yr}\right] * 10^{-6}\left[\frac{Ci}{\mu Ci}\right]$

**TABLE 2A** All data and equations used are as referenced to Attachment 3

**TABLE 2B**

Column 5: $-\text{Leach Rate}\left[\frac{1}{yr}\right] - \frac{\ln 2}{\text{half life}}\left[\frac{1}{yr}\right]$

Column 6: $\text{Solids Act. Limit}\left[\frac{\mu Ci}{gm}\right] * 1.95\left[\frac{gm}{cc}\right] * 1.98*10^{9}\left[\frac{cc}{yr}\right]$

Column 7: $\text{Column 6 Value}[\mu Ci] * \sum_{t=0}^{15} e^{t*\text{Col.5}}$

Column 9: $\text{Column 7}[\mu Ci] * \text{Leach Rate (Col 3)}\left[\frac{1}{yr}\right]$

Column 10 - obvious.

Column 11: $\text{Column 9 [unitless]} * e^{-15.5 * \frac{\ln 2}{t_{1/2}}}$

**TABLE 3**

Column 4: $\text{Solids Act Lmt}\left[\frac{\mu Ci}{gm}\right] * \text{Column 3}\left[\frac{mrem\ gm}{pCi\ hr}\right] * 10^{6}\left[\frac{pCi}{\mu Ci}\right]$

Column 6: $\text{Solids Act. Lmt.}\left[\frac{\mu Ci}{gm}\right] * \text{Column 5}\left[\frac{mrem\ m^3}{hr\ pCi}\right] * 5\times10^{-4}\left[\frac{gm}{m^3}\right] * 10^{6}\left[\frac{pCi}{\mu Ci}\right]$

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EQUATIONS FOR TABLES (SPREADSHEETS) 1A-6, cont'd

**TABLE 4** $\lambda$ (not shown) = decay constant = $\frac{\ln 2}{T_{1/2}}$

Column 5: Solids Act. Limit $\left[\frac{\mu Ci}{gm}\right]$ * Col. 4 Dose Factor $\left[\frac{mrem\ gm}{yr\ pCi}\right]$ * $10^6 \left[\frac{pCi}{\mu Ci}\right]$

Columns 6, 7, 8: Column 5 $\left[\frac{mrem}{yr}\right] * e^{-\lambda * \text{Decay Time}}$

**TABLE 5** $3.87 * 10^9$ grams deposited = 70,000 $[ft^3]$ * 1.95 $\left[\frac{gm}{ml}\right]$ * 28,317 $\left[\frac{ml}{ft^3}\right]$

Column 5: (Initial Deposit Activity) =
Solids Act. Lmt. $\left[\frac{\mu Ci}{gm}\right]$ * $3.87 \times 10^9$ [gm] * $10^6 \left[\frac{pCi}{\mu Ci}\right]$

Column 6: (Activity at last deposit) =
Initial Deposited Activity [pCi] * $\sum_{t=0}^{15} e^{-\lambda t}$

Column 7: Col. 6 Activity [pCi] * Annual TEDE factor $\left[\frac{mrem}{yr\ pCi}\right]$

Columns 8, 9, 10: Col. 7 dose rates $\left[\frac{mrem}{yr}\right] * e^{-\lambda * \text{decay time}}$

**TABLE 6**

Column 4: At 1% by weight in solids, the runoff activity would be 1% of the Solids Activity Limit.

Column 5: Simply the runoff Activity divided by the 10 CFR20 LIMIT.

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# Comparison of Environmental and Effluent LLD Levels and Dose Calculation Activity Levels for Flowable Solids

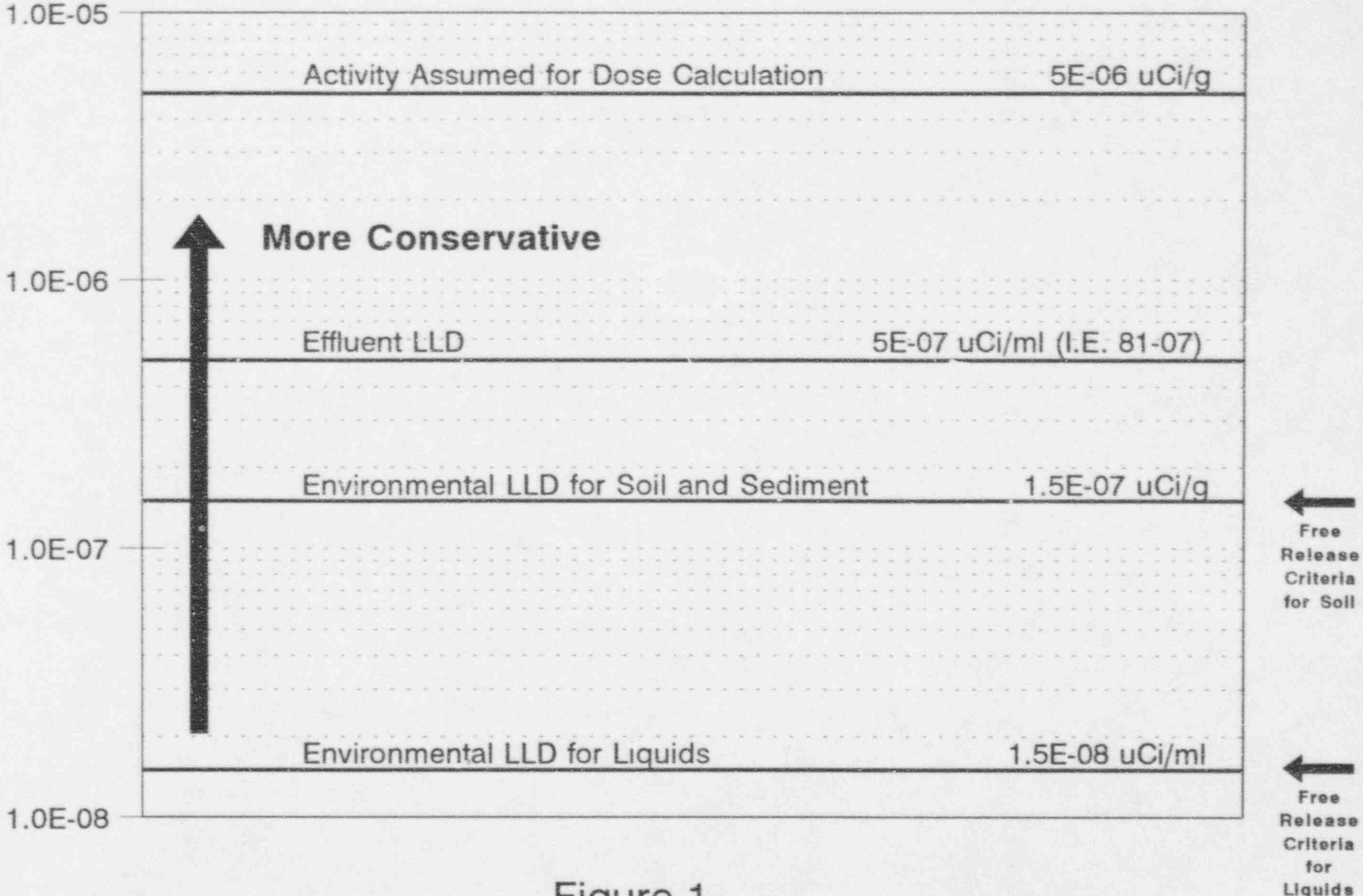


Figure 1