OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

1. QA: QA

ANALYSIS/MODEL COVER SHEET

Page: 1 of 33

Complete Only Applicable Items

<p>2. ☒ Analysis Check all that apply</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%;">Type of Analysis</td> <td> ☐ Engineering ☒ Performance Assessment ☐ Scientific </td> </tr> <tr> <td>Intended Use of Analysis</td> <td> ☐ Input to Calculation ☒ Input to another Analysis or Model ☐ Input to Technical Document ☐ Input to other Technical Products </td> </tr> <tr> <td colspan="2">Describe use:</td> </tr> <tr> <td colspan="2">To be used in TSPA-SR to calculate dose.</td> </tr> <tr><td colspan="2"> </td></tr> <tr><td colspan="2"> </td></tr> </table>	Type of Analysis	☐ Engineering ☒ Performance Assessment ☐ Scientific	Intended Use of Analysis	☐ Input to Calculation ☒ Input to another Analysis or Model ☐ Input to Technical Document ☐ Input to other Technical Products	Describe use:		To be used in TSPA-SR to calculate dose.						<p>3. ☐ Model Check all that apply</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%;">Type of Model</td> <td> ☐ Conceptual Model ☐ Abstraction Model ☐ Mathematical Model ☐ System Model ☐ Process Model </td> </tr> <tr> <td>Intended Use of Model</td> <td> ☐ Input to Calculation ☐ Input to another Model or Analysis ☐ Input to Technical Document ☐ Input to other Technical Products </td> </tr> <tr> <td colspan="2">Describe use:</td> </tr> <tr><td colspan="2"> </td></tr> <tr><td colspan="2"> </td></tr> <tr><td colspan="2"> </td></tr> </table>	Type of Model	☐ Conceptual Model ☐ Abstraction Model ☐ Mathematical Model ☐ System Model ☐ Process Model	Intended Use of Model	☐ Input to Calculation ☐ Input to another Model or Analysis ☐ Input to Technical Document ☐ Input to other Technical Products	Describe use:							
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4. Title:

Abstraction of BDCF Distributions for Irrigation Periods

5. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-NBS-MD-000007, Rev. 00/ICN 01

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A CD is included with this document as Attachment III. The CD contains the Excel files (Microsoft Excel SR-2) discussed in this document.

OFFICE OF CIVILIAN RADIOACTIVE WASTE
MANAGEMENT ANALYSIS/MODEL REVISION RECORD

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1. Page: 2 of 33

2. Analysis or Model Title:

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ANL-NBS-MD-000007, Rev. 00/ICN 01

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ICN issued to show the calculational details and results of distribution fitting to new BDCF distributions.

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1. PURPOSE

The purpose of this analysis is to derive the abstractions for the time evolution of the Biosphere Dose Conversion Factors (BDCFs) due to radionuclide build-up effects in soil to be used in Total System Performance Assessment for Site Recommendation (TSPA-SR). One predecessor Analysis and Modeling Report (AMR) titled "*Distribution Fitting to the Stochastic BDCF Data*" (CRWMS M&O 2000a) identified a justifiable approximating distribution for the BDCFs over an appropriate period of irrigation. The data analyzed in this predecessor AMR were generated under the QA program as reported in CRWMS M&O (2000b) by use of the GENII-S code (Leigh et al. 1993). Another predecessor AMR "*Evaluate Soil/Radionuclide Removal by Erosion and Leaching*" (CRWMS M&O 2000c) assessed the radionuclide removal from contaminated soil by erosion. The soil erosion mechanism is not considered in the GENII-S code. This analysis will incorporate soil loss into the time evolution of BDCFs after prolonged periods of irrigation and remove unnecessary conservatism in dose predictions.

The biosphere model used in the stochastic GENII-S code is the same as that used in the deterministic GENII code reported by Napier (Napier, et al 1988). The calculations incorporate the build-up and removal of radionuclides in agricultural surface soil for several processes. The processes considered within GENII-S are the duration (years) of previous irrigation with contaminated water, harvest removal, radioactive decay, and leaching to deeper soil layer (Napier, et al; 1988. Volume 1 Section 4.6 *Soil Contamination Model*, p. 4.56).

It should be noted that the data processed in the predecessor AMR (CRWMS M&O 2000a) considers and incorporates the uncertainties in the form of statistical distributions from model parameters used to define the biosphere and receptor into the generation of the BDCFs (CRWMS M&O 2000b). This AMR simply uses the information provided to generate BDCF distributions for use in TSPA that account for soil erosion. This AMR cannot justify or further qualify the input data provided.

This Interim Change Notice (ICN) was necessitated by the generation of updated BDCFs data in the effort reported in CRWMS M&O (2000a).

The activities described in this report were conducted in accordance with the Technical Work Plan (TWP) titled *Technical Work Plan Biosphere Modeling and Expert Support* (CRWMS M&O 2000d).

2. QUALITY ASSURANCE

The quality assurance (QA) program applies to the development of this analysis and its documentation. The information provided in this analysis will be used for evaluating the post-closure performance of the Monitored Geologic Repository (MGR) waste package and engineered barrier segment. Addendum A to the TWP titled, *Biosphere Modeling And Expert Support* (CRWMS M&O 2000d) has determined that the preparation and review of this technical document is subject to *Quality Assurance Requirements and Description* (DOE 2000) requirements.

The effort reported in this AMR was conducted and documented in accordance with AP-3.10Q, *Analyses and Models* and procedures invoked therein. A technical work plan was developed, issued, and utilized in the preparation of this document (CRWMS M&O 2000d). Since the analysis does not involve any field activity, there is no determination of importance evaluation developed in accordance with NLP-2-0, *Determination of Importance Evaluations*. There are no permanent items addressed in this AMR, so it is not subject to QAP-2-3, *Classification of Permanent Items*.

The control of the electronic management of electronic data was accomplished in accordance with the methods specified in the TWP (CRWMS M&O 2000d).

3. COMPUTER SOFTWARE AND MODEL USAGE

No models were developed in this analysis. The analysis presented in Section 6 invoked the soil model used in the GENII-S code to generate the stochastic BDCF data. The only software used was a commercially available spreadsheet (Microsoft® Excel 97 SR-2) with the data being stored in electronic files with extension *.xls. This spreadsheet was constructed as template. (In this context, a template is a single spreadsheet that uses the standard Excel functions. Various data sets can be inserted into the template by the simple action of "cut and paste" to generate the required numerical outputs specific to the data inserted). The template was appropriately used within its range of validation as an aid in performing a set of identical calculations. The spreadsheet used is documented in Attachment II, where the details of each cell entry is given and discussed. The spreadsheet is provided as an Excel file in Attachment III. No macros, or other applications were developed and used. Use of this software is documented in this report in accordance with AP-SI.1Q, *Software Management*.

The software was developed as Single Use Software (Section 5.1.1 of AP-SI.1Q) and as such is documented in Attachment II and was therefore not under CM control. Attachment III provides electronic copies in standard Excel format of both the Template used (filename *Exponential Fitting Routine V1_1.xls*) and the complete set of calculations with results and input data on the individual worksheets in the Spreadsheet file (*Calc.xls*).

This template routine was developed using Microsoft Excel 97 SR-2 running on a DELL POWEREDGE 2200 (Control Number 112375) with the Microsoft Windows NT operating system located in the CRWMS M&O facilities in Las Vegas (location 1526E).

4. INPUTS

4.1 DATA AND PARAMETERS

The data used in this analysis were developed by Performance Assessment in support of the Biosphere effort for TSPA-SR. All data and information used were provided by two AMRs identified in the following sections.

4.1.1 BDCF Abstraction Parameters

The BDCF abstraction parameters were developed in *Distribution Fitting to the Stochastic BDCF Data* (CRWMS M&O 2000a) and were obtained from the Technical Data Management System (TDMS) by its associated Data Tracking Number DTN:MO0010SPAABS08.008. These numerical data are reproduced in Tables 1, 2, and 3. These Tables also show the periods of previous irrigation (DTN:MO0010MWDPBD09.006) used when generating the BDCF data. In the source AMR (CRWMS M&O 2000a), these defined statistical distributions were demonstrated to provide a statistically acceptable fit to the individual stochastic BDCF data sets that reflected the uncertainty in the parameters defining the critical group and reference biosphere (CRWMS M&O 2000b). Thus the data and parameters used herein, are therefore appropriate for the analysis to be undertaken and subsequently reported in this AMR. Before processing the input data, CRWMS M&O (2000a) employed a multiplying factor (an integer exponent, n , of ten, i.e., $10^{\pm n}$) that multiplied each member of the set of stochastic BDCF's values for a given radionuclide to provided scaled BDCF values greater than unity. This was done for numerical convenience. The scale factor presented in the data that follows is the inverse of this multiplying factor and is the factor required to scale the distribution data to obtain BDCF values with the original units of rem/year per picocurie/liter

Table 1. Input Data for those Radionuclides where the Normal Distribution was Appropriate

Radionuclide	Irrig Time (yrs)	Scale Factor	Fitted Parameters	
			Mean	SD
²⁴¹ Am	0	1.E-04	38.072	21.2456
	93		40.741	21.3934
	207		43.818	21.6334
	354		46.568	21.8541
	561		49.452	22.2921
	915		52.215	22.5615
²³⁹ Pu	0	1.E-04	37.38	20.8584
	145		41.24	21.254
	322		45.327	21.3476
	551		49.116	21.4793
	873		52.969	21.6161
	1423		56.955	21.6496
²⁴⁰ Pu	0	1.E-04	37.315	20.8225
	136		40.904	21.2153
	304		44.809	21.3014
	519		48.334	21.4287
	822		51.977	21.5476
	1341		55.756	21.5222

Table 1. Input Data for those Radionuclides where the Normal Distribution was Appropriate (continued)

Radionuclide	Irrig Time (yrs)	Scale Factor	Fitted Parameters	
			Mean	SD
²⁴² Pu	0	1.E-04	34.746	19.3891
	148		38.443	19.7436
	329		42.309	19.799
	563		45.953	19.9955
	892		49.533	20.1065
	1455		53.308	20.0931
²³⁰ Th	0	1.E-03	0.585	0.3312
	825		5.038	1.1439
	1835		12.537	2.9153
	3136		20.89	5.0745
	4971		29.398	7.2129
	8108		38.005	9.2966
²³² U	0	1.E-04	13.945	7.6033
	6		15.285	7.7623
	14		17.248	7.9053
	24		19.269	7.9576
	38		21.076	7.9456
	62		23.075	8.0619
²³⁸ U	0	1.E-05	27.53	15.0679
	9		28.671	15.1032
	21		29.728	15.2395
	36		30.674	15.5076
	57		31.803	15.5534
	93		32.841	15.6009

DTN:MO00010SPAABS08.008

NOTES: SD = Standard Deviation

The units of the truncated normal distribution parameters are such that when the truncated normal distribution is sampled and the resultant number is multiplied by the scaling factor, the resultant BDCF is in units of rem/year per picocurie/liter.

Table 2. Input Data for those Radionuclides where the Lognormal Distribution was Appropriate

Radionuclide	Irrig Time (yrs)	Scale Factor	Fitted Parameters	
			Log Mean	Log SD
²⁴³ Am	0	1.E-04	3.5563	0.6059
	405		4.0359	0.3908
	901		4.3573	0.3019
	1541		4.5955	0.2611
	2442		4.7897	0.2309
	3983		4.951	0.2132
²²⁶ Ra	0	1.E-04	2.2766	0.5919
	102		3.7313	0.2462
	227		4.3042	0.2397
	389		4.6623	0.2423
	616		4.9172	0.2526
	1005		5.1234	0.2485
⁹⁰ Sr	0	1.E-05	2.623	0.6039
	3		2.7212	0.6297
	6		2.8017	0.6339
	10		2.866	0.6435
	16		2.9358	0.6606
	26		2.9947	0.6562
²²⁹ Th	0	1.E-03	1.2548	0.5985
	595		2.5412	0.2322
	1323		3.0639	0.2239
	2262		3.4051	0.2156
	3586		3.6658	0.2216
	5848		3.8722	0.2263

DTN:MO00010SPAABS08.008

NOTES: SD = Standard Deviation

The units of the lognormal distribution parameters are such that when the lognormal distribution is sampled and the resultant number multiplied by the scaling factor, the resultant BDCF is in units of rem/year per picocurie/liter.

Table 3. Input Data for those Radionuclides where the Shifted lognormal Distribution was Appropriate

Radionuclide	Irrig Time (yrs)	Scale Factor	Fitted Parameters		
			Shift	Log Mean	Log SD
¹³⁷ Cs	0	1.E-05	1.6157	1.8523	0.8361
	7		7.0115	1.9852	0.7663
	16		13.0293	2.0582	0.7648
	27		17.7697	2.2577	0.7698
	43		21.1479	2.5453	0.7012
	71		23.805	2.8185	0.6521
⁶³ Ni	0	1.E-07	-3.3826	2.2943	0.399
	21		-6.4557	2.6293	0.3164
	47		-5.9144	2.6295	0.3499
	80		-4.6092	2.5674	0.4099
	128		-3.0404	2.4688	0.4793
	208		-3.8007	2.5764	0.4593
²³¹ Pa	0	1.E-03	-9.5679	3.0049	0.2979
	146		-24.5145	3.7211	0.1555
	324		-31.0008	4.0055	0.129
	554		-18.5455	3.8955	0.1619
	878		-22.7912	4.1025	0.1501
	1432		-14.6811	4.0804	0.1818

DTN:MO00010SPAABS08.008

NOTES: s = shift (translation of axis)

SD = Standard Deviation

The units of the shifted lognormal distribution parameters are such that when the lognormal distribution is sampled, the shift value added, and the resultant number multiplied by the scaling factor, the resultant BDCF is in units of rem/year per picocurie/liter.

Identified in CRWMS M&O 2000a, is that build-up is only significant (that is greater than 15%) for ²⁴¹Am, ²⁴³Am, ¹³⁷Cs, ⁶³Ni, ²³¹Pa, ²³⁹Pu, ²⁴⁰Pu, ²⁴²Pu, ²²⁶Ra, ⁹⁰Sr, ²²⁹Th, ²³⁰Th, ²³³U and ²³⁸U. It was also shown that the distributions providing an acceptable fit were as follows:-

- (a) Truncated normal distribution for ²⁴¹Am, ²³⁹Pu, ²⁴⁰Pu, ²⁴²Pu, ²³⁰Th, ²³²U and ²³⁸U,
- (b) Lognormal distribution for ²⁴³Am, ²²⁶Ra, ⁹⁰Sr, and ²²⁹Th,
- (c) Shifted lognormal distribution for ¹³⁷Cs, ⁶³Ni, and ²³¹Pa.

It should be noted that in the shifted lognormal cases of ⁶³Ni and ²³¹Pa, the fact that the shifts are negative leads to a small but finite probability of a negative BDCF. For the purpose of the analyses conducted here, this possibility is of no consequence. However, the data provided to TSPA in Section 7.3.3 for the lognormal distributions is conservatively modified to preclude stochastic sampling in TSPA deriving a negative BDCF.

4.1.2 Soil Erosion Data

In the AMR titled "*Evaluate Soil/Radionuclide Removal by Erosion and Leaching*" (CRWMS M&O 2000c), Section 7, Summary and Conclusions contains the following statement on erosion. "The annual soil depth reduction estimates (Table 6) for the soils occurring in the vicinity of Lathrop Wells ranged from a low of 0.026 cm/yr for the Shamock series with a bulk density of 1.70 g/cm³ to a high of 0.080 cm/yr for the Arizo, Commski, Sanwell, and Yermo soils with bulk densities of 1.40 g/cm³. However, with the exception of the Shamock series, which is a moderately deep, gravelly fine sandy loam soil and therefore less resilient to soil erosion before experiencing a reduction in productivity, the calculated annual soil depth reduction rates are generally between 0.06 and 0.08 cm/yr. It should be noted that this is the net rate of soil loss from surficial processes. For sustained productive land use, this surface loss has to be compensated by soil formation from the transformation of underlying material. For the conservative bounding estimate, soil erosion was assumed to be minimized to negligible levels (i.e., no surface soil erosion loss)."

CRWMS M&O (2000c) continues, "Projected changes in climate (e.g., average annual precipitation and temperatures) during the repository's 10,000-yr regulatory compliance period are not sufficient in themselves to impart significant change to the sandy-textured Amargosa Valley soils and their plant growth limiting horizons." For the purposes of this analysis, the lower bound (i.e., conservative in terms of loss) of the calculated annual soil depth reduction (viz. 0.06 cm/year) will be used to include the effect of contaminated soil loss into the build-up due to prolonged irrigation periods. This datum was retrieved using DTN SN9912T0512299.002.

4.1.3 Surface Soil Thickness

To be consistent with the GENII-S parameters used to generate the BDCFs (CRWMS M&O 2000b) a surface soil thickness of 15 cm was used in this analysis. This parameter is in the package with DTN MO0010SPAPET07.004 (Environmental Transport Parameter Values for Dose Assessment. Submittal date: 11/12/1999).

4.1.4 Soil Leaching Rate

The leaching rates for radionuclides in the soil appropriate to this AMR were taken from CRWMS M&O (2000c). These data from DTN: SN9912T0512299.003 are reproduced in Table 4.

Table 4. Best Estimates of Leaching Rates

Element	Best Estimate Leaching Coefficient (yr ⁻¹)	Element	Best Estimate Leaching Coefficient (yr ⁻¹)	Element	Best Estimate Leaching Coefficient (yr ⁻¹)
Ac	1.50E-03	Ni	1.69E-03	Se	1.23E-02
Am	3.56E-04	Np	1.32E-01	Sm	2.76E-03
Bi	6.76E-03	Pa	1.23E-03	Sn	5.20E-03
C	1.32E-01	Pb	2.51E-03	Sr	4.47E-02
Cm	1.69E-04	Pd	1.23E-02	Tc	2.77E+00
Cs	2.42E-03	Po	4.51E-03	Th	2.12E-04
I	5.92E-01	Pu	1.23E-03	U	1.93E-02
Mo	6.68E-02	Ra	1.35E-03	Y	3.98E-03
Nb	4.23E-03	Sb	1.50E-02	Zr	1.13E-03

DTN: SN9912T0512299.003

4.2 CRITERIA

The U.S. Nuclear Regulatory Commission's (NRC's) Total System Performance Assessment and Integration (TSPA&I) Issue Resolution Status Report (IRSR) (NRC 1998) establishes generic technical acceptance criteria for analyses supporting TSPA. These criteria are considered by the NRC staff to be essential to a defensible, transparent, and comprehensive assessment methodology for the repository system. These regulatory acceptance criteria address five fundamental elements of the Department of Energy (DOE) TSPA model for the Yucca Mountain site, namely:

1. Data and model justification (focusing on sufficiency of data to support the conceptual basis of the process model and abstractions)
2. Data uncertainty and verification (focusing on technical basis for bounding assumptions and statistical representations of uncertainties and parameter variabilities)
3. Model uncertainty (focusing on alternative conceptual models consistent with available site data)
4. Model verification (focusing on testing of model abstractions using detailed process-level models and empirical observations)
5. Integration (focusing on appropriate and consistent coupling of model abstractions).

Relevant to the topic of this AMR, elements (1) through (4) of the acceptance criteria were used to generate the abstraction for, first, soil build-up effects and, second, incorporate soil erosion

into build-up effects. For each radionuclide, for which build-up effects are significant, this AMR reduces the set of six discrete BDCF distributions to a condensed empirical form. The process must preserve the integrity of the data (elements 1 & 4) while retaining the uncertainty inherent in the biosphere model/data (elements 2 & 3). The process conducted by this AMR (and its predecessor) is part of element (5) of the NRC acceptance criteria. This element applies to the synthesis of process-level models as discussed in the Biosphere PMRs and the abstraction conducted here that will be integrated into the TSPA-SR predictive code. The details of how this integration is implemented in the TSPA code will be addressed in the TSPA-SR.

4.3 CODES AND STANDARDS

4.3.1 Codes

This AMR was prepared to conform with DOE interim guidance (Dyer 1999) which is based on the proposed NRC high-level waste rule, 10 CFR Part 63 (64 FR 8640). Specified Subparts of this proposed rule that are particularly applicable to data include Subpart B, Section 15 (Site Characterization) and Subpart E, Section 114 (Requirements for Performance Assessment).

4.3.2 Standards

There are no applicable standards.

5. ASSUMPTIONS

It is assumed that the data feed as defined in section 4.1, accurately and acceptably reflects the reference biosphere and the receptor as defined (Dyer 1999). The data discussed in section 4.1 and used in this analysis were developed under AP-3.10Q, *Analyses and Models*, and are therefore considered reasonable for use and therefore no additional confirmation is required.

In Section 6.1, the assumption is made that there is only one reservoir (a compartment where radionuclides can accumulate over a period of many years) of importance in the GENII model. This reservoir is soil where adsorption can cause radionuclides to build-up in concentration over time from continuing irrigation with contaminated groundwater. The GENII manual (Napier et al 1988) does not provide any statements that contradict this assumption. A finding, reported in Section 6.4, shows that the maximum fractional difference between the mean BDCF generated using analysis developed here and the mean BDCF results from the GENII-S calculations at each of the six periods of previous irrigation are generally within a few percent. This agreement indicates that this soil model assumption is valid. A direct consequence of this agreement is that no further confirmation is required.

6. ANALYSIS/MODEL

To achieve the stated purpose of this AMR, two analysis steps are needed. The first is to derive an acceptable abstraction of the variation in BDCFs distributions over time consistent with the statistical BDCF distributions given in 4.1.1 that were derived from the GENII-S calculations. The resulting abstraction would only incorporate the radionuclide loss mechanisms of harvest,

leaching, and decay as incorporated in GENII (Napier et al. 1988. p. 4.56). The second step is to incorporate the additional loss mechanism of soil erosion into the abstraction predicting the radionuclide build-up in soils.

The analysis approach is appropriate because it is based on the model used in the GENII-S code (Napier et al. 1988. p. 4.45) that generated the BDCF data being analyzed (CRWMS M&O 2000a). Radionuclide concentration build-up in soil for continual irrigation has been shown to result in significant (i.e., many fold) increases in BDCF values (CRWMS M&O 2000b). The use of this analysis is important as it allows the mitigating effect of soil erosion, a radionuclide removal mechanism not available in the GENII-S code, to be justifiably taken into account.

6.1 A SIMPLE ABSTRACTION FOR GENII-S BDCF EVOLUTION OVER TIME

To assess the effect of radionuclide build-up in soil from continuing irrigation, BDCFs were calculated for six periods of previous irrigation in the effort reported in CRWMS M&O (2000b). The defining parameters of the distribution for each of these sets of data were inputs to this AMR and the distributions and their parameters are defined in 4.1.1 where they were given in Table 1.

A BDCF for prescribed conditions is the annual committed dose that the receptor would receive if there were unit concentration of the specific radionuclide in the groundwater used by the community as modeled in CRWMS M&O (2000b). Although the assessment of the all pathway dose is not a trivial problem, some basic concepts can be introduced for the sake of this analysis. First for a given radionuclide and set of conditions the BDCF can be considered to have two components. The first z_0 is a component that is independent of time (i.e., of previous irrigation periods). The second $z(t)$ is the time varying component that is dependent upon the dynamics (input/output or gain/loss) in the "radionuclide reservoirs" present in the system under consideration.

$$BDCF(t) = z_0 + z(t) \quad (\text{Eq. 1})$$

Examples of z_0 are components of the BDCF due to ingestion of drinking water and the intake of the radionuclide that enters the food chain by contact of the irrigation water with the leaf system of the edible crop. For $z(t)$, examples are external exposure to radiation from contaminated soil, inhalation of re-suspended soil particles, and the radionuclides taken up by edible crop through their root system. The three examples given above all have soil as the radionuclide reservoir. It should be remembered that other reservoirs could exist and that each could have its own characteristic dynamics.

Consider now a single reservoir; for the purposes of this analysis, this reservoir can be taken to be soil. If the GENII-S generated BDCFs showed it necessary, multiple reservoirs could be incorporated.

If the concentration of a radionuclide in the reservoir (soil) at time t is $q(t)$ then by the conservation rule (the "increase" over a time period must equal "in" minus "out" over that same time period),

$$\frac{dq(t)}{dt} = I - \lambda q(t) \quad (\text{Eq. 2})$$

where, I is the rate at which radionuclides are added (in this case the irrigation rate with contaminated water) and λ ($= \lambda_1 + \lambda_2 + \lambda_3$) is the total removal coefficient (for GENII-S this includes the leaching rate λ_1 , radioactive decay λ_2 , and crop removal λ_3).

This equation can be rearranged into a form that can readily be integrated.

$$\frac{-\lambda dq(t)}{I - \lambda q(t)} = -\lambda dt \quad (\text{Eq. 3})$$

On the left-hand side, we have the derivative of the denominator appearing in the numerator, so this can be easily integrated to give,

$$\ln(I - \lambda q(t)) = -\lambda t + c \quad (\text{Eq. 4})$$

where c is a constant of integration.

Rearranging this equation gives,

$$q(t) = \frac{I - de^{-\lambda t}}{\lambda} \quad (\text{Eq. 5})$$

where d is the transformed constant of integration given by $d = e^c$

At time $t = 0$, $q(t) = 0$, so $d = I$, and

$$q(t) = \frac{I(1 - e^{-\lambda t})}{\lambda} \quad (\text{Eq. 6})$$

The time varying component of the BDCF, $z(t)$, is proportional to the level of contamination in the particular reservoir under consideration, $q(t)$.

Therefore, using k as the constant of proportionality, we can write

$$BDCF(t) = z_0 + \frac{kI(1 - e^{-\lambda t})}{\lambda} \quad (\text{Eq. 7})$$

In the accompanying Excel spreadsheet showing the actual calculations, the constants in the above equation have been defined as B, C, and D, such that,

$$BDCF(t) = C + DB(1 - e^{-\frac{t}{B}}) \quad (\text{Eq. 8})$$

As expected, Eq. 8 has the functional form (i.e., a constant plus a time dependent term) as defined in Eq. 1. The intent in this AMR is to use the available Excel functions to determine the parameter values (B, C, and D) that best fit this equation to the optimized distributions of the GENII-S data. Equation 8 uses a measure of the BDCF distribution in linear space, and not the logarithm of the BDCF as a measure (the mean of the logarithms of BDCFs). To use Equation 8, the logarithmic measures used in the distribution based on the lognormal distribution require a transformation into linear space. So the values used for BDCF(t) in fitting equation 8, are the *mean* values when the distributions was normal, *exp(mean)* values when lognormal, and *exp(mean) + shift* values when the distribution was shown to be shifted lognormal.

In using the above equation to fit the distribution parameters, it was assumed that there is only one reservoir of importance (i.e., the soil) in play within the GENII-S code. If this assumption is correct, it will be evident from the juxtaposition of the actual and predicted responses. If this assumption is not valid, a multiple reservoir model (two or more of the above functions) will have to be developed and used.

From the above equation, it can be seen (by setting *t* to be zero) that *C* in Equation 8 is the BDCF with no prior irrigation. This is the same parameter as *z₀* in Eq. 1 and is discussed in Section 6.1. In addition, it can be seen that *C+DB* is the asymptotic BDCF value (the exponential terms approaches zero) after an infinitely long period of irrigation. (As *t* becomes infinitely large, the negative exponential term in the equation becomes infinitesimally small.)

6.2 INCORPORATION OF SOIL EROSION LOSS MECHANISM INTO BDCF EVOLUTION

6.2.1 Overview For Incorporation Of Additional Loss Mechanism

If the Eq. 8 has been demonstrated (by using the GENII-S data) to provide a reasonable predictive tool for the time evolution of the BDCFs with the irrigation period, additional loss mechanisms can be incorporated and the appropriate BDCFs generated. The rate of radionuclide loss parameter (*λ*) for the mechanisms in the GENII-S code will have been determined by the fitting process. This parameter can be updated to incorporate addition loss mechanisms,

$$\lambda_{revised} = \lambda_{GENII-S} + \lambda_{new\ mechanism}$$

(Eq 9)

Once the new value of λ has been determined, the time evolution of the BDCFs with the additional loss mechanism can be generated.

6.2.2 Soil Erosion Parameter λ

The appropriate soil parameter values are defined in Sections 4.1.2, 4.1.3, and 4.1.4.. The first is the thickness of the soil layer considered appropriate for determination of the leaching factors, 15 cm (Section 4.1.3). The second is the lower limit (conservative) of annual soil loss estimate of 0.06 cm/year (Section 4.1.2).

This analysis discussed in 4.1.2 uses the same approximation for the distribution of radionuclides in soil as is used in GENII-S. This approximation is that the surface soil (i.e., topsoil) has a radionuclide distribution of radionuclides with depth that is constant over the (15 cm) rooting zone (Napier, et al 1988 section 4.6.2). For cultivated soil, this is justified by assuming plowing (roto-tilling for home gardens) to this depth provides this uniform mixing.

If the total concentration of a radionuclide in the 15 cm. top soil layer is x (Ci per m^2), then the rate of loss due (solely) to erosion is given by

$$\frac{dx}{dt} = -\frac{rx}{d}$$

(Eq. 10)

where, t is time (years), r (m) is the annual thickness of soil lost by erosion, and d (m) is the thickness of the soil layer (0.15m).

Substituting the values defined for the variables in this equation gives,

$$\frac{dx}{dt} = -4 \times 10^{-3} x$$

(Eq. 11)

The characteristic period (i.e., the time required for the concentration to decrease by a factor of e , the base of the natural logarithms) appropriate for this loss mechanism is the reciprocal of the coefficient of x . Thus, for Amargosa Valley soils this value is 250 years $[(0.004 \text{ per year})^{-1}]$. Note that as we took the lower limit of the rate of loss due to erosion, this time estimate is a conservative upper limit.

6.2.3 Simultaneous Leaching and Soil Erosion

For those radionuclides where the leaching rate is much higher than the loss from soil erosion, the degree of build-up predicted by the GENII-S code is insensitive to the rate of soil loss. This

is understandable as the soil loss mechanism only starts to be effective at times approaching the characteristic period of 250 years. For such radionuclides, the predicted BDCFs are essentially unchanged when erosion is considered.

In cases where the leaching rates are small, large build-up factors are possible. For radionuclides in this category, soil erosion can be the dominant loss mechanism and can have a significant effect on the BDCFs. However, before applying Equation 9 to determine the net effect of erosion on the change in BDCFs due to radionuclide build-up in soil, some thought has to be given to processes involved.

Consider a radionuclide, with a relatively low leaching rate compared to the erosion rate that is predicted by GENII-S (i.e., with soil loss not considered) to exhibit a significant soil build-up effect. At all times, there is insignificant loss due to leaching ($\lambda_{leaching}q(t)$) compared to the loss due to soil erosion ($\lambda_{soil\ loss}q(t)$) as $\lambda_{leaching} \ll \lambda_{soil\ loss}$. Thus leaching is never a significant mechanism and radionuclides are not flushed into the sub-soil layers in significant quantities. In this case, Equation 9 can be used to predict a modified time evolution of the BDCFs.

For the intermediate case where the loss rate from leaching and erosion are comparable, the dynamics are a little more complex. At early times, the concentration of radionuclides in the soil ($q(t)$) is well below the equilibrium values predicted by GENII-S. During this period, there are comparable losses from both mechanisms. As time passes and equilibrium conditions are approached, the leaching process causes build-up of radionuclides in the sub-soil layers. Thus when mechanical tilling incorporates some of this layer into the top-soil layer to replace that lost to erosion, some radionuclides previously considered lost, are re-introduced into the top-soil. Thus, the use of the sum of the removal rates from leaching and erosion over-predicts the loss of radionuclides from the productive soil and under-predicts (i.e., is not conservative) the BDCF build-up effect.

One solution to this problem would be to construct a more detailed representation of radionuclide dynamics in the top-soil/sub-soil layers than is employed in GENII-S. Such an approach cannot be easily justified. It would imply using the results from the GENII-S simple (first order differential) equation model for leaching to determine the boundary conditions that are to be used for a more detailed (second or higher order differential equation) leaching model.

A simpler approach, and the one adopted here, is to only consider one of the two loss (leaching or erosion) mechanisms. The mechanism considered will be the one with the larger loss rate. As one mechanism is totally ignored this approach is conservative.

When the loss from leaching exceeds the loss from soil removal ($\lambda_{leaching} > \lambda_{soil\ loss}$), the GENII-S BDCF data are used without modification for soil loss. In the other cases ($\lambda_{leaching} < \lambda_{soil\ loss}$), no credit is taken for leaching. In this case

$$\lambda_{revised} = \lambda_{GENII-S} - \lambda_{leaching} + \lambda_{erosion}$$

(Eq. 12)

It should be noted that $\lambda_{\text{GENII-S}}$ is retained as this includes the losses from radioactive decay and plant removal, in addition to leaching. The leaching rate ($\lambda_{\text{leaching}}$) is first subtracted from the removal rate determined from the GENII-S data ($\lambda_{\text{GENII-S}}$) before including the erosion loss rate (λ_{erosion}).

6.3 ANALYSIS OF THE GENII-S DISTRIBUTION PARAMETERS

The analysis was conducted using the Excel spreadsheet and some of its built-in functions. The spreadsheet file that was used as a template to perform the analysis on each radionuclide input data set is documented in Attachment II. This documentation satisfies the requirement of AP-SI.1Q. Attachment II discusses the computational details of the Excel spreadsheet named EXPONENTIAL FITTING ROUTINE V1_1.xls Version 1.1, while Attachment III contains the Excel file, EXPONENTIAL FITTING ROUTINE V1_1.xls. These attachments contain two worksheets; one for the normal distribution and one for both the lognormal distribution and the shifted lognormal distribution. Attachment II identifies the equation in each cell and provides the user step by step instructions on how to make use of the template to generate the required results. Also included in the worksheets is the interpolation/extrapolation routine to provide the required values of the standard deviation and where appropriate the shift in the shifted lognormal distribution for the estimated mean values of the build-up factor. The procedure was performed on the input data for each radionuclide and the associated distribution defined in Section 4.1.1. To assist the reader in reproducing these calculations, Attachment III contain the file CALC.xls, a spreadsheet containing multiple worksheets where all the calculation are shown.

6.4 RESULTS OF FITTING FOR BDCF PARAMETER VALUES

The parameters determined to provide the optimum fit to the GENII-S data for each radionuclide are provided in Table 5. The penultimate column in Table 5 gives the largest fractional deviation in the fitting parameter X (defined in 6.1 for the three distributions used) for each radionuclide.

i.e., $\text{MAX} \left| \frac{(X_{\text{predicted}} - X_{\text{observed}})}{X_{\text{predicted}}} \right|$ between the distribution data derived from GENII-S and the fit as

defined above for each of the radionuclides. In most cases, the maximum absolute error is less than two percent, and it is considered that the single reservoir approach is justified, with no need to attempt a higher order approximation. In the three cases (^{229}Th , ^{230}Th , and ^{232}U) where the deviation was greater than two percent, the increased discrepancy was attributed to decay product in-growth over the period considered for previous irrigation. In the case of ^{230}Th , a modified approach to the fitting had to be adopted. Because of the large GENII-S predicted build-up (from approximately 0.6 millirem/yr per pCi/l to about 38 millirem/yr per pCi/l), the errors in the fitting resulted in a prediction of the BDCF for period one (i.e., the constant term C in equation 8) being negative. To overcome this, the value of C in Excel Solver function was set at the GENII-S mean prediction for period 1 and not used as a variable in the optimizing process. The optimization was performed by varying the other two parameters B and D over the first four irrigation periods. As discussed in Section 6.2.2, the soil loss process has a characteristic period of (i.e., occurs over) a few hundred years. Thus, for ^{230}Th using only the first set of irrigation periods should not impact the interpolation over the first few hundred years.

Figure 1 gives the graphical representation of the data points and fit for ^{229}Th , an example of a radionuclide with a large build-up effect.

Figure 1. Comparison of GENII-S Predicted Values of the BDCF as a Function of Previous Irrigation Periods with Predicted Analytical Fit for ^{229}Th

6.5 INCORPORATING SOIL EROSION INTO THE FITTED PARAMETERS

The soil loss mechanism has its own characteristic loss rate (see Section 6.2.2.). As shown in 6.2.3, it is conservative to take (Eq. 12) $\lambda_{new} = \lambda_{old} - \lambda_{leaching} + \lambda_{soil\ loss}$, therefore from 6.1 ($\lambda = 1/B$), then

$$B_{new}^{-1} = B_{old}^{-1} - B_{leaching}^{-1} + B_{erosion}^{-1}$$

(Eq. 13)

This calculation is given in the attached spreadsheet in the Summary worksheet and the results are reproduced in Table 6.

Section 6.1, gives the BDCF values appropriate for zero previous irrigation (i.e., C) and the asymptotic value after a long period of previous irrigation ($C + DB$). These values have been calculated and included in Table 6 for BDCFs with and without soil loss.

Table 5. Parameter Values Resulting in the Best Fit

Radionuclide	Distribution (See Note)	Scale Factor	Parameter			Maximum Relative Deviation	Comment
			B	C	D		
²⁴¹ Am	N	1.E-04	502.7513	38.00954	0.03376	0.33%	
²⁴³ Am	LN	1.E-04	2185.491	35.11079	0.05794	0.22%	
¹³⁷ Cs	SLN	1.E-05	39.76837	7.966907	0.985344	0.41%	
⁶³ Ni	SLN	1.E-07	76.72803	6.615345	0.036877	1.61%	
²³¹ Pa	SLN	1.E-03	832.653	10.42589	0.049961	1.83%	
²³⁹ Pu	N	1.E-04	790.223	37.37713	0.029631	0.25%	
²⁴⁰ Pu	N	1.E-04	749.0186	37.30798	0.029517	0.28%	
²⁴² Pu	N	1.E-04	796.0394	34.74819	0.027726	0.21%	
²²⁶ Ra	LN	1.E-04	542.1563	9.735982	0.345651	0.22%	
⁹⁰ Sr	LN	1.E-05	13.18821	13.77084	0.546639	0.41%	
²²⁹ Th	LN	1.E-03	3268.304	3.634601	0.016298	3.50%	See Text
²³⁰ Th	N	1.E-03	281013.2	0.584647	0.006351	14%	See Text
²³² U	N	1.E-04	185.301	14.49113	0.171887	5.00%	See Text
²³⁸ U	N	1.E-05	49.8617	27.70568	0.12231	0.63%	

Note N = normal
LN = lognormal
SNL = shifted lognormal

Table 6. Lognormal Fitting Parameters Before And After Soil Erosion Is Taken Into Account

Parameter	Radionuclide				
	²⁴¹ Am	²⁴³ Am	¹³⁷ Cs	⁶³ Ni	²³¹ Pa
Distribution	N	LN	SLN	SLN	SLN
Scale Factor	1.E-04	1.E-04	1.E-05	1.E-07	1.E-03
B _{GENII}	502.75135	2185.4905	39.768367	76.728027	832.65298
λ _{GENII}	1.989E-03	4.576E-04	2.515E-02	1.303E-02	1.201E-03
λ _{Leaching}	3.560E-04	3.560E-04	2.420E-03	1.690E-03	1.230E-03
λ _{Erosion}	4.000E-03	4.000E-03	4.000E-03	4.000E-03	4.000E-03
λ _{New}	5.633E-03	4.102E-03	2.673E-02	1.534E-02	3.971E-03
B _{New}	177.52	243.81	37.42	65.18	251.83
C	3.801E+01	3.511E+01	7.967E+00	6.615E+00	1.043E+01
D	3.376E-02	5.794E-02	9.853E-01	3.688E-02	4.996E-02
Mean BDCF No Prior Irrigation	38.0	35.1	8.0	6.6	10.4
BDCF Late Time No Erosion	54.98	161.74	47.15	9.44	52.03
BDCF Late Time With Erosion	44.00	49.24	44.84	9.02	23.01
Build-up Factor With No Erosion	1.45	4.61	5.92	1.43	4.99
Build-up Factor With Erosion	1.16	1.40	5.63	1.36	2.21

See NOTES at end of Table

Table 6. Lognormal Fitting Parameters Before And After Soil Erosion Is Taken Into Account (continued)

Parameter	Radionuclide				
	²³⁹ Pu	²⁴⁰ Pu	²⁴² Pu	²²⁶ Ra	⁹⁰ Sr
Distribution	N	N	N	LN	LN
Scale Factor	1.E-04	1.E-04	1.E-04	1.E-04	1.E-05
B _{GENII}	790.22298	749.01858	796.03938	542.15625	13.188206
λ _{GENII}	1.265E-03	1.335E-03	1.256E-03	1.844E-03	7.583E-02
λ _{Leaching}	1.230E-03	1.230E-03	1.230E-03	1.350E-03	4.470E-02
λ _{Erosion}	4.000E-03	4.000E-03	4.000E-03	4.000E-03	4.000E-03
λ _{New}	4.035E-03	4.105E-03	4.026E-03	4.494E-03	7.583E-02
B _{New}	247.80	243.60	248.37	222.49	13.19
C	3.738E+01	3.731E+01	3.475E+01	9.736E+00	1.377E+01
D	2.963E-02	2.952E-02	2.773E-02	3.457E-01	5.466E-01
Mean BDCF No Prior Irrigation	37.4	37.3	34.7	9.7	13.8
BDCF Late Time No Erosion	60.79	59.42	56.82	197.13	20.98
BDCF Late Time With Erosion	44.72	44.50	41.63	86.64	20.98
Build-up Factor With No Erosion	1.63	1.59	1.64	20.25	1.52
Build-up Factor With Erosion	1.20	1.19	1.20	8.90	1.52
See NOTES at end of Table					
Parameter	Radionuclide				
	²²⁹ Th	²³⁰ Th	²³² U	²³⁸ U	
Distribution	LN	N	N	N	
Scale Factor	1.E-03	1.E-03	1.E-04	1.E-05	
B _{GENII}	3268.3038	281013.19	185.30101	49.861697	
λ _{GENII}	3.060E-04	3.559E-06	5.397E-03	2.006E-02	
λ _{Leaching}	2.120E-04	2.120E-04	1.930E-02	1.930E-02	
λ _{Erosion}	4.000E-03	4.000E-03	4.000E-03	4.000E-03	
λ _{New}	4.094E-03	3.792E-03	5.397E-03	2.006E-02	
B _{New}	244.26	263.74	185.30	49.86	
C	3.635E+00	5.846E-01	1.449E+01	2.771E+01	
D	1.630E-02	6.351E-03	1.719E-01	1.223E-01	
Mean BDCF No Prior Irrigation	3.6	0.6	14.5	27.7	
BDCF Late Time No Erosion	56.90	>50 (D)	46.34	33.80	
BDCF Late Time With Erosion	7.62	2.26	46.34	33.80	
Build-up Factor With No Erosion	15.66	>80 (D)	3.20	1.22	
Build-up Factor With Erosion	2.10	3.86	3.20	1.22	

NOTES N = Normal Distribution

LN = Lognormal Distribution

SLN = Shifted Lognormal

D = Due to decay product build-up these numbers are lower limits

Soil loss, with its characteristic period of removal of 250 years, has a dominant effect on the expected BDCF build-up for those radionuclides where the predicted GENII-S build-up periods are approaching or above a thousand years. Thus for these radionuclides there is no need to consider the potential of previous irrigation much greater than a few hundred years. This fact justifies using a limited set of irrigation periods for deriving the build-up for ^{230}Th .

6.6 BUILD-UP EFFECT ON THE OTHER DISTRIBUTION PARAMETERS

For the three distributions used to represent the BDCF data, the parameter variations of the mean and standard deviations (and the shift for the shifted lognormal distribution) are given in Tables 1, 2, and 3. These values were used to determine the appropriate intermediate values of the standard deviation and shift (when appropriate) from the value of the mean (or exponential of the log mean plus shift for the lognormal distributions). Linear interpolation or, when necessary, extrapolation was used to generate the distribution parameters associated with a predicted asymptotic mean BDCF. The metric employed for interpolation/extrapolation was the same as used for fitting the build-up evolution and was distribution dependent. This metric was (a) the mean for the normal distribution, (b) the geometric mean for the lognormal distribution, and (c) the geometric mean plus the shift for the lognormal distribution.

The details of this action are given in Attachment II.

7. CONCLUSIONS

This document may be affected by technical product information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

7.1 SUMMARY

Fourteen radionuclides were identified in a predecessor AMR (CRWMS M&O 2000b) to have significant BDCF build-up factors from prior irrigation. Such an increase in BDCFs could have a significant impact on dose calculations in TSPA-SR for a community that has farmed the same land for many years. The distribution fitting used the stochastic BDCF output that had been generated by the GENII-S. GENII-S does not consider soil erosion as a radionuclide loss mechanism. Soil loss was addressed in another predecessor AMR (CRWMS M&O 2000c).

The purpose of this AMR effort was twofold. First, to develop and fit, for each radionuclide, an analytical approximation for the abstracted BDCF distributions over the period of time considered for irrigation. Second, to incorporate into this approximation the soil loss data generated by CRWMS M&O 2000c. The result is to provide Performance Assessment with an abstraction for soil build up effects on BDCFs to be used to calculate dose.

7.2 FINDINGS

The analytic approximation, developed using the mass balance equation, provided a good representation of the time evolution for the BDCF (normal distribution, lognormal distribution and shifted lognormal distribution) means as a function of irrigation times. Soil loss, with a predicted characteristic period of 250 years, has a significant effect on BDCF build-up for those radionuclides that were predicted by GENII-S to have build-up time approaching and in excess of a thousand years. The effect of soil erosion on those radionuclides that had leaching as the dominant removal mechanism (^{90}Sr , ^{232}U , and ^{238}U) was ignored because of the possibility of not correctly allowing for the re-introduction (mixing of deep soil into the top soil to replace material removed by erosion) of radionuclides that had previously been removed by leaching.

7.3 RECOMMENDATIONS FOR TSPA-SR

The work reported in this AMR permits the following recommendations are made for TSPA-SR.

The soil loss mechanism is included in the BDCFs for all radionuclides, with the exception of ^{90}Sr , ^{232}U , and ^{238}U , where the GENII-S predictions show a significant (greater than 15%) build-up in BDCF values from previous irrigation periods.

Soil erosion provides a reduction in the degree of BDCF build-up from previous irrigation. A possible approach to account for farming activity would be to randomly sample the BDCF growth in time over the period of previous irrigation. This approach would require a technically justified assessment defining the probability distribution for the number of years over which irrigation has been applied. In reality it is likely that each of the farms in the hypothetical community would rotate in and out of production over the period of assessment. To avoid the complexities inherent in such an evaluation it is recommended that mean BDCF appropriate to the late time-asymptotic values are used (see Table 6). The soil build-up factors without and with soil erosion are summarized in Table 7.

The additional parameters defining each distribution (the appropriate standard deviation for all three distributions, plus the shift for the shifted lognormal) were derived by interpolation or extrapolation of the parameters values determined by the distribution fitting to the six irrigation period BDCFs. This interpolation/extrapolation was discussed in Section 6.6.

The recommended parameters for the radionuclides with soil erosion included are given in Table 8. For distributions using the lognormal distribution, the parameters in Table 8 are the mean and standard deviation of the natural logarithms of the BDCF values. In the event that the geometric parameters (e raised to the power of the appropriate parameter in Table 8) of the lognormal distribution are required these are given in Table 9.

These data were submitted to the TDMS and were allocated DTN:MO0011SPAABS07.009. These data are to be used to support TSPA-SR. This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

Table 7. Predicted Increases in BDCFs due to Radionuclide Build-up in Soil with and without Soil Erosion

Radionuclide	Build-up Factor	
	With Leaching No Erosion	With Dominant Mechanism: Leaching or Erosion
²⁴¹ Am	1.45	1.16
²⁴³ Am	4.61	1.40
¹³⁷ Cs	5.92	5.63
⁶³ Ni	1.43	1.36
²³¹ Pa	4.99	2.21
²³⁹ Pu	1.63	1.20
²⁴⁰ Pu	1.59	1.19
²⁴² Pu	1.64	1.20
²²⁶ Ra	20.25	8.90
⁹⁰ Sr	1.52	1.52
²²⁹ Th	15.66	2.10
²³⁰ Th	NM (>60)	3.86
²³² U	3.20	3.20
²³⁸ U	1.22	1.22

NOTE The numerical entries have the same value when the removal rate due to leaching is greater than the removal rate due to soil erosion.

7.3.1 Truncated Normal Distribution

For ²⁴¹Am, ²³⁹Pu, ²⁴⁰Pu, ²⁴²Pu, ²³⁰Th, ²³²U and ²³⁸U the appropriate distribution is the truncated normal distribution. The distribution is truncated at zero to eliminate the selection of a negative BDCF. To generate the stochastic BDCFs (in units of rem/year per picocurie/liter) from the data given in Table 8, the following steps are taken.

- Use the TSPA code to randomly sample for a truncated normal distribution with the defined mean and standard deviation given in Table 8.
- Multiply the resulting number by the scaling factor.
- The result is the BDCF for the specified radionuclide that reflects the uncertainty in the Biosphere Model.

7.3.2 Lognormal Distribution

For ²⁴³Am, ²²⁶Ra, ⁹⁰Sr, and ²²⁹Th, the appropriate distribution is the lognormal distribution. To generate the stochastic BDCFs (in units of rem/year per picocurie/liter) from the data given in Table 8 or 9, the following steps are taken.

- Either use the TSPA code to randomly sample from a lognormal distribution with the defined logarithmic mean and standard deviation given in Table 8 or use the TSPA code to randomly sample from a lognormal distribution with the defined geometric mean and

standard deviation given in Table 9. (NOTE. The terms logarithmic mean and logarithmic standard deviation are respectively the mean and standard deviation of the logarithm of random variable. CRWMS M&O (2000a) and Excel use this definition.

- (b) Multiply the resulting number by the scaling factor.
- (c) The result is the BDCF for the specified radionuclide that reflects the uncertainty in the Biosphere Model.

7.3.3 Shifted Lognormal Distribution

For ^{137}Cs , ^{63}Ni , and ^{231}Pa the appropriate distribution is the shifted lognormal distribution. As identified in Section 4.1.1, the negative shift in the distributions for ^{63}Ni and ^{231}Pa (Tables 8 and 9) allow for a small probability of generating a BDCF less than zero. This is physically unrealistic. To prevent such an occurrence, the recommendation is made to TSPA to sample a truncated lognormal distribution prior to applying the shift. Such an action is conservative as the elimination of negative values can only increase the expected value (mean) of the distribution, i.e., the average dose prediction will be increased (by some small amount).

To generate the stochastic BDFs (in units of rem/year per picocurie/liter) from the data given in Table 8, the following steps are taken.

- (a) For ^{137}Cs use the TSPA code to randomly sample from a lognormal distribution with the defined logarithmic mean and standard deviation given in Table 8 or use the TSPA code to randomly sample from a lognormal distribution with the defined geometric mean and standard deviation given in Table 9.
- (b) For ^{63}Ni and ^{231}Pa use the TSPA code to randomly sample from a truncated lognormal distribution with the defined logarithmic mean and standard deviation given in Table 8 or use the TSPA code to randomly sample from a truncated lognormal distribution with the defined geometric mean and standard deviation given in Table 9. The truncation at the lower end is set such that the minimum sampled value is greater than the absolute value of the shift. This action eliminates the possibility of generating a negative BDCF. When using truncated distributions, the TSPA code requires the user to supply an upper truncation limit. To satisfy this requirement without having any significant restraining effect of the upper end of the distribution an upper truncation limit is to be defined as five times the standard deviation.
- (c) Add the offset to the value derived in (a) or (b).
- (d) Multiply the resulting number by the scaling factor.
- (e) The result is the BDCF for the specified radionuclide that reflects the uncertainty in the Biosphere Model.

Table 8. Parameters Defining the BDCF Distributions Recommended for use TSPA-SR

Normal Distribution (Truncated at Zero)					
Radionuclide	Scale Factor	Arithmetic Mean	Arithmetic SD	Comments	
²⁴¹ Am	1.E-04	44.000	21.648	The units of the truncated normal distribution parameters are such that when the truncated normal distribution is sampled and the resultant number is multiplied by the scaling factor, the resultant BDCF is in units of rem/year per pico-Curie/liter.	
²³⁹ Pu	1.E-04	44.720	21.334		
²⁴⁰ Pu	1.E-04	44.500	21.290		
²⁴² Pu	1.E-04	41.630	19.789		
²³⁰ Th	1.E-03	2.260	0.637		
²³² U	1.E-04	46.340	9.415		
²³⁸ U	1.E-05	33.800	15.645		
Lognormal Distribution (Mean and Standard Deviation of Natural Log (ln) Values)					
Radionuclide	Scale Factor	Logarithmic Mean	Logarithmic SD	Comments	
²⁴³ Am	1.E-04	3.872	0.464	The units of the lognormal distribution parameters are such that when the lognormal distribution is sampled and the resultant number multiplied by the scaling factor, the resultant BDCF is in units of rem/year per pico-Curie/liter.	
²²⁶ Ra	1.E-04	5.773	-0.239		
⁹⁰ Sr	1.E-05	3.121	0.734		
²²⁹ Th	1.E-03	1.831	0.435		
Shifted Lognormal Distribution (Mean and Standard Deviation of ln Values) Truncated at Zero					
Radionuclide	Scale Factor	Logarithmic Mean	Logarithmic SD	Shift	Comments
¹³⁷ Cs	1.E-05	2.629	0.428	33.168	The units of the shifted lognormal distribution parameters are such that when the lognormal distribution is sampled, the shift value added, and the resultant number multiplied by the scaling factor, the resultant BDCF is in units of rem/year per pico-Curie/liter.
⁶³ Ni	1.E-07	3.248	0.164	-12.128	
²³¹ Pa	1.E-03	3.970	0.132	-30.191	

Notes

- SD = Standard Deviation
- Arith Mean = Arithmetic Mean
- ln Mean = Logarithmic Mean
- Arith SD = Arithmetic Standard Deviation
- ln SD = Logarithmic Standard Deviation
- N = Truncated Normal Distribution
- LN = Lognormal Distribution
- SLN = Shifted Lognormal Distribution

Table 9. Geometric Parameters Defining the BDCF Distributions Recommended for use TSPA-SR for lognormal based distributions

Lognormal Distribution (Geometric Mean and Standard Deviation)					
Radionuclide	Scale Factor	Geometric Mean	Geometric SD	Comments	
²⁴³ Am	1.E-04	48.054	1.591	The units of the lognormal distribution parameters are such that when the lognormal distribution is sampled and the resultant number multiplied by the scaling factor, the resultant BDCF is in units of rem/year per pico-Curie/liter.	
²²⁶ Ra	1.E-04	321.626	0.787		
⁹⁰ Sr	1.E-05	22.660	2.084		
²²⁹ Th	1.E-03	6.238	1.544		
Shifted Lognormal Distribution (Geometric Mean and Standard Deviation) Truncated at Zero					
Radionuclide	Scale Factor	Geometric Mean	Geometric SD	Shift	Comments
¹³⁷ Cs	1.E-05	13.865	1.534	33.168	The units of the shifted lognormal distribution parameters are such that when the lognormal distribution is sampled, the shift value added, and the resultant number multiplied by the scaling factor, the resultant BDCF is in units of rem/year per pico-Curie/liter.
⁶³ Ni	1.E-07	25.728	1.178	-12.128	
²³¹ Pa	1.E-03	52.983	1.141	-30.191	

Notes SD = Standard Deviation
 Geom Mean = Geometric Mean
 Geom SD = Geometric Standard Deviation
 LN = Lognormal Distribution
 SLN = Shifted Lognormal Distribution

8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

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CRWMS M&O 2000c. *Evaluate Soil/Radionuclide Removal by Erosion and Leaching*. ANL-NBS-MD-000009 REV 00/ICN 01. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0748.

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8.2 CODES, STANDARDS, REGULATIONS AND PROCEDURES

64 FR(Federal Register) 8640. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada. Readily Available.

AP-3.10Q, Rev.2, ICN 3. *Analyses and Models*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000217.0246.

AP-SI.1Q, Rev. 2, ICN 4, ECN 1 *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20001019.0023 .

NLP-2-0, Rev. 5. *Determination of Importance Evaluations*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981116.0120.

QAP-2-3, Rev. 10. *Classification of Permanent Items*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19990316.0006.

8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

8.3.1 Input Data

MO0010MWDPBD09.006. Biosphere Dose Conversion Factors for Nominal Performance. Submittal date: 05/10/2000. Submit to RPC URN-0776.

MO0010SPAABS08.008. Abstracted BDCF Distributions for Use in Soil Erosion Analysis. Submittal date: 10/27/2000. Submit to RPC URN-0778

MO0010SPAPET07.004. Environmental Transport Parameters used as Input Data for GENII-S Runs. Submittal date: 10/03/2000. Submit to RPC URN-00659.

SN9912T0512299.002. Annual Surface Soil Removal Estimates for Amargosa Valley Soils. Submittal date: 12/09/1999.

SN9912T0512299.003. Revised Leaching Coefficients for GENII-S Code. Submittal date: 12/09/1999.

8.3.2 Output Data

MO0011SPAABS07.009. Abstracted BDCF Distribution with Soil Erosion for Use in TSPA-SR. Submittal date: 11/15/2000.

ATTACHMENTS

The attachments are listed as follows:

Attachment Title

- I. List of Acronyms
- II. Spreadsheet Calculation To Optimize The Goodness Of Fit Of The Single Exponential Representation Of BDCF Abstractions Due To Radionuclide Build-Up In Soil As A Result Of Periods Of Previous Irrigation With Contaminated Groundwater (Exponential Fitting Template V1_1 with File name EXPONENTIAL FITTING ROUTINE V1_1.XLS Version 1.1)
- III. Computer Medium titled Abstraction of BDCF Distributions for Irrigation Periods. This medium contains two files, with details given below, to provide the user with the details of both the template used and the actual data sheets showing the analysis for each radionuclide.

Item	File Name	Date	Time	Size	QA Designator
1	Exponential Fitting Routine V1_1.xls	11/15/00	5:55 PM	21 KB	QA:QA
2	Calc.xls	12/13/00	8:57 PM	143 KB	QA:QA

ATTACHMENT I

LIST OF ACRONYMS AND ABBREVIATIONS

Am	Americium
AMR	Analysis/Modeling Report
BDCF	Biosphere Dose Conversion Factor
CRWMS	Civilian Radioactive Waste Management Systems Management and Operating
M&O	Contractor
Cs	Cesium
DOE	Department of Energy
DTN	Data Tracking Number
IRSR	Issue Resolution Status Report
Ln	Natural logarithm (i.e., logarithm to base <i>e</i>)
Lt	Liter
MAX	Maximum (Excel function)
^M E	The isotope of atomic mass M of element represented by the chemical symbol E
Ni	Nickel
NRC	US Nuclear Regulatory Agency
OCRWM	Office of Civilian Radioactive Waste Management
Pa	Protactinium
Pb	Lead
pci	Picocurie
PMR	Process Model Report
Pu	Plutonium
Ra	Radium
Rem	Roentgen equivalent man
Sr	Strontium
TDMS	Technical Database Management System
Th	Thorium
TSPA	Total System Performance Assessment
TSPA&I	Total System Performance Assessment and Integration
TSPA-SR	Total System Performance Assessment – Site Recommendation
TWP	Technical Work Plan
U	Uranium
Yr	Year

ATTACHMENT II
SPREADSHEET CALCULATION TO OPTIMIZE THE GOODNESS OF FIT OF THE
SINGLE EXPONENTIAL REPRESENTATION OF BDCF ABSTRACTIONS DUE TO
RADIONUCLIDE BUILD-UP IN SOIL AS A RESULT OF PERIODS OF PREVIOUS
IRRIGATION WITH CONTAMINATED GROUNDWATER

Exponential Fitting Template V1_1

File name EXPONENTIAL FITTING ROUTINE V1_1.XLS Version 1.1

OVERVIEW

This attachment provides documentation for the Excel Spreadsheet template routine used in this AMR to determine the parameters that are associated with the optimal fit for the exponential representation of the time evolution of the abstracted distribution mean of the BDCF's over periods of previous irrigation. The abstracted data were obtained from DTN MO0010SPAABS08.008.

The Excel Spreadsheet template routine that was used for all of the data in the AMR and DTN was worksheet named *Exponential Fitting Routine V1_1 Version 1.1* with file name *EXPONENTIAL FITTING ROUTINE V1_1.xls*.

This template routine was developed using Microsoft Excel 97 SR-2 running on a DELL POWEREDGE 2200 (Control Number 112375) with the Microsoft Windows NT operating system.

DESCRIPTION OF THE TEMPLATE

The Excel routine developed to process the multiple files of source data was classed as a template. The use of the word template was justified as a single Excel file (with extension .xls) was developed that contained the function and the "instructions" could be "cut and pasted" into multiple worksheets containing the data. Within the template, two worksheets were developed. One was for use with the normal distribution and the other for the lognormal and shifted lognormal distributions. The difference between the two worksheets within the template was restricted to the calculation of the linear measure of the estimated build-up at each irrigation period. The difference is explained in detail below (in the discussion of Table II-2). The resulting worksheets after integration of the template and the data were given names that uniquely identified the radionuclide for which the data is processed in each sheet.

The template is structured into four compartments. These compartments are discussed sequentially as processed by Excel. The following tables show the equations entered in the cells of the template.

Table II-1 shows the input portion of the template. Table II-1 shows data that are those applicable to ^{137}Cs . It should be noted that this and some following tables are copied from Excel with the display in "show equation mode". In this mode the full value of each number is displayed as shown in the spreadsheet memory. The user cannot define the number of significant places to be shown. This example selected here was ^{137}Cs that had been abstracted as a shifted lognormal distribution. The other abstractions were normal (discussed below) or lognormal (a shifted lognormal with zero shift i.e., column B is blank (effectively full of zeros). Cell C:2 contained the identifier for the radionuclide under consideration. The six sets (one for each period of previous period of irrigation) of parameters to describe the abstracted statistical distributions for the radionuclide identified in C:2 are to be copied into cells B6:F11. The input is distributed by column as follows.

- Column A was intentionally left blank.

- Column B contains the shift (as noted above this only applicable to the shifted lognormal distribution).
- Column C contains the serial number of period of previous irrigation (this is for reference and is not used in calculations).
- Column D contains the number of years of previous irrigation appropriate that the radionuclide under consideration for the period identified in column C.
- Column E contain the mean value of the (normal, lognormal or shifted lognormal) distribution.
- Column F contain the standard deviation of the (normal, lognormal or shifted lognormal) distribution.
- Cell H4 is used to define the distribution applicable for the radionuclide being assessed. N = Normal, LN = lognormal, SNL = shifted lognormal.

Table II-1. The Parameter Input Section of the Template

	B	C	D	E	F
2	Cs_137				
3			Scaling Factor	100000	
4					
5	Shift	Period #	Years Irrigation	Mean	SD
6	1.61573447742848	1	0	1.85232882400785	0.836113831222013
7	7.01146021682756	2	7	1.98520574187064	0.76633143200682
8	13.0292859643505	3	16	2.05815554478855	0.764840886422622
9	17.7696943883306	4	27	2.25766749263509	0.769832469568871
10	21.1478976470873	5	43	2.54530987304246	0.701176759892492
11	23.804996023715	6	71	2.81851246858017	0.652114943291111

The second portion of the template is shown in Table II- 2. This is the working space where the expression derived in Eq. 8 in Section 6.1 is fitted to the abstracted data. As the equations derived in section 6.1, apply to the actual values of the BDCF parameter and not to the logarithm of that parameter, the first calculation in column H for the lognormal (with and without a shift) distribution is to represent the abstracted parameters as an actual BDCF. This is achieved by raising e, the base of the natural logarithm, to the power of the parameter and in the case of a shifted lognormal distribution adding in the shift. . For these distributions, this on the worksheet with tab "LN & SLN." For the normal distribution the mean values of the distribution required no modification and can be copied directly into column J. For the normal distribution, this on the worksheet with tab "Normal."

Column J and L contain the instructions that allow the user to calculate the values of the parameters in Eq. 6 that provide the optimum fit to the time evolution of the mean of the BDCF abstractions.

- Cells J1:J3 are loaded with estimates of the three parameters defined in Eq. 6, i.e., B, C, and D respectively.
- Cells J6:J11 contain the expression (Eq. 6) required to generate the predicted value of the BDCF value derived in the corresponding row of column H.
- Cells L6:L11 contain the square of the differences between the actual value and value predicted by Eq. 6.
- Cell L:13 contain the sum of the values in cells L6:L11, i.e., the sum of the squares of the differences between the actual and predicted values.

By varying the parameters in cells J1:J3 such that cell L13 attains a minimum will provide the best estimate of the parameters in Eq. 6 according to the least squares fitting criterion. This optimization process is discussed in the next Section (Use of the Template).

The final part of the template is shown in Table II- 3. This section evaluates, in column N, the maximum relative deviation between actual and the optimized predicted values. Table II- 3 is self-explanatory and required no discussion.

Table II-2. Exponential Fitting Portion of the Template

	H	I	J	K	L
1		B	39.768366511857		
2		C	7.96690745149441		
3		D	0.985344277055818	=+J3*J1	
4	SLN				
5	= "Av "&E5	Predicted			Difference^2
6	=+EXP(E6)+B6	=+\$J\$2+\$J\$3*(1-EXP(-D6/\$J\$1))*\$J\$1			=+(H6-J6)^2
7	=+EXP(E7)+B7	=+\$J\$2+\$J\$3*(1-EXP(-D7/\$J\$1))*\$J\$1			=+(H7-J7)^2
8	=+EXP(E8)+B8	=+\$J\$2+\$J\$3*(1-EXP(-D8/\$J\$1))*\$J\$1			=+(H8-J8)^2
9	=+EXP(E9)+B9	=+\$J\$2+\$J\$3*(1-EXP(-D9/\$J\$1))*\$J\$1			=+(H9-J9)^2
10	=+EXP(E10)+B10	=+\$J\$2+\$J\$3*(1-EXP(-D10/\$J\$1))*\$J\$1			=+(H10-J10)^2
11	=+EXP(E11)+B11	=+\$J\$2+\$J\$3*(1-EXP(-D11/\$J\$1))*\$J\$1			=+(H11-J11)^2
12					
13				SS	=SUM(L6:L11)

NOTE In the worksheet "Normal" the cell H6:H11 simply copy the values from E6:E!!
 I.e., Cell H6 contains =+E6

Table II-3. Portion of the Template that Calculates the Maximum Relative Deviation Between Actual and the Optimized Eq. 6 Fit

	J	K	L	M	N
1	39.768366511857				
2	7.96690745149441				
3	0.985344277055818	=+J3*J1			
4					
5	Predicted	Difference^2			
6	=+\$J\$2+\$J\$3*(1-EXP(-D6/\$J\$1))*\$J\$1	=(H6-J6)^2		=(H6-J6)/J6	
7	=+\$J\$2+\$J\$3*(1-EXP(-D7/\$J\$1))*\$J\$1	=(H7-J7)^2		=(H7-J7)/J7	
8	=+\$J\$2+\$J\$3*(1-EXP(-D8/\$J\$1))*\$J\$1	=(H8-J8)^2		=(H8-J8)/J8	
9	=+\$J\$2+\$J\$3*(1-EXP(-D9/\$J\$1))*\$J\$1	=(H9-J9)^2		=(H9-J9)/J9	
10	=+\$J\$2+\$J\$3*(1-EXP(-D10/\$J\$1))*\$J\$1	=(H10-J10)^2		=(H10-J10)/J10	
11	=+\$J\$2+\$J\$3*(1-EXP(-D11/\$J\$1))*\$J\$1	=(H11-J11)^2		=(H11-J11)/J11	
12					
13		SS =SUM(L6:L11)		=+MAX(N6:N11)	
14				=-MIN(N6:N11)	
15				=+MAX(N13:N14)	

The portion of the template used to perform interpolation or extrapolation of the standard deviation and (for the shifted lognormal distribution) to shift is given in Table II-4. The predicted late time mean values of the BDCFs is entered into cell C19 (this values is from Table 6). Cells E19:E20 are loaded with the values of the interpolating variable (the measure of the linear mean of the BDCFs) that are closest to the values in cell C19. The corresponding parameters of mean, standard deviation, and shift are loaded into cells F19:H20. In row 22, the changes in these value are determined (by subtraction). Row 24 calculates the change in the appropriate variable per unit change in the measure of BDCF (division of Cells F22:H22 by cell E22). Cell E27 gives the difference between the predicted BDCF value in cell C19 and lower value of the BDCF range in cell E19. Cells F27:H27 give the predicted increment in the parameter being interpolated (extrapolated). By addition of cell F27:H27 to E19:H19 give the required values in cell F29:H29.

Table II-4. Interpolation/Extrapolation Portion of the Template

	C	D	E	F	G	H
17	Late Time BDCF		Av Mean	Mean	SD	Shift
18						
19	44.84		=+H10	=+E10	=+F10	=+B10
20			=+H11	=+E11	=+F11	=+B11
21						
22		Changes	=+E20-E19	=+F20-F19	=+G20-G19	=+H20-H19
23						
24		Change per unit Av Mean		=+F22/\$E\$22	=+G22/\$E\$22	=+H22/\$E\$22
25						
26						
27		Change	=+C19-E19	=+F24*\$E\$27	=+G24*\$E\$27	=+H24*\$E\$27
28						
29		Estimated parameters	=+E19+E27	=+F19+F27	=+G19+G27	=+H19+H27

Data – Template Integration

The abstracted BDCF distribution file was opened. Additional worksheets (one for each radionuclide) were added. The appropriate template file was opened, the used cells (A1:N15) were highlighted and COPIED on to the clipboard. The clipboard was then pasted into cell A:1 of each of the new worksheets. The TAB of each of the additional worksheets were given a unique name (the radionuclide to be considered in that worksheet). The appropriate data was copied from the summary sheet containing all the abstracted data into the input cells of the template.

Initial Action

The initial estimates of the parameters *B*, *C*, and *D* were loaded into cells J1:J3. It should be noted that these estimates need only be approximate. Reasonable estimates could be obtained as follows

- For C (cell J:2), the value of BDCF for irrigation period 1.
- For B (cell J:1), a value of the time corresponding to about midway between minimum and maximum BCDFs.
- For D (cell J:3), a value that is approximately given by the BDCF for the period 6 less C all divided by B.

Optimization

The Excel “Solver” was initiated. This is found on the pull down menu for “Tools” In the “Solver Parameters” box, the following actions are taken.

1. “Set Target Cell” to L13.

2. Set the "Equal to" radio button to "Min".
3. Set the "By Changing Cells" to J1:J3.
4. Push the "Options" button and check the "Use Automatic Scaling" box, push "OK" button.
5. Push the "Solve" button.

If the "Solver" finds a minimum, accept the values.

If the "Solver" is unable to converge to a solution, reset the values to their initial values.

Repeat the sequence 1 to 5 above but in item 3, select only one of the parameters to vary. Repeat the last step but using a different parameter to vary. Once solutions have been reached by varying each parameter in turn, vary two at a time. Finally use the initial approach and generate a solution by varying all three parameters together.

Demonstration of Functionality

To provide a demonstration that the template performs the required fitting of Eq. 6 to the data, a simple test was conducted. The test used six data points derived from Eq. 6 generated by using an Excel calculation with predefined parameters (B, C, and D). The initial conditions are shown in Table II- 4, as are the exact values for the (artificial) BDCFs.

Table II-5. Starting Conditions for Template Test

	C	D	E	F	G	H	I	J	K	L
1		B	100				B	50		
2	TEST	C	1				C	0.8		
3		D	1.E-02				D	0.01		5.00E-01
4										
5	Period #	Years Irrigation	Mean	SD		Test Values		Predicted		Difference^2
6	1	0				1		0.8		4.00E-02
7	2	25				1.22119922		0.99673467		5.04E-02
8	3	50				1.39346934		1.116060279		7.70E-02
9	4	100				1.63212056		1.232332358		1.60E-01
10	5	200				1.86466472		1.290842181		3.29E-01
11	6	400				1.98168436		1.299832269		4.65E-01
12										
13									SS	1.12E+00

Following the use of the built-in SOLVER function as directed above provides the values shown in Table II-6. To within the desired accuracy the template determined a good approximation to the expected results. By using the Excel format capability to only show two decimal place would have indicated an exact fit to the known solution.

Table II-6. Optimized Conditions after use of SOLVER on Template Test

	C	D	E	F	G	H	I	J	K	L
1		B	100				B	99.99668358		
2	TEST	C	1				C	0.999985481		
3		D	1.E-02				D	0.010000381		1.00E+00
4										
5	Period #	Years Irrigation	Mean	SD		Test Values		Predicted		Difference^2
6	1	0				1		0.999985481		2.11E-10
7	2	25				1.22119922		1.221192245		4.86E-11
8	3	50				1.39346934		1.393466818		6.36E-12
9	4	100				1.63212056		1.632121356		6.35E-13
10	5	200				1.86466472		1.864663435		1.64E-12
11	6	400				1.98168436		1.981677109		5.26E-11
12										
13									SS	3.21E-10

The interpolation/extrapolation portion of the template was tested by inserting some values in the cell that could be readily checked by observation. Cells E6:E11 were loaded with an arithmetic sequence starting at 1.0 with increments of 0.1. Similarly the equivalent cell in column F were loaded with an arithmetic series stating at 0.8 decreasing by 0.1. The shift in column B were loaded with the sequence 1, 4, 7, 10, 13, and 16. The values for which interpolation was to be

performed was the mean values of cells H10 and H11. Row 29 shows that the interpolations yielded the expected values (i.e., the mid-points of the data points being used for the interpolation).

Table II-7. Simple Test of the Interpolation Portion of the Template

	B	C	D	E	F	G	H
5	Shift	Period #	Years Irrigation	Mean	SD		Av Mean
6	1	1	0	1	0.8		3.7183
7	4	2	7	1.1	0.7		7.0042
8	7	3	16	1.2	0.6		10.3201
9	10	4	27	1.3	0.5		13.6693
10	13	5	43	1.4	0.4		17.0552
11	16	6	71	1.5	0.3		20.4817
12							
13							18.76844
14							
15							
16							
17		Late Time BDCF		Av Mean	Mean	SD	Shift
18							
19		18.76844		17.0552	1.4	0.4	13
20				20.4817	1.5	0.3	16
21							
22			Changes	3.4265	0.1000	-0.1000	3.0000
23							
24			Change per unit Av Mean		0.029184	-0.02918	0.875532
25							
26							
27			Change	1.7132	0.05	-0.05	1.5
28							
29			Estimated parameters	18.7684	1.4500	0.3500	14.5000

CONCLUSION

As further evidence that the integrated routine functions as expected is provided by Table II- 3, in Section 6.4. Here it was shown that the template when used with the actual BDCF data, gave over 13 of the 14 radionuclide data sets a maximum relative deviation of 5 percent or better. For nine of the examples, the maximum deviations were less than one percent. The sole exception was ²³⁰Th where the in-growth of decay products caused a larger deviation at late-times. The agreement, bearing in mind the stochastic source of the BDCFs, demonstrated the functionality of the methodology employed.

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