February 23, 2017

Mr. Robert Compernolle
President, FMRI
FMRI, Inc.
Number 10 Tantalum Place
Muskogee, OK 74403

SUBJECT: NRC STAFF EVALUATION OF FMRI REVISED DERIVED CONCENTRATION GUIDELINE LEVELS (DCGLs)

Dear Mr. Compernolle:

In previous communications provided to the U. S. Nuclear Regulatory Commission (NRC), FMRI proposed revised Derived Concentration Guideline Level (DCGL) values for the Muskogee site. The revised values are a response to the deficiencies identified in the NRC's Safety Evaluation Report ("SER") on the July 24, 2003 Decommissioning Plan (Agencywide Documents Access and Management System ("ADAMS") Accession No. ML033250083).

On December 14, 2015, FMRI sent the NRC a DCGL submission[1] (ML15351A474). The NRC staff assessed the submission, found it unacceptable, and responded via letter dated January 19, 2016, (ML16013A020). FMRI then submitted a response on February 3, 2016, (ML16036A035). By letter dated March 30, 2016, (ML16069A084), NRC staff stated FMRI had not adequately addressed concerns described in the NRC 2003 SER. NRC staff stated that FMRI must consider existing groundwater contamination and include exposure through the groundwater pathway in the development of DCGLs. NRC staff also stated that FMRI should re-evaluate parameter values in the model used to develop DCGL values for soils and sediments given in the 2003 Decommissioning Plan (DP) to ensure they were justified in a scenario in which the groundwater pathway was included.

By letter dated June 10, 2016, (ML16166A041), FMRI submitted concentration limits (CLs) for groundwater and revised DCGL values for soils with a sensitivity analysis supporting those values. DCGLs for equipment and building surfaces had previously been approved by NRC (NRC, 2003) and were not revised.

On September 2, 2016, NRC sent FMRI a Request for Additional Information (RAI) (ML16236A383) regarding the DCGLs for soils and sediments proposed in the FMRI June 2016 submittal. The RAI had two questions. One requested that FMRI supply DCGL values for Elevated Measurement Comparisons ($DCGL_{EMC}$ values). The other questioned the basis for excluding certain parameters related to the groundwater pathway from the sensitivity analysis and requested that FMRI submit a revised sensitivity analysis. In that question, the NRC also asked that FMRI make any necessary changes to parameter values resulting from the revised sensitivity analysis, in accord with the NRC Consolidated Decommissioning Guidance (NUREG-

[1] Condition 5A of the August 17, 2015 Forbearance Agreement obligated FMRI to submit revised DCGL values for the Muskogee site to the NRC by December 31, 2015.

1757) in Volume 2, Revision 1, Appendix I, Section I.6.4. On October 26, 2016, FMRI responded with a revised sensitivity analysis and revised DCGL values for protactinium (Pa-231) and uranium isotopes (U-238+D, U-235+D, and U-234+D) (ML16305A337). FMRI also explained that $DCGL_{EMC}$ values would be supplied with the Final Status Survey Plan (FSSP).

In response to the above communications, the NRC staff find the criteria proposed for groundwater (ML16166A041) and surfaces of structures/equipment (ML16036A035) at the FMRI site to be adequate when applied in a sum-of-fractions approach, including all media remaining on site, such that the total potential exposure would remain below 25 mrem/y. The NRC staff reviewed the submittal of October 26, 2016, regarding DCGLs for soil and sediments and arrived at mixed conclusions. First, with regards to revision of the elevated area $DCGL_{EMC}$ values, the staff finds FMRI's response to address this issue when the FSSP is resubmitted to be acceptable. However, with regards to the second issue, the DCGLs applicable to soil and sediments, the NRC finds that the model established by FMRI to determine DCGLs for soil and sediments remains less than adequate for most radionuclides of interest. Specifically, staff finds the DCGL values for soils and sediments for Pa-231, U-234, U-235, and U-238 should be revised using site-specific data for the length parallel to the aquifer flow, well pump intake depth, saturated zone hydraulic conductivity, and saturated zone hydraulic gradient. NRC staff finds the soil and sediment DCGL values for Ra-226, Ra-228, Th-238, Th-230, and Th-232 should be revised based on a conservative or more site-specific value of the external gamma shielding factor. Finally, NRC staff finds the soil and sediment DCGL values for Pb-210 and Ac-227 proposed in the FMRI October 2016 submittal to be satisfactory. NRC staff will approve the entirety of the DCGLs, once all issues are resolved, by amendment of license SMB-911.

NRC staff's evaluation of FMRI's DCGLs as amended by the October 26, 2016, submittal is attached as an enclosure to this letter.

In accordance with 10 CFR 2.390 of the NRC's "Agency Rules of Practice and Procedure," a copy of this letter will be available electronically for public inspection in the NRC Public Document Room or from the Publicly Available Records component ADAMS. ADAMS is accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html.

Please contact Mr. Greg Chapman if you have any questions concerning the above. He can be reached at (301) 415-8718 or via e-mail at Gregory.Chapman@nrc.gov.

Sincerely,

/RA/

Theodore B. Smith, Acting Chief
Materials Decommissioning Branch
Division of Decommissioning, Uranium
Recovery, and Waste Programs
Office of Nuclear Material Safety
and Safeguards

Docket No. 40-7580
License No. SMB-911

Enclosure

cc: Molly Marsh, NRC/OGC
Pam Dizikes, Oklahoma Department of
Environmental Quality
Richard Gladstein, Department of Justice

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Please contact Mr. Greg Chapman if you have any questions concerning the above. He can be reached at (301) 415-8718 or via e-mail at Gregory.Chapman@nrc.gov.

Sincerely,

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Theodore B. Smith, Acting Chief
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Docket No. 40-7580
License No. SMB-911

Enclosure

cc: Molly Marsh, NRC/OGC
Pam Dizikes, Oklahoma Department of
Environmental Quality
Richard Gladstein, Department of Justice

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ML17018A294

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NRC Staff Evaluation Of FMRI DCGLs As Amended On October, 26 2016

1.0 Background and Scope

In 2003, FMRI submitted a Decommission Plan (DP) that proposed Derived Concentration Guideline Level (DCGL) values for the Muskogee site. NRC staff documented deficiencies in the DP in the NRC's 2003 Safety Evaluation Report (SER) (Agencywide Documents Access and Management System (ADAMS) Accession No. ML033250083). Specifically, the SER indicated that FMRI must consider potential doses from the consumption of groundwater. License Conditions (LCs) 35 and 37 of License SMB-911, Amendment 13 state the Licensee shall establish DCGLs as part of the Phase 3 workplan that was to be submitted by August 1, 2011. However, there have been significant delays and site decommissioning has not progressed to a point where a Phase 3 workplan has been submitted.[1]

On December 14, 2015, FMRI sent the NRC a DCGL submission (ML15351A474). The NRC staff assessed the submission, found it unacceptable, and responded via letter dated January 19, 2016 (ML16013A020). FMRI then submitted a response on February 3, 2016 (ML16036A035). By letter dated March 30, 2016 NRC staff stated FMRI had not adequately addressed concerns described in the NRC 2003 SER (ML16069A084). NRC staff stated that FMRI must consider existing groundwater contamination and include exposure through the groundwater pathway in the development of DCGLs. NRC staff also stated that FMRI should re-evaluate parameter values in the model used to develop DCGL values for soils and sediments given in the 2003 DP to ensure they were justified in a scenario in which the groundwater pathway was included.

By letter dated June 10, 2016, FMRI submitted concentration limits (CLs) for groundwater and revised DCGL values for soils with a sensitivity analysis supporting those values (ML16166A041). DCGLs for equipment and building surfaces had previously been approved by the NRC (NRC, 2003) and were not revised.

On September 2, 2016, NRC sent FMRI a Request for Additional Information (RAI) (ML16236A383) regarding the DCGLs for soils and sediments proposed in the FMRI June 2016 submittal. The RAI had two questions. One requested that FMRI supply DCGL values for Elevated Measurement Comparisons ($DCGL_{EMC}$ values). The other questioned the basis for excluding certain parameters related to the groundwater pathway from the sensitivity analysis and requested that FMRI submit a revised sensitivity analysis. In that question NRC also asked that FMRI make any necessary changes to parameter values resulting from the revised sensitivity analysis, in accord with the NRC Consolidated Decommissioning Guidance (NUREG-1757) in Volume 2, Revision 1, Appendix I, Section I.6.4. On October 26, 2016, FMRI responded with a revised sensitivity analysis and revised DCGL values for protactinium (Pa-231) and uranium isotopes (U-238+D, U-235+D, and U-234+D) (ML16305A337). FMRI also explained that $DCGL_{EMC}$ values would be supplied with the Final Status Survey (FSS).

Because certain aspects of the FMRI approach had previously been approved by the NRC in its 2003 SER (ML033250083) on the FMRI 2003 DP, the scope of this review is limited to changes in the DCGL values made in response the Forbearance Agreement and subsequent NRC

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[1] Subsequently, Condition 5A of the August 17, 2015 Forbearance Agreement obligated FMRI to submit revised DCGL values for the Muskogee site to the NRC by December 31, 2015. The Forbearance Agreement indicted that the revised values must address deficiencies identified in the NRC staff's 2003 SER.

communications related to that agreement, as well as a small number of other changes FMRI chose to make during the revision process. Thus, topics addressed in this review include the following:

(1) FMRI's compliance approach to considering potential exposures from groundwater, soils and sediments, and equipment buildings and surfaces;

(2) FMRI's development of CLs for groundwater;

(3) The RESRAD model used to develop DCGL values for soils and sediments in the June 10, 2016 submittal as revised in the October 26, 2016 submittal including the supporting sensitivity analysis; and

(4) The resulting DCGL values for soils and sediments.

2.0 <u>Compliance Approach</u>

In the NRC evaluations of the FMRI February and June 2016 submittals, NRC staff raised two concerns about the proposed FMRI compliance approach: (1) how FMRI would account for dose contributions from exposure to different media, and (2) development of $DCGL_{EMC}$ values.

To address the concern about accounting for dose contributions from multiple media, in the June 10, 2016 submittal FMRI stated:

> "FMRI shall remediate the site to residual radioactive levels to ensure that exposure to residual radiation in all media from applicable pathways will not result in a dose exceeding 25 mrem/yr, as specified in 10 CFR 21.1402. The residual radioactivity concentration for each media of groundwater, soils and sediments, and building and equipment surfaces will be remediated such that the sum of the sums-of-fractions does not exceed one."

FMRI also developed CLs applicable to groundwater to address existing groundwater contamination and to implement this approach (see Sections 2.1 and 3.2).

To address the concern about $DCGL_{EMC}$ values, FMRI stated that it would develop $DCGL_{EMC}$ values in the Final Status Survey (FSS) Plan. Specifically, in the October 26, 2016 submittal, FMRI stated:

> "The Forbearance Agreement of August 17, 2015 at conditions 5.A. and 5.B. distinguishes between revision of DCGLs and development of a Final Status Survey Plan. The MARSSIM makes an equivalent distinction by stating the development of DCGLs is outside its scope but provides specific guidance for development and application of the $DCGL_{EMC}$ for a final status survey. The $DCGL_{EMC}$ values are a modification of the DCGLs and thus cannot be determined until the DCGLs are established. FMRI recognizes revision of $DCGL_{EMC}$ values as a matter of the final status survey. FMRI will provide $DCGL_{EMC}$ values within the Final Status Survey Plan."

<u>2.1 Groundwater Concentration Limits</u>

Groundwater CLs proposed by FMRI in the June 2016 submittal (unmodified in the October

2016 submittal) are provided in Table 1. FMRI derived these values based on ingestion dose conversion factors in Federal Guidance Report (FGR) 11 and an assumed drinking water ingestion rate of 250 liters per year (L/yr). The drinking water ingestion rate is based on an assumption of 2 L per day drinking water ingestion, 250 days per year occupancy of the site, and half the total drinking water per day coming from onsite. Because each proposed CL would individually result in a projected 25 mrem/yr dose, FMRI stated that the CLs would be applied such that the sum-of-fractions did not exceed one.

Table 1. Groundwater concentrations that each result in a projected dose of 25 mrem/yr from drinking water ingestion.

Radionuclide and Progeny	**Concentration Limit (pCi/L)**
U-238 (Th-234, Pa-234m, Pa-234)	372
U-234	353
U-235 (Th-231)	375
Pa-231	9.43
Ac-227 (Th-227 to stable Pb-207)	6.76
Th-232	36.6
Th-230	182
Th-228 (Ra-224 to stable Pb-208)	124
Ra-226 (Rn-222 to Po-210)	75.2
Ra-228 (Ac-228)	69.4
Pb-210 (Bi-201 to stable Pb-206)	18.6

2.2 Equipment and Building Surface DCGLs

DGCL values for equipment and building surfaces are shown in Table 2. These DCGL values were not revised from the values provided in the 2003 DP. As explained in the NRC 2003 SER, these values were found to be acceptable to NRC staff as long as FMRI remediates equipment and building surfaces to have a removable fraction not exceeding 0.03. This constraint on the removable fraction of contamination was incorporated as a license condition.

Table 2. Equipment and building surface DCGL values that each result in a projected dose of 25 mrem/yr as provided in the FMRI 2003 DP (unchanged in the June and October 2016 submittals).

Radionuclide and Progeny	DCGL (dpm/100 cm^2)
U-238 (Th-234, Pa-234m, Pa-234)	58,140
U-234	54,349
U-235 (Th-231)	48,076
Pa-231	4,032
Ac-227 (Th-227 to stable Pb-207)	1,087
Th-232	4,545
Th-230	22,727
Th-228 (Ra-224 to stable Pb-208)	15,625
Ra-226 (Rn-222 to Po-210)	20,833
Ra-228 (Ac-228)	31,646
Pb-210 (Bi-201 to stable Pb-206)	15,625

2.3 Soil and Sediment DCGLs

Revised DCGL values for soils and sediments submitted by FMRI are shown in Table 3. To develop the revised DCGL values for soils and sediments, FMRI began with the RESRAD (Version 6.21) model it used to develop DCGL values for soils and sediments for the 2003 DP. As in the 2003 DP, FMRI used the ingestion and inhalation dose conversion factors in FGR 11 and external exposure dose conversion factors in FGR 12. In the June 2016 submittal, FMRI explained that during development of the FMRI response to the technical concerns NRC described in its March 2016 letter, FMRI determined it had inadequate justification for several parameter values. FMRI revised these parameters and provided justification for the revised values (see Table 4).

In the NRC September 2016 RAI, NRC staff questioned the FMRI basis for excluding certain parameters related to the groundwater pathway from its sensitivity analysis. NRC staff cited the NRC Consolidated Decommissioning Guidance (NUREG-1757, Volume 2, Revision 1, Appendix I) indicating that for parameters to which the projected dose is sensitive, FMRI should choose site-specific values or, if site specific values were not available, conservative percentiles of distributions instead of mean or median values of generic distributions. In its October 2016 submittal, FMRI revised several parameter values to reflect site-specific soil types. In addition, FMRI revised two parameter values (i.e., sorption coefficients (K_d values) for Pa-231 and uranium isotopes) to select more conservative values based on a revised sensitivity analysis that showed the peak projected dose was sensitive to those values. Table 4 provides the changes to parameter values made since the 2003 DP with the bases supplied by FMRI in the June 2016 and October 2016 submittals.

Table 3. Soil and sediment DCGL values proposed in the FMRI 2003 DP, June 10, 2016 submittal, and October 26, 2016 submittal. Each is based on a dose of 25 mrem/yr individually.

Radionuclide (progeny included in DCGL)	2003 (pCi/g)	June 2016 (pCi/g)	October 2016 (pCi/g)
U-238 (Th-234, Pa-234m, Pa-234)	967	1058	61.0
U-234	7915	2880	58.1
U-235 (Th-231)	211	285	59.9
Pa-231	251	34.2	4.2
Ac-227 (Th-227 to stable Pb-207)	54.6	39.0	39.0
Th-232	255	13.8	13.8
Th-230	3,300	59.0	58.8
Th-228 (Ra-224 to stable Pb-208)	19.2	27.5	27.5
Ra-226 (Rn-222 to Po-210)	14.7	21.2	21.3
Ra-228 (Ac-228)	22.8	24.5	24.5
Pb-210 (Bi-201 to stable Pb-206)	799	780	780

Table 4. Changes made to parameter values used in the RESRAD model supporting development of DCGL values for soils and sediments since the 2003 DP

Parameter	2003 DP value	June 2016 Value	June 2016 Basis	October 2016 Value	October 2016 Basis
Exposure Pathways and Biosphere parameters					
Exposure pathways	Groundwater ingestion not included	Groundwater ingestion included	Required by NRC	No change from June 2016	
Drinking water ingestion rate (L/yr)	Not used (pathway not included)	250	Based on 2 L/day ingestion, 250 days/year occupancy, half of daily intake on site	No change from June 2016	
Inhalation rate (m^3/yr)	11400	8400	NUREG/CR-6697 “most likely” value	No change from June 2016	
Mass loading for inhalation (g/m^3)	0.0001	0.00023	Basis given as median from NUREG/CR-6697 for PM_{10}, however, value appears to be overestimated (see Section 3.4.2)	No change from June 2016	
Indoor dust filtration factor (unitless)	0.4	0.58	Estimated from NUREG/CR-6697 for daytime PM_{10}	No change from June 2016	
External gamma shielding factor (unitless)	0.552	0.27	Basis give as NUREG/CR-6697 mean value but actually corresponds to median value	No change from June 2016	
Precipitation (m/yr)	1.1	1.19	Estimate for	No change from June 2016	

2003 DP value	June 2016 Value	June 2016 Basis	October 2016 Value	October 2016 Basis
		Muskogee county[3]		
4.52	3.2	Estimate for Muskogee county[4]	No change from June 2016	
18.25	18.3	NUREG/CR-6697 "most likely" value	No change from June 2016	
25	1	Reflects annual dose limit (does not affect DCGL values)	No change from June 2016	
Characteristics				
1.51	1.52	NUREG/CR-6697 mean for generic soil	1.67	NUREG/CR-6697 average of means for sandy clay and silty clay
0.44	0.425	NUREG/CR-6697 mean for generic soil	0.37	NUREG/CR-6697 average of means for sandy clay and silty clay
0.27	0.20	RESRAD Default	0.38	NUREG/CR-6697 average of means for sandy clay and silty clay
5500	9.9	NUREG/CR-6697 mean for generic soil	0.94	NUREG/CR-6697 average of means for sandy clay and silty clay
4.05	2.9	NUREG/CR-6697 mean for generic soil	8.25	NUREG/CR-6697 average of means for sandy clay and silty clay

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Parameter	2003 DP value	June 2016 Value	June 2016 Basis	October 2016 Value	October 2016 Basis
Evapotranspiration coefficient (unitless)	0.99	0.625	Estimate for Muskogee County[6]	No change from June 2016	
Runoff coefficient (unitless)	0.4	0.4	NUREG/CR-6697 value for open sandy loam	No change from June 2016	
Soil-to-water partitioning coefficients (K_d values)	See Table 5	See Table 5	NUREG/CR-6697 geometric means of generic distributions	See Table 5	NUREG/CR-6697 25th percentile values used for protactinium and uranium based on sensitivity analysis results
Unsaturated Zone Characteristics					
Thickness (m)	Not used	4	RESRAD default [7]	2.75	DP Section 3.5.2 thickness of unconsolidated soils minus thickness of saturated soil minus thickness of contaminated zone
Density (g/cm^3)	Not used	1.52	NUREG/CR-6697 mean for generic soil	1.67	NUREG/CR-6697 average of means for sandy clay and silty clay
Total Porosity (unitless)	Not used	0.425	NUREG/CR-6697 mean for generic soil	0.37	NUREG/CR-6697 average of means for sandy clay and silty clay
Effective Porosity (unitless)	Not used	0.355	NUREG/CR-6697 mean for generic soil	0.29	NUREG/CR-6697 average of means for

[6] Sanford, W.E., and Selnick, D.L. (2013) Estimation of Evapotranspiration Across the Conterminous United States Using a Regression with Climate and Land-cover Data. JAWRA Journal of the American Water Resources Association, 49:217-230.
[7] Yu, C., et al. (2001) User's Manual for RESRAD Version 6. Argonne National Laboratory. ANL/EAD-4. July 2001.

Parameter	2003 DP value	June 2016 Value	June 2016 Basis	October 2016 Value	October 2016 Basis
					sandy clay and silty clay
Field capacity (unitless)	Not used	0.2	RESRAD Default	0.38	NUREG/CR-6697 average of means for sandy clay and silty clay
Hydraulic conductivity (m/yr)	Not used	9.9	NUREG/CR-6697 mean for generic soil	0.94	NUREG/CR-6697 average of means for sandy clay and silty clay
b parameter (unitless)	Not used	2.9	NUREG/CR-6697 mean for generic soil	8.25	NUREG/CR-6697 average of means for sandy clay and silty clay
Soil-to-water partitioning coefficients (K_d values)	Not used	See Table 5	NUREG/CR-6697 geometric means of generic distributions	See Table 5	NUREG/CR-6697 25th percentile values used for protactinium and uranium based on sensitivity analysis results
Saturated Zone Characteristics					
Length parallel to aquifer flow (m)	275 (not used in model)	239	Basis given as diameter of circular contaminated zone but value corresponds to the radius of an assumed circular 1.8 x 10^5 m^2 area (see Section 3.4.2)	No change from June 2016	
Well pump intake depth (m)	Not used	6.5 m	Site-specific information, assumed equal to average depth of unconsolidated sediments	No change from June 2016	

Parameter	2003 DP value	June 2016 Value	June 2016 Basis	October 2016 Value	October 2016 Basis
Density (g/cm^3)	Not used	1.52	NUREG/CR-6697 mean for generic soil	1.51	NUREG/CR-6697 mean for sand
Porosity (unitless)	Not used	0.425	NUREG/CR-6697 mean for generic soil	0.43	NUREG/CR-6697 mean for sand
Field capacity (unitless)	Not used	0.2	RESRAD Default	0.1	RESRAD Data Collection Handbook value for sand
Hydraulic conductivity (m/yr)	Not used	9.9	NUREG/CR-6697 mean for generic soil	2506	NUREG/CR-6697 median for sand
Hydraulic gradient (unitless)	Not used	0.21	NUREG/CR-6697 national average	0.27	NUREG/CR-6697 mean for sand and gravel
Soil-to-water partitioning coefficients (K_d values)	Not used	See Table 5	NUREG/CR-6697 geometric means of generic distributions	See Table 5	NUREG/CR-6697 25th percentile values used for protactinium and uranium based on sensitivity analysis results

Table 5. Soil-to-water sorption coefficients (K_d values) used in the 2003 Decommissioning Plan (contaminated zone only), June 10, 2016, and October 26, 2016 submittals (contaminated zone, unsaturated zone, and saturated zone)

Element	2003 DP (mL/g)	June 2016 (mL/g)	October 2016 (mL/g)
U	2.18	126	15[a]
Th	119	5884	5884
Ra	3530	3533	3533
Pb	2380	2392	2392
Pa	4.8	380	43[b]
Ac	1739	825	825

[a] Initially 126 mL/g, changed to 15 mL/g based on sensitivity analysis
[b] Initially 380 mL/g, changed to 43 mL/g based on sensitivity analysis

2.4 Sensitivity Analyses

FMRI included many parameters relevant to the groundwater pathway in its sensitivity analysis included with the June 2016 FMRI submittal. In that analysis, FMRI used the generic distributions in NUREG/CR-6697 to develop ranges for sensitivity analyses. FMRI found that the uncertainty in the parameters it considered did not have a significant effect on DCGL values. In its September 2016 letter, NRC staff questioned the bases for excluding the following parameters relevant to the groundwater pathway from the sensitivity analysis: unsaturated zone thickness, unsaturated zone density, unsaturated zone total porosity, unsaturated zone effective porosity, unsaturated zone hydraulic conductivity, the unsaturated zone b parameter, water table drop rate, well pump intake depth, well pumping rate, and K_d values.

In its October 2016 letter, FMRI responded with a revised sensitivity analysis that included all of these parameters except the water table drop rate and well pumping rate. The water table drop rate was excluded on the basis that it reflected site conditions of an unsaturated aquifer. The basis for excluding the well pumping rate was given as "see well pump intake depth (previous)." The meaning of this basis for excluding the well pumping rate from the sensitivity analysis was unclear because the well pump intake depth was included in the sensitivity analysis.

FMRI based the October 2016 sensitivity analysis on changes to the total projected peak dose instead of changes to DCGL values. To calculate the projected peak dose, FMRI developed a source term based on the DCGLs developed in the June 2016 submittal. Specifically, FMRI assigned a concentration of 1 pCi/g to Th-232, and then assigned the concentrations of the remaining radionuclides in proportion to the DCGLs developed in the June 2016 submittal. FMRI then reduced the concentrations of U-234 and U-235 to their naturally-occurring proportion with U-238. FMRI modeled the dose from this source term with the parameter values for the October 2016 submittal as shown in Tables 4 and 5, except that the sorption coefficient (K_d) values for Pa-231 and uranium isotopes reflected the June 2016 values (See Table 5 footnotes). The text of the October 2016 submittal indicates that the peak projected dose based on this source term was 15 mrem/yr, whereas Table 6 of the FMRI October 2016 submittal indicates that the peak projected dose is 13 mrem/yr. NRC staff replicated this analysis and found a peak projected dose of 13 mrem/yr.

The bases for the ranges of parameter values tested are provided in Table 6. FMRI tested the sensitivity of the projected dose to these parameters by varying the values one at a time. FMRI determined that the projected dose was sensitive to the parameter if the peak dose when the parameter was changed exceeded 25 mrem/yr (i.e., reflecting an increase of a factor of 1.9 or more as compared to 13 mrem/yr).

Table 6. Parameters included in the FMRI October 26, 2016 sensitivity analysis and the bases for the parameter ranges used

Parameter	**Basis for Range Used in Sensitivity Analysis**
K_d values for all elements	Basis provided as the 25th and 75th percentile values from NUREG-1757.[a] NRC staff determined the values corresponded to the 25th and 75th percentiles from the radionuclide-specific distributions for generic soils in NUREG/CR-6697.
Contaminated zone density, porosity, hydraulic conductivity, and b parameter	Basis provided as the 25th and 75th percentile values from a distribution formed by averaging distributions for sandy clay and silty clay from NUREG-1757.[a] NRC staff determined the values used were generally consistent with the appropriate ranges from NUREG/CR-6697. [b]
Unsaturated zone density, porosity, effective porosity, hydraulic conductivity, and b parameter	Basis provided as the 25th and 75th percentile values from a distribution formed by averaging distributions for sandy clay and silty clay from NUREG-1757.[a] NRC staff determined the values used were generally consistent with the appropriate ranges from NUREG/CR-6697. [b]
Saturated zone density, porosity, effective porosity, and hydraulic conductivity	Basis provided as the 25th and 75th percentile values from NUREG-1757.[a] NRC staff determined the values corresponded to the 25th and 75th percentiles for sand NUREG/CR-6697.
Saturated zone hydraulic gradient	Basis provided as the 25th and 75th percentile values from NUREG-1757.[a] The values do not appear to correspond to distributions provided in NUREG/CR-6697 (see Section 3.4.3.3)
Well pump intake depth, thickness of contaminated zone, thickness of unsaturated zone	Site-specific expected variation
evapotranspiration coefficient	Basis given as "a maximum expected variation" with the reference given as NUREG-1757.[a] NRC staff determined the values corresponded to the 24th and 100th percentiles for distribution given in NUREG/CR-6697.
wind speed, precipitation, drinking water intake	Basis given as "a maximum expected variation" without a reference given
inhalation rate, field capacity of the saturated, unsaturated, and contaminated zones	Basis given as "an expected variation" without a reference given

Parameter	**Basis for Range Used in Sensitivity Analysis**
external gamma shielding factor	Basis given as "an expected variation" with the reference given as NUREG/CR-6697. NRC staff confirmed the values correspond to the 25th and 75th percentiles of the distribution in NUREG/CR-6697.
mass loading for inhalation	Basis given as "an expected variation" without a reference given. The deterministic value chosen and the lower end of the range tested is greater than the 100th percentile value in the distribution in NUREG/CR-6697 (see Sections 3.4.2 and 3.4.3.3).
Runoff coefficient, indoor dust filtration factor, soil ingestion, depth of soil mixing layer	Basis given as "a maximum expected variation" with the reference given as NUREG/CR-6697. NRC staff determined the values used did not reflect the maximum extent of the ranges given in NUREG/CR-6697 but did reflect significant variation within those ranges (see Section 3.4.3.3).
Length parallel to aquifer flow, contaminated zone erosion rate	Arbitrary order of magnitude variation

[a] Although NUREG-1757 provides decommissioning guidance, it does not provide parameter ranges.
[b] NRC staff used the distributions for silty clay and sandy clay from NUREG/CR-6697 to calculate corresponding percentiles of the ranges FMRI used (see Section 3.4.3.3).

3.0 NRC Evaluation

3.1 Compliance Approach

NRC staff finds the sum-of fractions approach to applying the groundwater concentration limits and DCGL values to be acceptable. The FMRI commitment to ensure the final sum of the individual sums-of-fractions for groundwater, soils and sediments, and equipment and building surfaces does not exceed one is acceptable because, if applied correctly, it will ensure the regulatory requirement is met.

In the June 2016 submittal, FMRI submitted revised DCGL values for soils and sediments; however, it did not submit revised $DCGL_{EMC}$ values. In response to the NRC RAI requesting revised $DCGL_{EMC}$ values, FMRI indicated that it would develop $DCGL_{EMC}$ values during the Final Status Survey. NRC staff finds this approach to be acceptable because MARSSIM provides guidance for developing $DCGL_{EMC}$ values as part of the development of the Final Status Survey.

3.2 Groundwater Concentration Limits

NRC staff verified the ingestion dose conversion factors from FGR 11 that FMRI used to develop the concentration limits for groundwater. NRC staff replicated the CL values in Table 1 based on an assumed drinking water ingestion rate of 250 L/yr. NRC staff replicated the drinking water ingestion rate based on assumptions of 2 L/day total water ingestion, 250 days/yr site occupancy, and half of daily water intake from onsite sources. NRC staff found these assumptions to be appropriate based on an industrial worker scenario. NRC staff found the industrial worker scenario to be appropriate in its 2003 SER (NRC, 2003). The total water

consumption of 2 liters/day is a reasonably conservative value consistent with NRC guidance (NRC, 1977). FMRI chose the fraction of the on-site water that is contaminated to be 1, which is the most conservative value. Because the CL values were based on assumptions that were consistent with the critical group and a reasonably conservative value for the total water intake of 2 liters per day, NRC staff finds the values of the CLs to be acceptable.

Because each proposed CL would individually result in a projected 25 mrem/yr dose, FMRI stated that the CLs would be applied such that the sum-of-fractions did not exceed unity. NRC staff finds this approach to be acceptable because, if applied with a sum-of-fractions for all media, as described in Section 3.1, it will ensure the regulatory dose requirement is met.

3.3 Equipment and Building Surface DCGLs

Neither the DCGL values for equipment and building surfaces (Table 2) nor the corresponding $DCGL_{EMC}$ values for equipment and building surfaces were changed from the values provided in the 2003 DP. In the 2003 SER (NRC, 2003), NRC staff found those DCGL and $DCGL_{EMC}$ values to be acceptable provided that FMRI remediated the equipment and building surfaces to have a removable fraction of contamination not exceeding 0.03. This stipulation was included as a license condition and is still applicable. NRC staff finds the approach of using the DCGL values from the 2003 DP acceptable because (1) concerns staff had with the DCGL values in the 2003 SER were addressed in license conditions and (2) the potential dose from ingestion of contaminated groundwater is addressed by FMRI's commitment to applying the CLs for groundwater and DCGL values for soils and sediments and equipment building surfaces with a sum-of-fractions approach.

3.4 Soil and Sediment DCGLs

3.4.1 Approach to DCGL Calculation

FMRI used a RESRAD (Version 6.21) model to calculate DCGL values for soils and sediments. NRC used the input values in the FMRI June 2016 submittal to replicate the revised DCGL values for soil and sediments in that submittal using two different versions of RESRAD. Staff replicated all of the DCGL values except that for U-238 with associated progeny (U-238 + D) using RESRAD (Version 7.0). Staff replicated the value for U-238 + D with RESRAD (Version 6.5). RESRAD 6.5, like RESRAD 6.21 (used by FMRI) uses decay chains based on ICRP 38 (ICRP, 1983), whereas RESRAD 7.0 uses decay chains based on ICRP 107 (ICRP, 2008). NRC staff confirmed that the difference between the DCGL values for U-238 + D generated by RESRAD 6.5 and RESRAD 7.0 using the same input file occurred because of differences in the projected ingrowth of Pa-234 based on differences between these two ICRP references for decay data. NRC staff finds the FMRI use of RESRAD 6.21 acceptable because licensees are not required to use the decay data from ICRP 107. Furthermore, in this case, using the decay data from ICRP 38 yielded a lower DCGL value for U-238 + D. NRC staff used the input values in the FMRI October 2016 submittal with RESRAD (Version 6.5) to replicate the revised DCGL values for soil and sediments in that submittal. NRC staff replicated the DCGL values proposed in the October 2016 submittal using the parameter values in that submittal with RESRAD Version 6.5.

FMRI based the DGCL values on the time of the peak dose from each individual radionuclide. In the October submittal, the peaks for Ac-227, Pb-210, and Th-228 occurred at zero years after site release and the peaks for Pa-231, Ra-226, Ra-228, Th-230, Th-232, and the uranium isotopes occurred at times ranging from 2 to 1000 years after site release. NRC staff finds this

approach acceptable because basing the DCGL value for a radionuclide on the time of the maximum projected dose for that radionuclide results in more conservative (i.e., lower) DCGL values than basing the DCGL values on the time of the peak projected dose from all radionuclides.

3.4.2 Parameter Values

FMRI revised the RESRAD model it used to derive DCGL values for soils and sediments in the 2003 DP to include the groundwater pathway. To include the groundwater pathway, FMRI had to develop values for parameters that were not used in the 2003 model (e.g., unsaturated zone and aquifer properties) and revise others (e.g., K_d values). FMRI submitted that revised model in June 2016, and NRC questioned the bases for some of parameters in a September 2016 RAI. FMRI submitted a response to that RAI with revised parameter values in October 2016. This section provides the NRC evaluation of the parameter values as they were after any changes made in the FMRI September 2016 response (see Table 4).

In the June 2016 submittal, FMRI established values for several parameters related to the drinking water pathway that were not used in the model supporting the 2003 DP. For the drinking water intake rate, FMRI assumed an individual would drink 2 liters of water per day, for an average of 250 days per year, and would consume approximately half of their daily water intake on site. NRC staff finds the number of days per year and the fraction of water consumed on site to be consistent with the industrial worker critical group. The total water consumption of 2 liters/day is a reasonably conservative value consistent with NRC guidance (NRC, 1977). FMRI chose the fraction of the on-site water that is contaminated to be 1, which is the most conservative value. Because the value is based on assumptions that are consistent with the definition of the critical group and are based on a reasonably conservative value for total water consumption, NRC staff finds the value of the drinking water intake rate to be acceptable.

In the June submittal (unchanged in the October submittal), FMRI selected a non-dispersion instead of a mass-balance model for the groundwater pathway. In general, the non-dispersion model allows more dilution than the mass balance model; however, the amount of dilution is small if the contaminated area is much larger than the well capture area. Details of each approach are provided in NRC Consolidated Decommissioning Guidance Volume 2, Appendix I, Section I.4.3.2.1.2. As described in that guidance, the capture area can be estimated from the following equation:

$$A_w = \frac{U_w}{I}$$

Where A_w is the well capture area, U_w is the well pumping rate and I is the infiltration rate.

FMRI assumed a well pumping rate of 250 m^3/yr. Although the well pumping rate for a potential future industrial land use scenario is unknown, the value of 250 m^3/yr is a minimal value consistent with the use of the well for drinking water. Use of a larger pumping rate would increase the well capture area and increase dilution. Therefore, use of this minimal value is acceptable to NRC because it is a conservative choice. For a site without irrigation, like the FMRI site, the infiltration rate is given by

$$I = precipitation\ rate \cdot (1 - evapotranspiration\ coefficient) \cdot (1 - runoff\ coefficient)$$

Using the precipitation rate, evapotranspiration coefficient, and runoff coefficient selected by FMRI (see Table 4), the modeled infiltration rate is 0.169 m/yr. Based on this infiltration rate

and the FMRI estimated well pumping rate of 250 m^3/yr, the estimated well capture area is 1480 m^2. This value is significantly smaller than the estimated contaminated area of 1.8 x 10^5 m^2, which implies that the non-dispersion model should be acceptable. Therefore, NRC staff finds the FMRI choice of the non-dispersion model to be acceptable because it is consistent with the size of the contaminated area and NRC guidance.

The estimate of the well capture area relies on the precipitation rate, evapotranspiration coefficient, and runoff coefficient. In the June 2016 submittal (unchanged in the October submittal), FMRI used mean data for Muskogee County for the precipitation rate and evapotranspiration coefficient. NRC staff verified those values and determined they are acceptable because they are consistent with site-specific conditions. For the runoff coefficient, FMRI referenced NUREG/CR-6697. Based on the site description and soil type information in the 2003 DP, NRC staff used the coefficients in NUREG/CR-6697 Table 4.2-1 for rolling woodlands (uncultivated land) with a mixture of clay and loam soils and derived a runoff coefficient of 0.4, consistent with the FMRI value. Therefore, NRC staff finds the FMRI value of the runoff coefficient to be acceptable.

In the June and October submittals, FMRI also noted site-specific reasons in setting the water table drop rate to zero, indicating that the value was chosen to “recognize unconfined groundwater system.” Since the water table drop rate quantifies the rate at which the water table is lowered, having an unconfined groundwater system would not mean that the water table drop rate must be zero. FMRI may have meant to indicate that there was site-specific data that the particular groundwater system at the site has zero water table drop. Since the meaning of the basis was unclear, NRC staff tested the sensitivity of the DCGL values to the water table drop rate and found that the choice of a zero water table drop is conservative. Therefore, NRC staff finds the value of zero for the water table drop rate to be acceptable.

FMRI changed several hydraulic parameters for the contaminated and unsaturated zones between the June and October submittals by using generic distributions for site-specific soil types. These parameters included the density, porosity, hydraulic conductivity, and b parameter of the contaminated and unsaturated zones, as well as the effective porosity of the unsaturated zone. For these parameters, FMRI indicated that it used the average of the means of the distributions for sandy clay and silty clay in NUREG/CR-6697. For the density, porosity, and effective porosity, NUREG/CR-6697 recommends normal distributions. NRC staff verified that FMRI used the means of the distributions recommended for silty clay and for sandy clay for these parameters. For the b-parameter and the hydraulic conductivity, NUREG/CR-6697 recommends lognormal distributions. NRC staff verified that FMRI used the average of the exponentials of the underlying means (i.e., the parameter value was set equal to the average of $e^{\text{mean sandy clay}}$ and $e^{\text{mean silty clay}}$). Using independent sensitivity analyses, NRC staff determined that the DCGL values were not sensitive to these parameters. Because of this insensitivity, it was acceptable to use distribution means (i.e., instead of conservative percentiles). NRC staff also determined the use of distributions for silty clay and sandy clay was consistent with site-specific information about soil types on the site in the FMRI 2003 DP. Therefore, NRC staff finds these parameter values to be acceptable.

For the field capacity of the contaminated and unsaturated zones, FMRI referenced the RESRAD Data Collection Handbook (Yu et al., 2015). NRC staff verified that FMRI used the recommended value for silty clay loam. NRC staff finds the use of this parameter value to be acceptable because it reflects the site-specific soil type for the contaminated and unsaturated zones. In an independent sensitivity analysis, NRC staff also determined that the DCGL values were not sensitive to the field capacity for the contaminated and unsaturated zones.

In the June 2016 submittal, FMRI had to establish values for parameters related to saturated zone that were not used in the model supporting the 2003 DP. Several of these were subsequently changed between the June and October submittals. Two that remained the same were the length parallel to aquifer flow and the well pump intake depth.

In the June 2016 submittal, FMRI stated that the length parallel to aquifer flow was changed to equal the diameter of a circle with the same area as the site. However, the value chosen appears to represent the radius of a circle with the same area of the site rather than the diameter:

$$\sqrt{\frac{1.8\ \times\ 10^5\ m^2}{\pi}} = 239\ m$$

The diameter of a circle with an area equal to the site area (1.8 x 10^5 m^2) would be equal to 479 m. Based on Figure 3-8 from the FMRI 2003 DP, a value of 479 m appears to be representative of the length parallel to the direction of groundwater flow from the groundwater divide to the western edge of the site, and therefore appears to be a more appropriate value for this parameter. FMRI did not find any sensitivity of dose to this parameter. However, because of concerns about the FMRI sensitivity analysis, NRC staff tested the effect of using this value for the length parallel to aquifer flow on the DCGL values. NRC staff found that using a value of 479 m reduced the DCGL values for Pa-231 and the uranium isotopes by 30 percent, and had no effect on the DCGL values for other radionuclides. Therefore, NRC staff does not find the justification for the length parallel to the aquifer flow to be adequate because it appears to be based on an arithmetical error and it is inconsistent with known information about the site. Furthermore, using a value more representative of the site would result in lower DCGL values for Pa-231 and the uranium isotopes. For these reasons, NRC staff does not find the value of this parameter to be acceptable.

In the June submittal, FMRI set the well pump intake depth to 6.5 m (21.3 feet) and stated that the value was based on the thickness of the unconsolidated sediments. Because the well pump intake depth is used in the model to determine the depth over which a contaminant is mixed in the aquifer, the saturated thickness of the unconsolidated sediments[8] would be more appropriate than the total thickness. FMRI did not find any sensitivity of dose to this parameter in its sensitivity analysis. However, because of concerns about the FMRI sensitivity analysis (see Section 3.4.3.2), NRC staff tested the sensitivity of the DCGL values to this parameter.

Section 3.7.2 of the 2003 FMRI DP states that the thickness of the saturated unconsolidated sediments on site ranges from 0.46 to 5.33 m (1.5 to 17.5 feet). The DP does not provide an average thickness of the saturated unconsolidated sediments. Therefore, to estimate the potential effect, NRC staff evaluated the effect of changing the well pump intake depth to equal the simple average of the ends of the range 0.46 to 5.33 m (i.e., 2.90 m (9.5 feet)). NRC staff found the change caused a decrease of 55 percent in the DCGL values for Pa-231 and the uranium isotopes. Therefore, NRC staff does not find the justification for well pump intake depth to be adequate because it uses the total depth of the unconsolidated sediments instead of the saturated thickness of the unconsolidated sediments, and the more appropriate site-specific

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[8] Although there is a layer of saturated fractured bedrock at the site, Section 3.7.2 of the 2003 FMRI DP indicates that it is a confined aquifer that is separated from the saturated consolidated sediments. Since contaminants would not be expected to mix significantly over the saturated fractured bedrock, the most appropriate well pump intake depth would be the saturated thickness of the unconsolidated sediments.

values would result in lower DCGL values for Pa-231 and the uranium isotopes.

FMRI changed several parameters for the saturated zone between the June and October submittals by using the means of generic distributions for sand. These parameters included the density, porosity, and effective porosity. For these parameters, NUREG/CR-6697 recommends normal distributions for various soil types. NRC staff verified that FMRI used the means of the NUREG/CR-6697 parameter distributions for sand. Using independent sensitivity analyses, NRC staff determined that the DCGL values were not sensitive to these parameters. Because of this insensitivity, it was acceptable to use distribution means (i.e., instead of conservative quartiles). NRC staff also determined the use of distributions for sand was consistent with site-specific information in the FMRI 2003 DP for the saturated zone. Therefore, NRC staff finds these parameter values to be acceptable.

For the field capacity of the saturated zone, FMRI referenced the RESRAD Data Collection Handbook (Yu et al., 2015). NRC staff verified that FMRI used the recommended value for sand. NRC staff finds the use of this parameter value to be acceptable because it reflects the site-specific soil type for the saturated zone. In an independent sensitivity analysis, NRC staff also determined that the DCGL values were not sensitive to this value.

For the hydraulic conductivity of the saturated zone, FMRI used the median value from a distribution for sand. However, unlike for the contaminated and unsaturated zones, site-specific measurements of hydraulic conductivity were reported in the 2003 DP for the saturated zone. In general, site-specific measurements are preferable to generic values and it is unclear to NRC why a generic value was used instead of the available site-specific data provided in the 2003 DP. FMRI did not find any sensitivity of dose to this parameter in its sensitivity analysis. However, because of concerns about the FMRI sensitivity analysis (see Section 3.4.3.2), NRC staff tested the sensitivity of the DCGL values to this parameter. NRC staff found that using the site-specific value for the hydraulic conductivity of the saturated zone decreased the calculated DCGLs for Pa-231 and uranium isotopes by approximately 15 percent each. Although a 15 percent decrease is not a very large effect, the effect is additive with similar concerns with other saturated zone parameters. Therefore, NRC staff does not find the justification for the hydraulic conductivity of the saturated zone to be adequate because it is based on generic data that conflicts with known site-specific data, and the site-specific value would result in lower DCGL values for Pa-231 and the uranium isotopes.

Similarly, for the hydraulic gradient of the saturated zone, FMRI used the mean value from a distribution for sand and gravel in NUREG/CR-6697 even though site-specific data was provided in the 2003 DP. NRC staff has two concerns with the generic data used for the hydraulic gradient. Most importantly, it is unclear why a generic value was used rather than the available site-specific measurements. In addition, the generic value used for the nominal value was the arithmetic mean of a lognormal distribution (0.027) instead of the geometric mean (0.005). The geometric mean would have been more appropriate for a lognormal distribution because it would represent a 50^{th} percentile value, whereas the mean represented the 84^{th} percentile. As noted in Table 6 and discussed in more detail in Section 3.4.3, the range for the sensitivity analysis of this parameter only appeared to include values above the 65^{th} percentile. More significantly, the range of values tested in the FMRI sensitivity analysis did not include any values as low as the site-specific measured values. An NRC sensitivity analysis using the site-specific measurements decreased the calculated DCGLs for Pa-231 and uranium isotopes by approximately 30 and 40 percent, respectively. Therefore, NRC staff does not find the justification for the hydraulic conductivity of the saturated zone to be adequate because it is based on generic data that conflicts with known site-specific data, and the site-specific value

would result in lower DCGL values for Pa-231 and the uranium isotopes.

For sorption coefficients (K_d values), FMRI used the median values from distributions representing generic soil (i.e., a variety of soil types) from NUREG/CR-6697. NRC staff finds this approach acceptable to establish initial values, prior to conducting a sensitivity analysis. As described in NRC consolidated decommissioning guidance, NUREG-1757 Volume 2, Rev 1, Appendix I central tendencies of generic distributions are acceptable for parameters to which the dose is not sensitive, but site-specific or conservative values should be used for parameters to which the dose is sensitive. In response to an NRC RAI, FMRI developed a new sensitivity analysis and determined that the projected dose was sensitivity to the K_d values for Pa-231 and the uranium isotopes. In accordance with NRC guidance, FMRI then set the K_d values for Pa-231 and the uranium isotopes to the 25^{th} percentile values in the nuclide-specific distribution in NUREG/CR-6697. NRC staff found that approach acceptable because the values were conservative for generic soil and were representative or conservative for the site-specific soil types. Because of concerns with the FMRI sensitivity analysis (Section 3.4.3.3), NRC staff also tested the sensitivity of the DCGL values to the K_d values for the remaining isotopes and did not find any parameter sensitivities. Therefore, NRC staff finds the use of the median values from distributions representing generic soil from NUREG/CR-6697 to be acceptable for those radionuclides.

In the June submittal, FMRI used the RESRAD default value of 4 m for the unsaturated zone thickness. In its September 2016 RAI, NRC staff indicated FMRI should use site-specific information when possible, and specifically indicated that FMRI should consider the impact of excavations on the unsaturated zone thickness used in the sensitivity analysis. In the October 2016 submittal, FMRI changed the value of the unsaturated zone thickness from 4 m to 2.75 m. FMRI explained that this value was based on information from Section 3.5.2 of the 2003 DP. FMRI set the thickness of the unsaturated zone equal to the thickness of the unconsolidated sediments minus the thickness of the saturated unconsolidated sediments, minus the thickness of the unsaturated zone. Although FMRI did consider a range of unsaturated zone thicknesses in its sensitivity analysis, FMRI did not directly address the potential impacts of excavations on the unsaturated zone thickness. Therefore, NRC staff modified the FMRI model to evaluate a minimum value of zero unsaturated zone thickness, which would correspond to an area where contaminated soil reached the saturated zone. This scenario is consistent with areas of the FMRI site in which residual radioactivity has already reached the saturated zone.

NRC staff determined that using this minimum unsaturated thickness had a small effect (i.e., 2 to 8 percent decrease) on the DCGL values for Pa-231 and the uranium isotopes, and did not affect the DCGL values for the other radionuclides. The effect was small because the model conservatively does not take credit for dispersion, which would tend to reduce the peak concentration for longer transport lengths and because the half-lives of these radionuclides are sufficiently long that the additional transport time does not perceptibly change the projected peak dose. Therefore, the unsaturated zone thickness primarily affected the transport time for the radionuclides to reach hypothetical well and not the peak magnitude. Because the peak concentrations of Pa-231 and the uranium isotopes were already predicted to arrive within 1000 years of site release, changing the unsaturated zone thickness did not change the concentration of these radionuclides that arrived within 1000 years. In addition, the transport of the remaining radionuclides is expected to be sufficiently slow that even setting the unsaturated zone thickness to zero, they did not contribute to the groundwater pathway within 1000 years of site release. Setting the unsaturated zone thickness to zero for the whole site bounds the potential effect reducing the unsaturated zone thickness on the projected dose. Therefore, NRC staff finds the unsaturated zone thickness used in the FMRI model to be acceptable.

In addition to groundwater parameters, FMRI changed a small number of parameter values unrelated to the groundwater pathway. In the June 2016 submittal[9], FMRI explained that it changed the parameter values because it could not find adequate justification for the values in the 2003 DP. Those parameters included[10] the annual average wind speed, indoor dust filtration factor, inhalation rate, mass loading for inhalation, and external gamma shielding factor (see Table 4). Of those 5 parameters, the annual average wind speed, inhalation rate, mass loading for inhalation, and indoor dust filtration factor area are all related to the inhalation pathway. The external gamma shielding factor is related to the external dose pathway.

Regarding the inhalation pathway, NRC staff found the four parameter values should be considered together. For the annual average wind speed, FMRI used data for Muskogee County to support the revised value. NRC staff verified the data used by FMRI and found the value to be acceptable because regional and site-specific data are preferable to generic data.

The indoor dust filtration factor, which is the fraction of contaminated dust from outdoors that is available indoors (i.e., increasing the filtration factor increases the available contamination indoors), is represented in NUREG/CR-6697 with a uniform distribution. FMRI used a value of 0.58, which NUREG/CR-6697 recommends as a value representative for daytimes values for particulate material smaller than 10 micrometers diameter (PM_{10}). This value was slightly higher (i.e., more pessimistic) than the mean of the generic uniform distribution, which was 0.55. FMRI did not find any sensitivity to this parameter in its sensitivity analysis. In an independent sensitivity analysis, NRC staff found changing this parameter to the 75th percentile value in the distribution from NUREG/CR-6697 lowered the DCGL value for Ac-227 by 10 percent and had less of an effect on the other radionuclides. Given that Ac-227 is only one of many radionuclides that will contribute dose, NRC staff determined that the projected dose from the site is not likely to be sensitive to this parameter, and therefore found the FMRI value, which was slightly more conservative than the median value from the generic distribution in NUREG/CR-6697, to be acceptable.

For the inhalation rate, FMRI referenced NUREG/CR-6697. NRC staff confirmed that FRMI used the mode of the triangular distribution for the parameter in RESRAD in NUREG/CR-6697. However, it was not clear that the mode of this distribution was the appropriate value to use. As explained in Section 5.1 of NUREG/CR-6697, the distribution recommended for RESRAD is a yearly average that includes breathing rates for light activity and resting. The distribution recommended for RESRAD-BUILD, on the other hand, is intended to represent an occupational scenario. Because FMRI selected an industrial worker scenario, the distribution recommended in NUREG/CR-6697 for RESRAD-BUILD is more appropriate for the critical group than the distribution recommended for RESRAD. The mode of that distribution is 33.6 m^3/d, which is equivalent to 12,264 m^3/year, nearly 50 percent greater than the value used by FMRI. FMRI did not find any sensitivity of dose to this parameter in its sensitivity analysis. However, because of concerns about the FMRI sensitivity analysis (see Section 3.4.3.2), NRC staff tested the sensitivity of the DCGL values to this parameter and found that the DCGL for Ac-227 was sensitive to this parameter. Therefore, NRC staff did not find this parameter value to be acceptable on its own; however, taken as a whole, NRC staff found the inhalation pathway to be modeled conservatively, as explained below.

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[9] The values for these parameters were not changed after the June 2016 submittal.
[10] FMRI also changed the soil ingestion rate from 18.25 micrograms/day to 18.3 micrograms per day. Because this value changed by less than 0.3 percent, it was essentially identical to the previously-reviewed value in the 2003 PD and NRC staff did not review it as a changed parameter value.

The mass loading for inhalation was characterized with an empirical distribution with a minimum value of 0 23 micrograms/m^3, a maximum value of 100 micrograms/m^3, and a median value of approximately 23 micrograms/m^3. In the June 2016 submittal, FMRI indicated that it changed the value from 1 x 10^{-4} grams/m^3 to 2.3 x 10^{-4} grams/m^3 to represent the median of the distribution for PM_{10} given in NUREG/CR-6697. However, this value appears to be in error, because the original value of 1 x 10^{-4} grams/m^3 represented the 100^{th} percentile value for the distribution given in NUREG/CR-6697, and the value in the June 2016 submittal represented an added conservatism beyond that range. The NRC staff determined that reducing the mass loading for inhalation to the 75^{th} percentile value for the parameter in NUREG/CR-6697 would approximately double the allowable DCGL for Ac-227, which was the radionuclide most sensitive to the inhalation pathway. When NRC staff adjusted the mass loading to the 75^{th} percentile value and changed the inhalation rate to a value more consistent with the critical group, the DCGL for Ac-227 was greater than the DCGL proposed by FMRI. Therefore, although NRC staff does not find the basis for the inhalation rate to be adequate, taken together, NRC finds the changes to the parameters related to the inhalation pathway in the FMRI June 2016 submittal (unchanged in the October 2016 pathway) to be acceptable because collectively, they result in lower DCGL values.

The external gamma shielding factor, which represents the ratio of the gamma radiation indoors to the gamma radiation outdoors (i.e., increasing the shielding factor increases projected dose), is represented in NUREG/CR-6697 by a lognormal distribution. Although FMRI indicated it used the mean of the distribution, the value used actually corresponded to the median (50^{th} percentile value) of the distribution, which is preferable for a lognormal distribution. FMRI did not find any sensitivity of dose to this parameter in its sensitivity analysis, with the peak dose in the FMRI sensitivity analysis changing from 13 mrem/yr to 14 mrem/yr (i.e., a 7 percent increase) when the external gamma shielding factor was increased from the median to the 75^{th} percentile value of the generic distribution in NUREG/CR-6697. However, the effect on the peak dose was obscured by the inventory FMRI used for its sensitivity analyses (see Section 3.4.3.2).

To address that concern and to test the sensitivity of the DCGL values to the external gamma shielding factor, NRC staff evaluated the effect of changing the parameter from the median (base case) value to its 75^{th} percentile value (i.e., changing it from 0.27 to 0.41) using the FMRI October 2016 model. NRC staff found the change decreased the DCGLs for the thorium and radium isotopes by 17 to 18 percent, with negligible effect on the other radionuclides. These DCGLs were dominated by the external pathway; consequently, changing the mass loading for inhalation to a more representative (i.e., less conservative) value did not mitigate the effect of this change in the external gamma shielding factor on the thorium and radium DCGLs. Because the thorium and radium isotopes account for a significant fraction of the residual radioactivity at the site (FMRI DP Section 4.3.2.2), NRC staff considers an effect of this magnitude on the DCGL values to be significant. Therefore, NRC staff determined a conservative or site-specific value should be used for the external gamma shielding factor instead of a median value from a generic distribution.

A site-specific value for the external gamma shielding coefficient would account for the expected spatial configuration of residual radioactivity, the specific radionuclides involved, and the type of construction expected at the site. To provide context for the external gamma shielding factor values, referred to the results of a more detailed shielding analysis for a thorium-contaminated site (Barr, 2010). In that analysis, the authors calculated external gamma shielding coefficients suitable for use in RESRAD based on calculations performed with a Monte Carlo N-Particle Transport Code (MCNPX) for various radionuclide configurations and construction types.

Because of the spatial extent of contamination at the FMRI site, NRC staff considered results for "general contamination" instead of smaller elevated areas of contamination confined to be under the footprint of the hypothetical building. To be consistent with the future expected industrial land use, NRC staff considered results for buildings built on a concrete slab or with a basement, and either wood or brick walls. Based on those constraints, the work suggested an effective shielding coefficient for thorium isotopes would be approximately 0.35. This value was similar to the 75th percentile value from the generic distribution in NUREG/CR-6697 of 0.41. Therefore, based on either a conservative selection from the generic distribution, or a value selected to account for site-specific factors, NRC staff determined the value of 0.27 chosen by FMRI in the 2016 submittals is too low. Because the DCGL values for the thorium and radium isotopes were sensitive to this parameter, it should be revised based on conservative or site-specific approach.

In summary, NRC staff found the parameter values used in the October 2016 submittal to be acceptable with the following exceptions:

(1) The value for the inhalation rate was not consistent with the definition of the critical group, but was acceptable when used in conjunction with the conservative value of the mass loading for inhalation selected by FMRI;

(2) The values from generic distributions for the saturated zone hydraulic conductivity and hydraulic gradient were not acceptable because they conflicted with site measurements and resulted in higher DCGL values (i.e., they were non-conservative) when compared to a model using the site data for those parameters;

(3) The values of the length parallel to aquifer flow and well pump intake depth appeared to be calculated incorrectly, were inconsistent with available site-specific information, and resulted in higher (i.e., non-conservative) DCGL values when compared to a model using the site data; and

(4) The value of the external gamma shielding coefficient was set to the median value taken from a generic distribution; although the DCGL values for the thorium and radium isotopes were sensitive to the value in the NRC staff's sensitivity analysis. Site-specific consideration of the extent of contamination, potential future use of the site, and the specific radionuclides involved also would suggest a higher value should be used.

Points (2) and (3) above only affect the DCGL values for radionuclides from which the risk is dominated by the groundwater pathway and, therefore, only affect the DCGL values for Pa-231 and the uranium isotopes. FMRI did not detect any sensitivity of dose to these parameters because of limitations of its sensitivity analysis, as described in Section 3.4.3.2. An independent NRC analyses showed changing these parameter values to be more consistent with site data decreased the DCGLs for these radionuclides by approximately 70 percent. This value is an estimate, because NRC staff estimated the appropriate values of the parameters from the measurements reported in Section 3.7.2 of the FMRI 2003 DP. In particular, the estimate of the thickness of the saturated zone was a simple average of the measured range, and not a true mean thickness. FMRI may be able to improve upon these estimated parameter values. However, the results of the NRC analysis demonstrated the potential significance of using site-specific measurements for these hydraulic parameters. For this reason, NRC finds the DCGL values for soils and sediments for Pa-231, U-234, U-235, and U-238 should be revised using site-specific data for the length parallel to the aquifer flow, well pump intake depth,

saturated zone hydraulic conductivity, and saturated zone hydraulic gradient.

Point (4) affects the DCGL values for the thorium and radium isotopes. Because of the sensitivity of the DCGL values to this parameter, and the likelihood that a site-specific value would be more conservative than the value FMRI chose, NRC staff finds the DCGL values for Ra-226, Ra-228, Th-238, Th-230, and Th-232 should be revised based on a conservative or more site-specific value of the external gamma shielding factor.

3.4.3 Sensitivity Analyses

3.4.3.1 Sensitivity Analysis Scope

The FMRI sensitivity analyses included in the June 2016 and October 2016 submittals focused primarily on parameters related to the groundwater pathway, with a few additions related to the inhalation and direct exposure pathways. In the June 2016 submittal, FMRI omitted the unsaturated zone thickness, unsaturated zone density, unsaturated zone total porosity, unsaturated zone effective porosity, unsaturated zone hydraulic conductivity, the unsaturated zone b parameter, water table drop rate, well pump intake depth, well pumping rate, and K_d values. In a September 2016 RAI, NRC staff explained why it found the bases for excluding these parameters to be unacceptable and requested a new sensitivity analysis to include these parameters.

In response, in its October 2016 submittal, FMRI revised its model and performed a sensitivity analysis that included all of these parameters except the water table drop rate and well pumping rate. The water table drop rate was excluded on the basis of reflecting site-specific conditions by being set to "recognize unconfined groundwater system." As discussed in Section 3.4.2, having an unconfined groundwater system does not mean the drop rate must be zero; however, FMRI may have meant that the water table at FMRI is known to have zero drop. Because the basis for excluding the parameter was unclear, NRC staff tested values of water table drop rate a factor of 10 higher and lower than the RESRAD default value of 0.001 m/yr and found the choice to be conservative.

The basis for excluding the well pumping rate was given as "see well pump intake depth (previous)." The meaning of this basis for excluding the well pumping rate from the sensitivity analysis was unclear because the well pump intake depth was included in the sensitivity analysis; however, NRC staff determined it is appropriate to exclude this parameter from the sensitivity analysis because RESRAD does not use this parameter unless an agricultural pathway (i.e., plant milk, meat, or aquatic food ingestion) is used.

NRC staff finds the final list of parameters evaluated in the October 2016 sensitivity analysis acceptable because the scope of the revision was limited to NRC concerns about consideration of the groundwater pathway and a small number of other parameters FMRI voluntarily decided to change in the June 2016 submittal and the affected parameters were included in the FMRI sensitivity analysis.

3.4.3.2 Sensitivity Analysis Approach

The FMRI sensitivity analysis in the October 2016 submittal was not based directly on DCGL values. Instead, the sensitivity analysis was based on the projected peak dose from a hypothetical site inventory. As described in Section 2.4, this hypothetical site inventory was based on keeping the radionuclides in the same ratios as the June 2016 DGGL values for soils

and sediments, except that the values of U-234 and U-235 were reduced to their naturally-occurring proportion with U-238. FMRI modeled the dose from this source term with the parameter values for the October 2016 submittal as shown in Tables 4 and 5, except that the sorption coefficient (K_d) values for Pa-231 and uranium isotopes reflected the June 2016 values (See Table 5 footnotes). The June 2016 K_d values were used because they were changed based on the sensitivity analysis results (i.e., new values were not changed until after the sensitivity analysis was performed). The other parameter values FMRI changed between the June and October submittals were changed for other reasons (see Table 4) and were changed before the sensitivity analysis was conducted. NRC staff replicated the base case of the sensitivity analysis and verified the peak projected dose of 13 mrem/yr.[11] FMRI identified parameter sensitivity by varying the parameters individually and noting when the peak dose exceeded 25 mrem/yr.

Using a hypothetical site inventory and determining sensitivity by evaluating the effect on the projected peak dose is more convenient than evaluating sensitivity based on each individual DCGL value and is consistent with NRC guidance. NUREG-1757, Vol. 2, Appendix I, Section I.7.5 states “For sites with a suite of radionuclides, the licensee may use expected concentrations or relative ratios of radionuclides to focus resources on the overall critical pathways and parameters.” However, FMRI has not provided any support for the conclusion that the ratios they used to construct the hypothetical inventory are an appropriate estimate of the radionuclide concentration ratios that will be present after remediation. For example, if decommissioning activities do not selectively remove specific radionuclides, one might expect the ratios of radionuclides left at the site to reflect the ratios of radionuclides currently at the site, rather than the ratios of DCGL values. Furthermore, the DCGL values proposed in the June submittal were changed in the October submittal, so the meaning of an inventory based on the June 2016 DCGL values is unclear. A more straightforward approach in this situation would be to use unit concentrations, and to base the determination of sensitivity on changes to the DCGL values rather than changes to the projected peak dose. That was the approach used by NRC staff in the NRC independent sensitivity analyses.

The NRC staff’s greatest concern with the FMRI approach to the sensitivity analysis was that, because parameters were tested individually and the sensitivity analysis was not iterative, the analysis could not detect the sensitivity of dose to parameters that became important once changes were made to the model. Specifically, because the K_d values used in the base case of the sensitivity analysis were the K_d values proposed in June 2016, none of the radionuclides were projected to reach the groundwater well within 1000 years of site release. Therefore, when FMRI tested the hydraulic parameters, none of them had any effect on the projected dose. Thus, although FMRI varied the values of the hydraulic parameters in the sensitivity analysis runs, they were not meaningfully included in the sensitivity analysis because they were only tested with K_d values that prevented radionuclides from reaching the groundwater. Although the iterative approach implied by using K_d values that were only changed as a result of the sensitivity analysis in the sensitivity analysis for other parameters may appear complex, it is necessary to meaningfully test the impact of the hydraulic parameters if the parameters are only tested individually with one-off sensitivity analyses. Furthermore, NRC staff specifically provided guidance on this point in the September 2016 NRC RAI, which indicated that the sensitivity analyses for the hydraulic parameters should use appropriate K_d values.

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[11] The text of the October 26, 2016 submittal indicates that the peak projected dose based on this source term was 15 mrem/yr, whereas Table 6 of the FMRI October 26, 2016 submittal indicates that the peak projected dose is 13 mrem/yr.

To address these concerns, NRC staff performed independent sensitivity analyses. The NRC staff evaluation of parameter sensitivity was based on the FMRI October 2016 parameter values, including the October 2016 final K_d values (Table 5). To avoid the concerns NRC staff identified with the site inventory FMRI developed, NRC staff used unit concentrations and based the determination of parameter sensitivity on changes to the DCGL values rather than the projected peak dose.

3.4.3.3 Sensitivity Analysis Parameter Ranges

Table 6 provides the FMRI bases for the ranges of parameter values used in its sensitivity analysis.

For the K_d values for each element, FMRI indicated that it used 25^{th} and 75^{th} percentile values from generic distributions and cited the NRC Consolidated Decommissioning Guidance (NUREG-1757) as a reference. Although NUREG-1757 provides decommissioning guidance, it does not provide parameter ranges. However, NRC staff determined that the values used corresponded to the 25^{th} and 75^{th} percentile K_d values from distributions for generic soils in NUREG/CR-6697. Use of the generic distributions in NUREG/CR-6697 as a basis for sensitivity analyses is consistent with NRC guidance; therefore, the ranges used for the K_d values are acceptable.

FMRI provided the same basis for the ranges for the density, porosity, hydraulic conductivity, and b parameter of the contaminated and unsaturated zones, as well as the effective porosity of the unsaturated zone, and the density, porosity, effective porosity, and hydraulic conductivity of the saturated zone. For the contaminated and unsaturated zones, FMRI indicated that it used values drawn from a distribution created by averaging the means and standard deviations of distributions for sandy clay and silty clay. NRC staff used the distributions from NUREG/CR-6697 for those soil types and found that the low end of the ranges used appeared to correspond to approximately the 20^{th} percentile and the high end of the ranges used appeared to correspond to approximately the 85^{th} percentile of that “averaged” distribution. These values represent a slightly wider range than the 25^{th} to 75^{th} percentile range, but the difference is not significant. Parameter ranges suitable for sandy clay and silty clay are consistent with information about the soil types at the site; therefore, these ranges are acceptable for the sensitivity analysis.

For the density, porosity, effective porosity, and hydraulic conductivity of the saturated zone, NRC staff confirmed that FMRI used the 25^{th} and 75^{th} percentile values from the NUREG/CR-6697 distributions for sand. These ranges are consistent with the site-specific information about soil type in the saturated unconsolidated sediments at the site and are therefore acceptable for the density, porosity, and effective porosity. For the hydraulic conductivity of the saturated zone, site-specific measurements exist and would provide a better basis for the range of values to use in the sensitivity analysis. However, for the hydraulic conductivity, the range of values used did include the site-specific measurements at the lower end of the range (i.e., the range used was from 1457 m/year to 3659 m/year and the site-specific measurements given in Section 3.7.2 of the DP had an average value of 1880 m/year). Therefore, this range was acceptable for use in the sensitivity analysis.

For the saturated zone hydraulic gradient, FMRI also stated that it based the range on the 25^{th} and 75^{th} percentile values in NRC decommissioning guidance (NUREG-1757). Unlike for the saturated zone parameters discussed in the previous paragraph, the values used did not appear to correspond to a distribution in NUREG/CR-6697. For example, based on the distribution for

the hydraulic gradient for sand and gravel in NUREG/CR-6697, the low value used corresponded to the 65th percentile and the high value used corresponded to the 95th percentile. More significantly, the range of values used, from 0.01 to 0.073, all were greater than the average of the site-specific values given in Section 3.7.2 of the 2003 DP (i.e., 0.006 for the saturated unconsolidated sediments). Because the range of values used did not include the site-specific measurements, as described in Section 3.4.2, NRC staff used the site-specific values from the 2003 DP in its independent sensitivity analysis for this parameter.

FMRI stated that the ranges for the thickness of the contaminated zone, thickness of the unsaturated zone, and well pump intake depth were based on the site-specific expected variation. For the thickness of the contaminated zone, the range used (i.e., 0.5 to 3 m) was consistent with site data and the decommissioning plans and was acceptable. For the thickness of the unsaturated zone, the range used (i.e., 1.8 to 4.1 m) did not appear to account for the potential for excavated areas to reach the saturated zone (i.e., a minimum value of zero), which is not consistent with site-specific data indicating that some of the contamination has already reached the water table. For this reason, as explained in Section 3.4.2, NRC staff tested a minimum value of zero for this parameter. For the well pump intake depth, as explained in Section 3.4.2, the value should have been based on the thickness of the saturated unconsolidated sediments rather than the total thickness of the unconsolidated sediments. The range of values used (i.e., 4.3 to 9.8 m) did not include the lower or upper end of the range of values given in Section 3.7.2 of the FMRI 2003 DP (i.e., 1.5 to 17.5 m); therefore, NRC staff used the site-specific values in its independent sensitivity analyses.

For the evapotranspiration coefficient, FMRI stated that the parameter range represented “a maximum expected variation” with the reference given as NUREG-1757. NRC staff determined the values corresponded to the 24th and 100th percentiles for distribution given in NUREG/CR-6697. These values are consistent with site information and represent an acceptable range for use in the sensitivity analyses.

The basis for the ranges used for the wind speed and precipitation was given as the “maximum expected variation” without a reference. For the wind speed and precipitation, the base case values were based on site-specific regional information. Thus, although the bases of the ranges used (i.e., a factor of 1.5 less than and greater than the base case value for each) were unclear, the ranges are generally acceptable because they capture the relevant site-specific values and are reasonably consistent with the variation seen in the regional values.

For the drinking water intake, like the wind speed and precipitation, the basis for the range was given as the “maximum expected variation” without a reference. The range reflected a factor of 2 variation around the base case value of 2 L/day. Because the basis for the range was unclear, NRC staff compared the value to the generic distribution in NUREG/CR-6697 and determined the lower and upper values used corresponded to the 41st and 100th percentiles of the generic distribution. This range represented an adequate variation around the base-case value and was acceptable for use in the sensitivity analysis.

For the inhalation rate, NRC staff had a concern with the base case value used (see Section 3.4.2). The range of values used in the sensitivity analysis (i.e., from 6180 to 11400 m^3/year) did not cover the value NRC staff found more defensible for the inhalation rate for the industrial worker critical group (i.e., 12,300 m^3/year). For this reason, NRC staff used the higher value (12,300 m^3/year) in its sensitivity analyses.

For the field capacity of the contaminated zone, unsaturated zone, and saturated zone, FMRI

stated that ranges used represented “an expected variation” without a reference given. For each parameter, the range represented a factor of 1.5 variation around the base case value. NUREG/CR-6697 does not have generic distributions for field capacity. Therefore, the NRC staff qualitatively compared the range of 1.5 to the range of values given in the reference for the base case value (Yu, 1993) and found a factor of 1.5 to be generally consistent with the range of values given for various soil types. Therefore, these ranges were acceptable for the sensitivity analyses.

For the external gamma shielding factor, FMRI stated the range used in the sensitivity analysis represented “an expected variation” with the reference given as NUREG/CR-6697. NRC staff confirmed the values correspond to the 25th and 75th percentiles of the distribution in NUREG/CR-6697. Because this parameter represents a property of a hypothetical future scenario, there is no applicable site-specific information and the use of a generic range is appropriate. Therefore, this range was acceptable for the sensitivity analysis.

For the mass loading for inhalation, FMRI stated that the range represented “an expected variation” without providing a reference. The range used (i.e., from 1.5×10^{-4} g/m^3 to 3.5×10^{-4} g/m^3) all exceeded the 100th percentile value of 1.0×10^{-4} g/m^3 in the generic distribution in NUREG/CR-6697. Because this parameter represents a property of a hypothetical future industrial worker scenario, there is no site-specific reason for this difference between the range of values used and the generic scenario. Furthermore, the reference for the deterministic base case value was given as NUREG/CR-6697, although the deterministic value used did not appear to represent the distribution from that source (see Section 3.4.2). For these reasons, NRC staff used values from the distribution in NUREG/CR-6697 when testing the sensitivity of the DCGL values to this parameter (see Section 3.4.2).

For the runoff coefficient, indoor dust filtration factor, soil ingestion rate, and depth of soil mixing layer, the basis was given as “a maximum expected variation” with the reference given as NUREG/CR-6697. NRC staff determined the values used did not reflect the maximum extent of the ranges given in NUREG/CR-6697 but did reflect significant variation within those ranges. For the runoff coefficient, the values used corresponded to the 24th and 75th percentile values for the generic distribution provided. The deterministic value, which was based on information about the slope, soil types, and land use of the site, was within the generic range used in the sensitivity analyses. For the evapotranspiration coefficient and indoor dust filtration factor, the values used corresponded to the 24th and 100th percentiles of the distributions used. Similarly, the depth of the soil mixing layer extended approximately the entire range of the generic triangular distribution provided in NUREG/CR-6697. These ranges represented expected variation in these parameters and were acceptable for the sensitivity analyses.

The bases for the ranges for the contaminated zone erosion rate and the length parallel to the aquifer flow were given as “arbitrary as an order of magnitude.” For the contaminated zone erosion rate, the order of magnitude variation around the base case value covers most of the range of the generic distribution given in NUREG/CR-6697 and is acceptable for the sensitivity analysis for this parameter. For the length parallel to the aquifer flow, the order of magnitude variation is likely larger than needed because site-specific information could limit this large range of variability. Because of concerns with how this parameter value was calculated, NRC staff conducted an independent analysis with an alternate parameter value, as described in Section 3.4.2.

In summary, most of the parameter ranges were taken from generic distributions and were acceptable. However, in a few cases, the ranges conflicted with site-specific data (i.e., the

hydraulic conductivity and hydraulic gradient of the saturated zone), with the definition of the critical group (i.e., the inhalation rate), or with values in the cited references (i.e., mass loading for inhalation). In these cases, NRC staff used information in the FMRI 2003 DP or alternate information from generic distributions to establish alternate values to test in sensitivity analyses. The results of those analyses were used to assess the acceptability of parameter values, as described in Section 3.4.2.

4.0 Conclusions

As explained in Section 1.0, NRC staff reviewed changes FMRI has made to its proposed DCGL values (and CL values for groundwater) to address deficiencies documented in the NRC 2003 SER and other changes FMRI chose to make in its June and October 2016 submittals. In March 30, 2016, NRC staff expressed two concerns about the FMRI proposed DCGL values. First, NRC staff indicated that FMRI must account for the potential drinking water pathway and existing groundwater contamination. Second, NRC staff indicted that FMRI should re-evaluate the model used to generate its DCGL values for site soil and sediments and ensure parameter values were appropriate for a scenario in which drinking water consumption of groundwater is included, or revise the parameter values as appropriate.

NRC staff concludes that FMRI has adequately considered existing groundwater contamination by developing CL values for groundwater and committing to applying them with a sum-of-fractions approach, such that exposure to residual radiation in all media from all applicable pathways will not result in a dose exceeding 25 mrem/y. NRC staff replicated the CL values FMRI derived for groundwater contamination and concluded the assumptions underlying the calculations were acceptable because they are consistent with expected exposures to an industrial worker critical group. NRC staff found the industrial worker critical group to be acceptable in the NRC 2003 SER.

DCGL values for equipment and building surfaces were not changed from the values in the 2003 DP. In the NRC 2003 SER, NRC staff found the proposed DCGLs for equipment and building surfaces to be acceptable subject to the condition that FMRI remediate equipment and building surfaces to have a removable fraction of contamination no greater than 0.03. This constraint was included as a license condition. Therefore, NRC staff concludes the DCGL values for equipment and building surfaces in the 2003 DP are still acceptable.

In response to concerns described in the NRC March 2016 letter, FMRI submitted revised DCGL values for soils and sediments in June 2016. NRC staff replicated the DCGL values for soils and sediments that FMRI proposed in its June 2016 submittal with RESRAD (Versions 6.5 and 7.0). NRC reviewed those DCGL values and the supporting model and in September 2016, NRC sent FMRI an RAI with two questions. The first requested revised $DCGL_{EMC}$ values corresponding to the revised DCGL values. In an October 2016 reply, FMRI indicated it would develop $DCGL_{EMC}$ values at the time of the final status survey. As explained in Section 3.1, NRC staff finds this approach acceptable because it is consistent with NRC guidance.

The second RAI documented NRC concerns about the FMRI sensitivity analysis and requested a revised sensitivity analysis and any revised DCGL values developed as a result of the revised sensitivity analysis. Specifically, NRC staff expressed concern that the groundwater pathway had not been adequately evaluated because several parameters relevant to the groundwater pathway were excluded from the sensitivity analysis. NRC staff also directed FMRI to NRC guidance (NUREG-1757, Volume 2, Appendix I) which indicates that conservative or site-specific values should be used for parameters to which the projected dose is sensitive.

In an October 2016 submittal, FMRI submitted revised DCGL values supported by a revised model and sensitivity analysis. NRC staff replicated the DCGL values for soils and sediments that FMRI proposed in its October 2016 submittal with RESRAD (Version 6.5). Because of concerns NRC staff has with the FMRI October 2016 sensitivity analysis (Section 3.4.3.2), NRC staff used the RESRAD model to conduct a number of independent sensitivity analyses. NRC staff used these independent sensitivity analyses to evaluate the acceptability of parameter values and potential impacts on DCGL values for soils and sediments.

FMRI changed several parameter values in its RESRAD model used to derive DCGL values for site soil and sediments to support consideration of a groundwater pathway (Table 4). For many of the parameter values, FMRI used generic values from NUREG/CR-6697 and other sources. Some of these values appeared to conflict with site-specific data supplied in the 2003 DP. In general, site-specific data are preferable to generic data, and NRC staff found the justification for using generic data inadequate in some instances. In particular, the generic values used for hydraulic conductivity and hydraulic gradient in the saturated zone conflicted with site data in Section 3.7.2 of the FMRI 2003 DP and using the site data would result in lower DCGL values for Pa-231 and the uranium isotopes. In addition, it appears that there was an error in calculating the length parallel to aquifer flow and well pump intake depth, and using more appropriate values for these parameters would yield lower DCGL values for Pa-231 and the uranium isotopes.

FMRI did not detect sensitivity of dose to any parameters affecting the groundwater pathway other than the K_d values for Pa-231 and the uranium isotopes. However, as described in Section 3.4.3.2, NRC staff had significant concerns with the FMRI approach to the sensitivity analysis. The NRC staff's greatest concern with the FMRI approach was that all of the hydraulic parameters were tested with K_d values that prevented any radionuclides from reaching a modeled groundwater well within 1000 years of site release. Therefore, the sensitivity analysis was not able to detect any effects of changing any of the hydraulic parameters on the projected dose. Although using an iterative approach and re-testing parameter after the K_d values were updated may appear complex, it is necessary to meaningfully test the impact of the hydraulic parameters if the parameters are only tested individually with one-off sensitivity analyses. For this reason, NRC staff specifically provided guidance on this point in the September 2016 NRC RAI, which indicated that the sensitivity analyses for the hydraulic parameters should use appropriate K_d values.

Because of this and other concerns with the FMRI sensitivity analysis approach, after replicating the FMRI results with RESRAD, NRC staff used the RESRAD model to conduct independent sensitivity analyses. NRC staff determined that using site-specific values for the saturated zone hydraulic conductivity and hydraulic gradient, and correcting the length parallel to the aquifer flow and well pump intake depth all would decrease the allowable DCGL values for Pa-231, U-234, U-235, and U-238 by approximately 70 percent. This value is an estimate, as explained in Section 3.4.2, and FMRI may be able to improve upon these estimated parameter values. However, the results of the NRC analysis demonstrated the potential significance of using site-specific measurements for these hydraulic parameters. For this reason, NRC finds the DCGL values for soils and sediments for Pa-231, U-234, U-235, and U-238 should be revised using site-specific data for the length parallel to the aquifer flow, well pump intake depth, saturated zone hydraulic conductivity, and saturated zone hydraulic gradient.

DCGL values for radionuclides other than Pa-231 and the uranium isotopes (i.e., Pb-210, Ra-226, Ra-228, Ac-227, Th-228, Th-230, and Th-232) were dominated by water-independent

pathways, including direct radiation, dust inhalation, and soil ingestion. In the June and October 2016 submittals, FMRI changed a small number of parameters related to the inhalation and direct radiation pathways from the values used in the 2003 DP. For the direct radiation pathway, FMRI changed the external gamma shielding coefficient. Although FMRI did not find any sensitivity of peak dose to this parameter value, that result is obscured by the inventory FMRI chose for its sensitivity analysis. An independent NRC staff analysis showed that the DCGL values for the thorium and radium isotopes were sensitive to this parameter. NRC staff also compared the value FMRI used (0.27) to more detailed evaluations made for another thorium-contaminated site and found that an applicable value would likely be more conservative than the value FMRI used. Because of the sensitivity of the DCGL values to this parameter, and the likelihood that a site-specific value would be more conservative than the value FMRI chose, NRC staff finds the DCGL values for Ra-226, Ra-228, Th-238, Th-230, and Th-232 must be revised based on a conservative or more site-specific value of the external gamma shielding factor.

Regarding the inhalation pathway, although NRC did not find adequate justification for one of the parameters, conservatism in another inhalation pathway parameter had a greater effect on projected doses from inhalation. Therefore, taken as a group, the changes in the inhalation pathway parameters were acceptable. Therefore, for Pb-210 and Ac-227 which were not significantly affected by the external radiation or groundwater pathways, NRC staff finds the DCGL values for soils and sediments proposed in the FMRI October 2016 submittal to be acceptable.

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