APPENDIX H

SUMMARY OF RECENT INFORMATION RELEVANT TO THE BIOSPHERE PROCESS MODEL

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1. INTRODUCTION

This white paper contains a summary of recent information relevant to the biosphere process model used to support the *Yucca Mountain Science and Engineering Report* (YMS&ER) (DOE 2001a) and the *Yucca Mountain Preliminary Site Suitability Evaluation* (YMPSSE) (DOE 2001b). The U.S. Department of Energy (DOE) released these two documents for public review in May and August, respectively, of this year.

The white paper focuses on the additional information that was developed or became available after the biosphere process model was completed to support preparation of the YMS&ER and the YMPSSE. The summary of this recent information is being used to conduct an impact review in accordance with AP-2.14Q, *Review of Technical Products and Data*, to determine if this additional information has any impact on the technical analyses supporting the YMS&ER (DOE 2001a) and the YMPSSE (DOE 2001b). The documentation of the additional information in this white paper is an interim step, and primarily used to support this impact review. This information is expected to be formally documented in subsequent Project technical reports, as appropriate.

To assist in the impact review, this white paper briefly describes the biosphere process model that was used to support the YMS&ER (DOE 2001a) and the YMPSSE (DOE 2001b), provides a summary of the additional information, and discusses the potential implications of this additional information on our understanding of the biosphere process model.

2. SUMMARY DESCRIPTION OF THE BIOSPHERE PROCESS MODEL

The biosphere is the last component in the chain of process models considered in the total system performance assessment (TSPA) of a repository at Yucca Mountain. Within the TSPA model, the biosphere can receive the radioactive contamination from two possible sources: (1) the biosphere is coupled to the saturated zone flow and transport model for the groundwater release exposure scenario; and (2) the biosphere is coupled to the volcanic dispersal model for the extrusive igneous event scenario.

Although the biosphere is generally perceived as a global feature comprising those parts of the earth's crust, waters, and atmosphere that support life, the biosphere process model for Yucca Mountain applies to the reference biosphere. The reference biosphere is limited in spatial extent, such that it includes all biosphere-related features, events, and processes (FEPs) pertinent to the Yucca Mountain region that are important from the perspective of dose assessment. The biosphere process model provides the means of evaluating radiation exposure to humans from radioactive material that might be released to this limited Yucca Mountain biosphere. The biosphere model includes both the characteristics of the hypothetical human receptor (hereafter referred to as the receptor), such as lifestyles, including dietary and activity habits, and those characteristics of the environment that are important to determine the radiation exposure.

The biosphere process model is constructed based on the conceptual model, its mathematical representation, and the implementing computer code, GENII-S V.1.4.8.5 (Leigh et al. 1993).

The model is used to evaluate radionuclide transfer through various pathways from the source of contamination to the receptor to develop an annual dose prediction for unit concentration of each radionuclide in groundwater and ash. The term "annual dose" is an abbreviation for the total effective dose equivalent (TEDE) resulting from annual exposure (i.e., the sum of the committed effective dose equivalent from internal doses resulting from one year's exposure to radioactive materials and the effective dose equivalent from external radiation exposure during the year). The values of annual dose for unit radionuclide concentrations are known as biosphere dose conversion factors (BDCFs). As the underlying processes are linear, the BDCF is a multiplying parameter, which represents the receptor's annual dose from either the biosphere release of groundwater containing a unit activity concentration of particular radionuclide or from unit activity concentration in the soil following deposition of volcanic ash. The biosphere dose conversion factor for a particular radionuclide is then multiplied by the actual radionuclide concentrations in groundwater (determined by the saturated zone flow and transport modeling component of the TSPA model) or in soil (determined by the disruptive event TSPA model component) to calculate the dose the receptor would receive.

An inherent part of the biosphere model that allows evaluation of the effects of the potential contaminant pathways and processes for the Yucca Mountain is the representation of the exposed population. In previous evaluations, the focus had been on the receptor known as the "average member of the critical group," introduced by the U.S. Nuclear Regulatory Commission (NRC) in their proposed rule for 10 CFR Part 63 (64 FR 8640). Some later calculations, supporting the Final Environmental Impact Statement, based on the reasonably maximally exposed individual (RMEI) concept in 40 CFR Part 197 were also considered. The most recent biosphere effort concerns the annual dose from releases from the repository to the RMEI. This receptor is specified in the final rule for 10 CFR Part 63 (66 FR 55732). The RMEI is a hypothetical receptor assumed to live in the accessible environment above the highest concentration of radionuclides in the plume of contamination, having a diet and living style representative of the people residing in the Town of Amargosa Valley, and drinking 2 L (0.53 gal) of water per day from the contaminated groundwater. This rural-residential RMEI is believed to be among the most highly exposed individuals downgradient from Yucca Mountain.

The more detailed description of the biosphere model can be found in the *Biosphere Process Model Report* (CRWMS M&O 2000), YMS&ER (DOE 2001a), YMPSSE (DOE 2001b), and *FY01 Supplemental Science and Performance Analyses* (BSC 2001a; BSC 2001b).

3. SUMMARY OF RECENT RESULTS AND ADDITIONAL INFORMATION

This section summarizes recent information relevant to enhancing our understanding of the biosphere process model. The additional information is listed below and discussed in each of the sections that follow.

1. The dietary and lifestyle characteristics of the receptor
2. Dosimetric model of the receptor.

3.1 THE DIETARY AND LIFESTYLE CHARACTERISTICS OF THE RECEPTOR

Lifestyle characteristics of the RMEI were consistent with the NRC regulations for specifying characteristics of the RMEI at 10 CFR 63.312 (66 FR 55732). Consistent with the preamble to 40 CFR 197, the RMEI is a representative of a rural-residential population group that is part of a community typical of Amargosa Valley, who might do personal gardening and earn income from other sources of work in the area. The dietary characteristics of the receptor were based on the population of the Town of Amargosa Valley. A study was conducted in 1997 to collect socioeconomic information for biosphere modeling. For this purpose, dietary and lifestyle data were collected on adults residing within the 80-km (50-mi) grid centered on Yucca Mountain. It was estimated that nearly 13,000 adults resided in the total study area at the time of the survey, with about 900 of them in the Amargosa Valley (DOE 1997, p. v). The total survey sample consisted of 1,079 responses, with the Amargosa Valley sample of 195.

Consistent with the final rule at 10 CFR 63.312(b) (66 FR 55732), the dietary characteristics of the RMEI were represented by the mean values for the Amargosa Valley residents. Lifestyle characteristics of the receptor were based on the 1990 Census. The following information was considered (Bureau of the Census 1999, Summary File 3A):

- Employment by industry for Amargosa Valley residents
- Travel time to work data to determine the percentage of residents who work within the community or who commute to jobs outside the Amargosa Valley area
- Data on hours worked per week
- Housing by type of structure.

In the year 2000, the U.S. Census Bureau conducted the most recent census concerning population and housing. According to the Census 2000 data products release schedule, the Summary File 3A, containing updated information equivalent to what was used to develop the receptor for the biosphere model, will not be available until the June to September 2002 timeframe.

3.2 DOSIMETRIC MODEL OF THE RECEPTOR

The model of the receptor includes a component dosimetric model that provides the means of converting the receptor's internal and external exposure to dose. In the biosphere process model, this conversion is accomplished by using dose coefficients based on the dosimetric approach recommended by the International Commission on Radiological Protection (ICRP) over 20 years ago (ICRP 1977). Although the ICRP has since updated its recommendations, the older approach is the basis for the assessment methodology required by the regulations, including the individual protection standard for the potential repository at Yucca Mountain (10 CFR 63.311 [66 FR 55732]).

The International Atomic Energy Agency (IAEA) recently conducted an international peer review of the biosphere modeling program for the potential repository at Yucca Mountain (IAEA 2001). The final report included a list of 37 specific recommendations and suggestions for improving the biosphere assessment capability while remaining focussed on satisfying the regulatory requirements. In one of these recommendations the review panel suggested that "[T]he implications of applying more modern dosimetric data should be tested, especially since this data is widely adopted internationally…" This section presents the summary of such evaluation.

3.2.1 Dosimetric Models Used in Biosphere Assessments

The individual protection standard for Yucca Mountain at 10 CFR 63.311 (66 FR 55732) is based on the dosimetric quantity called the TEDE. The TEDE is defined as the sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (CEDE) (for internal exposure) (10 CFR 63.2). Both of these quantities (i.e., the external dose component and the internal dose component) are determined by summing the products of organ doses and weighting factors applicable to each of the body organs or tissues that are irradiated.

The organ/tissue weighting factors as well as the conceptual approach used in the definition of CEDE were recommended by ICRP in Publication 26 (ICRP 1977). The tissue/organ weighting factors reflect the relative contribution of the organs to the specified health detriment (risk) when the entire body is uniformly irradiated. These factors are based on the data and biokinetic models available at the time ICRP Publication 26 (ICRP 1977) was issued.

The dosimetric methods used to calculate committed dose equivalents to the organs and tissues were outlined in ICRP Publication 30 (ICRP 1979; ICRP 1980; ICRP 1981). This methodology was used to develop sets of exposure-to-dose conversion factors, more commonly referred to as dose coefficients or dose conversion factors. The dose coefficient is one of the fundamental representations of a dosimetric model used in assessing potential radiation dose. Specifically, it allows an exposure to a radionuclide to be converted to a dose. The biokinetic models used to develop dose coefficients using ICRP-30 methods reflect the state of the knowledge at the time the coefficients were generated.

After the ICRP-30 methodology and associated weighting factors were incorporated into various federal radiation protection standards, the ICRP issued its updated recommendations in Publication 60 (ICRP 1991). The recommendations introduced a new dosimetric quantity, the effective dose. The effective dose considers an expanded list of tissues/organs and revised tissue/organ weighting factors. In computing the revised weighting factors, the ICRP made two fundamental changes. First, the application of the weighting factor was changed from consideration of absorbed dose at a point in the organ to consideration of absorbed dose averaged over the total organ (ICRP 1991, p. 5). Second, the concept of detriment (risk) was expanded (ICRP 1991, p. 13). Under this concept, detriment considers the risk of both fatal and nonfatal cancers, hereditary defects over all future generations, and the relative loss of life expectancy given the occurrence of a fatal cancer or severe genetic disorder (ICRP 1991, p. 23). (To date, the revised ICRP conceptual approach has not been incorporated into federal radiation protection standards.) The new methodology, combined with the updated biokinetic data and models, formed a foundation for development of a new set of age-dependent dose coefficients, which are summarized in ICRP Publication 72 (ICRP 1996).

As previously noted, the biosphere model is designed to provide the capability of comparing the receptor's annual doses with the individual protection standard. Therefore, it is based on the same assessment methodology as that required by the regulations, i.e., the conceptual approach recommended in ICRP 26 (ICRP 1977) and the dosimetric methods outlined in ICRP Publication 30 (ICRP 1979; ICRP 1980; ICRP 1981). As an alternative model and to evaluate the effect of the new dosimetric methods on the model outcome, the BDCFs were calculated using the ICRP 72 dose coefficients rather than the ICRP 30-based dose coefficients.

3.2.2 Development of the Biosphere Dose Conversion Factors Using ICRP-72 Dosimetric Methods

For the purpose of quantifying the magnitude of the potential impact of the revised ICRP dosimetric method (ICRP 1996) on previously calculated BDCFs for the RMEI, the ICRP 72-based BDCFs for the two exposure scenarios were calculated. These were (1) the BDCFs for the groundwater release scenario for the current climate and (2) the BDCF for the volcanic release exposure scenario, transition phase, assuming a 1-cm (0.4-in.) ash layer and annual average mass loading.

In order to accomplish this, pathway-specific ICRP-30-based BDCFs for the RMEI (MO0109SPABDC00.008) for each radionuclide of interest and for each model realization were converted to ICRP-72-based BDCFs. The dose coefficients for inhalation and ingestion were taken from the ICRP Publication 72 (ICRP 1996), while the ICRP-72-based dose coefficients for external exposure were taken from the DOE Office of Environmental Policy and Guidance Dose and Risk Resources Web Page (http://www.ornl.gov/~wlj/fgr12tab.htm). More detailed description of the calculation methods can be found in the Readme file accompanying the data tracking number MO0109SPABDC00.008.

The results of the BDCF calculations are presented in Table 1 for both dosimetric methods and for both exposure scenarios, together with the BDCF ratios. The BDCF ratio is equal to the ICRP 72-based BDCF for a radionuclide divided by the ICRP 30-based BDCF for that radionuclide. The application of the ICRP 72 dosimetric methods decreases the BDCFs for the majority of radionuclides for both the groundwater and the volcanic release scenarios. However, the overall effect on the annual expected dose from all radionuclides depends on the specific radionuclide contributions at different times and on the repository performance scenario under consideration, i.e., the nominal and the igneous disruption performance.

4. IMPLICATIONS OF ADDITIONAL INFORMATION

The additional information reported here was generated as an alternative model to the one used in the TSPA analyses to improve confidence in the biosphere model. This has been achieved by supplementing BDCF data sets for the RMEI that were originally based on ICRP Publication 30 models by a set based on the more recent dosimetric methods summarized in ICRP Publication 72. As noted by the International Peer Review (IAEA 2001, §S23), the more modern dosimetric data are widely adopted internationally through the IAEA Basic Safety Standards (IAEA 1996) and are considered more representative of current understanding than those used in existing regulations.

Table 1. ICRP 30- and ICRP 72-Based Biosphere Dose Conversion Factors for the RMEI

Radionuclide	Groundwater Release Scenario			Volcanic Release Scenario		
	Mean BDCF rem/y per pCi/L		BDCF Ratio	Mean BDCF rem/y per pCi/m^2		BDCF Ratio
	ICRP30	ICRP72	ICRP72/ICRP30	ICRP30	ICRP72	ICRP72/ICRP30
Carbon-14	2.88E-05	2.98E-05	1.04	N/A	N/A	N/A
Selenium-79	1.18E-05	1.49E-05	1.26	3.84E-11	5.26E-11	1.37
Strontium-90	1.96E-04	1.68E-04	0.85	4.25E-09	3.74E-09	0.88
Technetium-99	2.76E-06	2.94E-06	1.07	N/A	N/A	N/A
Iodine-129	2.54E-04	4.10E-04	1.62	N/A	N/A	N/A
Cesium-137	3.35E-04	3.22E-04	0.96	1.25E-09	1.25E-09	1.00
Lead-210	5.11E-03	2.34E-03	0.46	1.36E-08	1.03E-08	0.75
Radium-226	4.99E-03	4.56E-03	0.91	4.19E-09	1.20E-08	2.86
Actinium-227	1.28E-02	3.81E-03	0.30	1.90E-06	5.80E-07	0.31
Thorium-229	6.07E-03	3.30E-03	0.54	6.03E-07	2.50E-07	0.41
Thorium-230	1.23E-03	1.43E-03	1.17	9.06E-08	1.04E-07	1.15
Protactinium-231	1.61E-02	4.95E-03	0.31	3.76E-07	1.48E-07	0.39
Urnium-232	1.80E-03	1.66E-03	0.92	1.90E-07	4.06E-08	0.21
Uranium-233	2.85E-04	1.76E-04	0.62	3.84E-08	1.01E-08	0.26
Uranium-234	2.74E-04	1.65E-04	0.60	3.77E-08	1.00E-08	0.27
Uranium-236	2.60E-04	1.58E-04	0.61	N/A	N/A	N/A
Uranium-238	2.60E-04	1.62E-04	0.62	N/A	N/A	N/A
Neptunium-237	4.53E-03	3.74E-04	0.08	1.89E-07	5.33E-08	0.28
Plutonium-238	2.88E-03	8.53E-04	0.30	1.14E-07	1.11E-07	0.97
Plutonium-239	3.47E-03	1.16E-03	0.33	1.27E-07	1.23E-07	0.97
Plutonium-240	3.46E-03	1.15E-03	0.33	1.26E-07	1.23E-07	0.97
Plutonium-242	3.23E-03	1.13E-03	0.35	1.18E-07	1.26E-07	1.07
Americium-241	3.50E-03	9.08E-04	0.26	1.29E-07	1.00E-07	0.78
Americium-243	4.02E-03	1.35E-03	0.34	1.29E-07	1.00E-07	0.78

Source: MO0109SPABDC00.008.

The models used to generate the two BDCF sets utilized the same receptor and the same reference biosphere. Therefore, the differences in the numerical values of the BDCFs are totally due to the changes in the dosimetric approach. Consequently, there is no impact on the biosphere model because current regulations require that the approach consistent with ICRP Publication 30 be used as the basis for the assessment methods for demonstrating compliance with the individual protection standard. However, as the more recent ICRP-72 model provides an alternative and a more comprehensive dosimetric model, the new BDCFs should offer additional confidence in the regulatory compliance approach and TSPA calculations. It needs to be noted that the BDCF based on ICRP Publication 72 may not be used in any performance assessment for the purpose of demonstration of compliance with the individual protection standard.

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