40 CFR Part 191
Subparts B and C
Compliance Recertification Application 2026
for the
Waste Isolation Pilot Plant

Appendix MgO-2026
Magnesium Oxide as an Engineered Barrier

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Field Office
Carlsbad, New Mexico

Compliance Recertification Application 2026
Appendix MgO-2026

TABLE OF CONTENTS

MgO-1.0 Introduction MgO-1

MgO-2.0 Emplacement of MgO MgO-2
MgO-2.1 MgO Vendors MgO-2

MgO-3.0 Characteristics of MgO MgO-2
MgO-3.1 Emplacement Since the CRA-2019 ..... MgO-2

MgO-4.0 Effects of MgO on the WIPP Disposal System MgO-3
MgO-4.1 Effects of MgO on Colloidal Actinide Concentrations MgO-4
MgO-4.2 Effects of MgO Carbonation MgO-4
MgO-4.3 Effects of MgO on Repository H_2O Content MgO-5
MgO-4.4 Effects of MgO on Gas Generation MgO-6
MgO-4.5 Effects of MgO on Room Closure MgO-6
MgO-4.6 Effects of MgO on Far-Field Actinide Transport MgO-6

MgO-5.0 The MgO Excess Factor MgO-7

MgO-6.0 References MgO-7

LIST OF TABLES

Table MgO-1. Emplacement Volumes for Transuranic Waste Since the CRA-2019 and First Waste Receipt. Waste Volumes Recorded as Land Withdrawal Act (LWA) Volumes (Offner 2025). MgO-3

Table MgO- 2. Emplacement Masses for CPR and MgO Since the CRA-2019 and First Waste Receipt (Offner 2025). MgO-3

Table MgO-3. Parameter Recommendations for the CRA-2026 for Inundated Hydration Rates of MgO in GWB and ERDA-6 (Nemer 2025). MgO-5

ACRONYMS AND ABBREVIATIONS

(aq)	aqueous
atm	atmosphere(s)
CCA	Compliance Certification Application
CPR	cellulosic, plastic, and rubber
CRA	Compliance Recertification Application
DOE	U.S. Department of Energy
ECO	Engineering Change Order
EPA	U.S. Environmental Protection Agency
(g)	gaseous
K_d	matrix distribution coefficient
kg	kilograms
lb	pound
LWA	Land Withdrawal Act
m^3	cubic meters
mol	mole
M&O	Management and Operating
PA	Performance Assessment
s	second(s)
(s)	solid
TRU	transuranic
WDS	Waste Data System
WIPP	Waste Isolation Pilot Plant

ELEMENTS AND CHEMICAL COMPOUNDS

Am	americium
An	actinide
CH_4	methane
CO_2	carbon dioxide
f_{CO_2}	fugacity of CO_2
Fe	iron
H^+	hydrogen ion
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulfide
Mg	magnesium
$Mg(OH)_2$	magnesium hydroxide
$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$	hydromagnesite
$MgCO_3$	magnesite
MgO	magnesium oxide
N_2	nitrogen
O_2	oxygen
pH	the negative, common logarithm of the activity of H^+
Pu	plutonium
Th	thorium
U	uranium

MgO-1.0 Introduction

The U.S. Department of Energy (DOE) emplaces magnesium oxide (MgO) in the Waste Isolation Pilot Plant (WIPP) repository to provide an engineered barrier. The engineered barrier is intended to remove carbon dioxide (CO_2) and maintain alkaline brine pH, thereby decreasing the solubilities of the actinide (An) elements in transuranic (TRU) waste in brine present in the post-closure repository. The MgO is a bulk granular material comprised of periclase (pure, crystalline MgO, which is the main reactive constituent of the WIPP engineered barrier) and various trace impurities described in the CRA-2009, Appendix MgO-2009, Section MgO-3.0 (U.S. DOE 2009).

As designed, the barrier system will utilize MgO in excess relative to the CO_2 potentially produced by the microbial degradation of the cellulosic, plastic, and rubber (CPR) materials in the TRU waste, waste containers, and waste-emplacement materials. Through the utilization of CO_2 by the MgO barrier, the repository will remain buffered at an alkaline pH range between 8-10 (Appendix SOTERM-2014, Section SOTERM-2.3.2) (U.S. DOE 2014) with low CO_2 fugacity (f_{CO_2}), resulting in decreased solubilities of An elements. The chemical equilibrium of this buffering process will result in low concentrations of CO_2 in the aqueous (aq) and gaseous (g) phases. Details concerning the conceptual model surrounding the MgO barrier function are provided in the Compliance Certification Application (CCA), Appendix BACK and Appendix SOTERM (U.S. DOE 1996).

Hydration of MgO in brine forms brucite. The conversion of brucite to hydromagnesite facilitates the sequestration of CO_2 during carbonation (Section MgO-4.2, MgO-4.3). This process effectively regulates repository CO_2 concentrations within a range that is favorable for the speciation and solubility of An elements, thereby decreasing their solubilities in the brine.

Details about the reaction between MgO and CO_2 and its role in decreasing An solubilities are provided in previous Compliance Recertification Application (CRA) documents, including CRA-2004 (U.S. DOE 2004), CRA-2009 (U.S. DOE 2009), CRA-2014 (U.S. DOE 2014), CRA-2019 (U.S. DOE 2019), and the CCA (U.S. DOE 1996). Appendix GEOCHEM-2026 and Appendix-SOTERM 2026 provide further information on repository chemistry influencing actinide solubility.

The DOE proposed four engineered barriers in the WIPP CCA: MgO, panel closures, shaft seals, and borehole plugs. In 40 CFR 191.12 (U.S. EPA 1993), the U.S Environmental Protection Agency (EPA) defined barriers as:

> Any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste provided that the material or structure substantially delays movement of water or radionuclides. (U.S. EPA 1993)

Because of the potential for MgO to decrease An(III), An(IV), and An(V) solubilities through buffering the pH around 9, substantially delaying the movement of radionuclides through lowering solubilities, the CFR 191.12 definition of a barrier is fulfilled. The EPA specified MgO as the only engineered barrier in the WIPP disposal system that meets the assurance requirement in its May 1998 certification rulemaking (U.S. EPA 1998a and U.S. EPA 1998b) because the EPA considered panel closures, shaft seals, and borehole plugs to be part of the disposal-system design.

MgO-2.0 Emplacement of MgO

Currently, the DOE is emplacing 3,000-lb and 4,200-lb supersacks of MgO. Between January 1, 2018, and January 10, 2025, Waste Handling Operations recorded 15 release orders of MgO totaling 3,000 tons. The EPA requires a reactivity test for periclase and lime per Engineering Change Order (ECO) 12137 (WTS 2009). In September 2022, the independent reactivity test laboratory was changed from ALS Fort Collins to Southwest Research Institute (Batchelder 2025).

Among the 15 MgO release orders, 360 samples were tested for reactivity with an average percent reactivity of 97.7 mole (mol) %. This average MgO reactivity meets the EPA's requirement of 96 mol % (WTS 2009). The current specification for prepackaged MgO backfill, D-0101, was implemented on February 28, 2023, and it included revisions to document formatting and attached procedures (WIPP 2023).

MgO-2.1 MgO Vendors

Historical information concerning MgO vendors can be found in CRA 2019, Appendix-MgO, Section MgO-2.2 (U.S. DOE 2019). Martin Marietta Magnesia Specialties, LLC, began providing MgO to the WIPP in January 2005 and continues to supply MgO to the WIPP as of January 10, 2025.

MgO-3.0 Characteristics of MgO

The CRA-2009, Appendix MgO-2009, Section MgO-3.0 (U.S. DOE 2009), describes the characteristics of the MgO provided to the WIPP by past vendors National Magnesia Chemicals and Premier Chemicals, as well as the current vendor, Martin Marietta Magnesia Specialties, LLC.

MgO-3.1 Emplacement Since the CRA-2019

The WIPP has continually received TRU waste for emplacement since the CRA-2019. Updated emplacement values for TRU waste, CPR, and MgO are recorded in Table MgO-1 and Table MgO-2.

Table MgO-1. Emplacement Volumes for Transuranic Waste Since the CRA-2019 and First Waste Receipt. Waste Volumes Recorded as Land Withdrawal Act (LWA) Volumes (Offner 2025).

Waste Type	Volume Emplaced (m^3) Between January 8, 2018, and January 10, 2025	Volume Emplaced (m^3) Since First Waste Receipt
Contact-handled TRU	12,502	77,957
Remote-handled TRU	11.44	386

Table MgO-2. Emplacement Masses for CPR and MgO Since the CRA-2019 and First Waste Receipt (Offner 2025).

Material	Mass (kg) Emplaced Between January 8, 2018, and January 10, 2025	Mass (kg) Emplaced Since First Waste Receipt
Cellulosic	410,755	4,247,639
Plastic	597,913	5,354,872
Rubber	36,543	406,388
MgO	2,912,749[1]	35,803,727

[1] Emplaced in 1,571 3,000-lb supersacks and 407 4,200-lb supersacks.

MgO-4.0 Effects of MgO on the WIPP Disposal System

This section reviews the effects of MgO specific to (1) mineral fragment colloid concentrations (Section MgO-4.1), (2) MgO carbonation (Section MgO-4.2), (3) repository H_2O content (Section MgO-4.3), (4) gas generation (Section MgO-4.4), (5) room closure (Section MgO-4.5), and (6) far-field An transport (Section MgO-4.6), and discusses any relevant changes since the CRA-2019. The primary effect of MgO on the disposal system is to buffer pH, as described in Section

MgO-1.0. The pH buffering effect of MgO contributes to a reduction in actinide solubilities. Further effects of MgO on brine composition, f_{CO2}, and pH are discussed in Appendix GEOCHEM-2026, Sections GEOCHEM-2.2 and GEOCHEM-3.0.

MgO-4.1 Effects of MgO on Colloidal Actinide Concentrations

There have been no changes to the mineral fragment colloid parameters or Colloidal Actinide Source Term conceptual model since the CCA. The Colloidal Actinide Source Term Conceptual model is described in the CCA, Appendix SOTERM (U.S. DOE 1996). The CRA-2019 Appendix MgO-2019, Section MgO 4.1 (U.S. DOE 2019), summarized WIPP-related experimental work concerning MgO colloids since the CCA.

Since the CRA-2019, the longevity of dispersions of colloidal MgO has been investigated. MgO colloids were observed to rapidly decrease in concentration over one to four days. The study concluded that the uncertainty in the formation of pseudo-colloids from MgO hydration and carbonation is well encompassed by the existing conservatism in the Colloidal Actinide Source Term conceptual model and the mineral fragment colloid parameter values currently implemented in PA (Foli 2024). No new mineral fragment colloid parameters are recommended for CRA-2026. Further information concerning mineral fragment colloids can be found in Appendix GEOCHEM-2026, Section GEOCHEM-5.0.

MgO-4.2 Effects of MgO Carbonation

The carbonation of brucite to form hydromagnesite will remove CO_2 produced by the microbial degradation of CPR materials in the repository. The fugacity of $CO_{2(g)}$ controlled by the assemblage of brucite-hydromagnesite in the repository is low, on the order of ~10^{-6} [atm]. The negligible impact of this minute fugacity of $CO_{2(g)}$ is represented in performance assessment (PA) by:

(1) Removing CO_2 from the gaseous phase in the Brine and Gas Flow calculations, thereby somewhat reducing the predicted pressurization of the repository.

(2) Using the values of f_{CO_2} and pH predicted for reactions among MgO, brine, and aqueous or gaseous CO_2 to calculate An solubilities.

Since the CRA-2019, loss on ignition data from hydration experiments on Martin Marietta MgO were analyzed. The study employed Bayesian regression to estimate hydration rate constants for inundated MgO in WIPP brines (Nemer 2025). The study recommended updated parameters for CRA-2026 which are given in Table MgO-3.

Table MgO-3. Parameter Recommendations for the CRA-2026 for Inundated Hydration Rates of MgO in GWB and ERDA-6 (Nemer 2025).

Parameter	Units	Description	Distribution Parameters	Distribution Type
WAS_AREA:BRUCITES	mol/kg/s	MgO inundated hydration rate in GWB brine	Mean = 1.4 x 10^{-7} S.E = 5 x 10^{-8} Max = 2.9 x 10^{-7} Min = 0	Truncated Normal
WAS_AREA:BRUCITEC	mol/kg/s	MgO inundated hydration rate in ERDA-6 brine	Mean = 8.2 x 10^{-8} S.E = 0.2 x 10^{-8} Max = 8.8 x 10^{-8} Min = 7.6 x 10^{-8}	Truncated Normal

Further details regarding MgO hydration and carbonation can be found in Appendix GEOCHEM-2026, Section GEOCHEM-2.2. Detailed information regarding parameter implementation in PA may be found in Appendix PA-2026.

MgO-4.3 Effects of MgO on Repository H_2O Content

The hydration of periclase could consume significant quantities of H_2O in the WIPP as shown in equation (MgO.1).

$$MgO(s) + H_2O\ (aq\ or\ g) \rightleftharpoons Mg(OH)_2(s) \qquad (MgO.1)$$

It is assumed that CO_2 is consumed in the brucite carbonation reaction to form hydromagnesite as shown in equation (MgO.2) (Brush et al. 2012).

$$5Mg(OH)_2(s) + 4CO_2(g) \rightleftharpoons Mg_5(CO_3)_4(OH)_2(s)\cdot 4H_2O \qquad (MgO.2)$$

The carbonation reaction of brucite to hydromagnesite, as shown in equation (MgO.2), buffers f_{CO_2} to 2.02 x 10^{-6} atm in GWB and ERDA-6 synthetic brines (Domski 2025). These values represent a change from the CRA-2019, where f_{CO_2} was buffered to 3.14 x10^{-6} atm in GWB and ERDA-6 brines. This change is attributed to a revision in the log K of hydromagnesite to that of Robie and Hemingway (1973), as recommended by the EPA (Sisk-Scott 2019).

Hydromagnesite will not release its waters of crystallization until transformation to magnesite, as shown in equation(MgO.3). Since hydromagnesite is not thermodynamically stable under repository conditions, this dehydration is assumed to occur. However, the timing of dehydration from hydromagnesite into magnesite is uncertain. Therefore, for PA this timing is

represented by a distribution of reaction rates by the HYMAGCON parameter (Section PA-1.1.8) (U.S DOE 2019).

$$Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O(s) \rightleftharpoons 4MgCO_3(s) + Mg(OH)_2(s) + 4H_2O(l) \qquad \text{(MgO.3)}$$

These three reactions are reflected in water balance calculations in performance assessments for WIPP. A detailed discussion of repository water content and the interactions of MgO within the repository is provided in-depth in CRA-2019, Appendix GEOCHEM-2019, and Appendix PA-2019 (U.S. DOE 2019).No additional information regarding the effect of MgO on repository water content is being introduced in CRA-2026.

MgO-4.4 Effects of MgO on Gas Generation

There are three assumed gas-producing processes in the WIPP environment after closure: (1) anoxic corrosion of steel and other iron (Fe) based alloys, (2) microbial degradation of CPR materials, and (3) brine radiolysis. Anoxic corrosion will produce hydrogen (H_2), and microbial activity will produce mainly CO_2, hydrogen sulfide (H_2S), and potentially methane (CH_4). Brine radiolysis will produce H_2 and oxygen (O_2). Currently, PA only accounts for radiolytic H_2 generation. Radiolytic O_2 generation was not considered a viable long-term contributor to gas production due to reactions with metals present in the inventory (Day 2019, McCormick 2024). Nitrogen (N_2) production by degradation of CPR will be negligible due to limited nitrate in the waste. The major function of MgO is to remove CO_2 introduced by gas producing processes. More detailed information on gas generation may be found in Appendix GEOCHEM-2026, Sections GEOCHEM-2.2 and GEOCHEM-2.4 .

By lowering WIPP CO_2 levels, the presence of MgO makes the acceleration of anoxic corrosion of steel and iron-based alloys by CO_2 unlikely. This process is described in of Appendix GEOCHEM-2026, Sections GEOCHEM-2.2 and GEOCHEM-2.4

MgO-4.5 Effects of MgO on Room Closure

MgO is not explicitly included in the PA room closure calculations. Appendix MgO-2009, Section 5.3.3 (U.S. DOE 2009), provides an overview of how room closure is modeled in PA. No new information on the effects of MgO on this process is being introduced for CRA-2026.

MgO-4.6 Effects of MgO on Far-Field Actinide Transport

The CRA-2009, Appendix MgO-2009, Section MgO-5.4 (U.S. DOE 2009), contains detailed discussion regarding the potential effects of MgO on far-field An transport. The discussion focused on the effects of MgO on pH, which could potentially influence the matrix distribution coefficients (K_ds) used to predict the transport of dissolved thorium (Th), uranium (U), plutonium (Pu), and americium (Am) through the Culebra Member of the Rustler Formation.

Since the CRA-2004, there have been no changes in the effects of MgO on these K_ds. No new information regarding the effect of MgO on far field actinide transport is being introduced for CRA-2026.

MgO-5.0 The MgO Excess Factor

The MgO excess factor is defined as the ratio of the total MgO to be emplaced in the WIPP to the total MgO required to consume all the CO_2 produced by microbial activity resulting from the complete consumption of CPR. The CRA-2009, Appendix MgO-2009, Section MgO-6.0 (U.S. DOE 2009), provides a detailed description of the MgO excess factor and its application in the WIPP. Waste Handling Operations uses the Waste Data System (WDS) to determine the appropriate size of supersack to emplace on every other row of waste stacks. This approach aims to maintain a minimum MgO excess factor of 1.2 while minimizing the use of MgO emplacement racks. As of January 10, 2025, the average MgO excess factor across all rooms and panels containing emplacements was 1.68 (Offner 2025).

The EPA conducted an inspection of the WIPP waste emplacement program in May 2022. During the post-inspection review of WIPP documentation, the EPA noted an error in the MgO excess factor reported by the WDS. The error caused the MgO excess factor value for a disposal panel to be applied to all disposal rooms in the panel. The DOE identified the cause as a software error resulting in an incorrect variable reference during the generation of the WDS report. The DOE investigated the extent of the error and determined that the issue was limited to Panel 7, Rooms 4 through 6, and further verified that documents using or that would use the incorrect data had the necessary corrections issued (U.S. EPA 2022). The software error was identified for correction in the next software version release, WDS Release 3.5 on March 4, 2024.

MgO-6.0 References

(*Indicates a reference that has not been previously submitted.)

Batchelder, T. 2025. E-mail message to Isaac Foli [EXTERNAL] RE: Data Query for Appendix MgO CRA 2026, March 13, 2025. Carlsbad, NM: Nuclear Waste Partnership.*

Brush, L.H., P.S. Domski, and Y.-L. Xiong. 2012. Analysis Plan for WIPP Near-Field Geochemical Process Modeling. AP-153, Rev. 1, February 8, 2012. Carlsbad, NM: Sandia National Laboratories. ERMS 556960.

Day, B. 2019. Reassessment of Need and Parameter Justification for Modeling Gas Generation due to Radiolysis of Brine and Cellulose/Plastic/Rubber in WIPP for CRA-2019. Carlsbad, NM. Sandia National Laboratories ERMS 570873.

Domski, P.S., 2025. Prediction of Baseline Actinide Solubilities for the 2026 WIPP Compliance Recertification Application Performance Assessment Interim-State Analysis (CRA-2026 IS). Analysis Report, June 26, 2025. Carlsbad, NM: Sandia National Laboratories. *

Foli, I. 2024. Milestone Report on Mineral Fragment Colloids under TP 22-02. September 24, 2024. Carlsbad NM: Sandia National Laboratories. ERMS 582426.*

McCormick, J., Kirkes, R., Hansen, C. 2024. Conceptual Models in WIPP Performance Assessment. October 8, 2024. Carlsbad, NM: Sandia National Laboratories. *

Nemer, M. 2025. MgO hydration rates for the CRA-2026 under AP-208, March 18, 2025. Albuquerque, NM: Sandia National Laboratories.*

Offner, S. 2025. E-mail message to Isaac Foli [EXTERNAL] RE: WDS Data Query for Appendix MgO CRA 2026, March 11, 2025. Carlsbad, NM: Nuclear Waste Partnership.*

Robie, R. A., and B. S. Hemingway. 1973. The enthalpies of formation of nesquehonite, $MgCO_3 \cdot 3H_2O$, and hydromagnesite, $5MgO \cdot 4CO_2 \cdot 5H_2O$. Journal of Research of the U.S. Geological Survey, Vol. 1: 543-547.

Sisk-Scott. 2019. Analysis Plan to Update the WIPP Geochemical Thermodynamic Database (DATA0.FM1) to Data0.FM4 for CRA-2019. February 20, 2019. Carlsbad, NM: Sandia National Laboratories. ERMS 571001.*

U.S. Department of Energy (DOE). 1996. Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant (October). 21 vols. Carlsbad, NM: Carlsbad Area Office. DOE/CAO-1994-2184.

U.S. DOE. 2004. Title 40 CFR Part 191 Compliance Recertification Application for the Waste Isolation Pilot Plant (March). 10 vols. Carlsbad, NM: Carlsbad Field Office. DOE/WIPP 2004-3231.

U.S. DOE. 2009. Title 40 CFR Part 191 Compliance Recertification Application for the Waste Isolation Pilot Plant, Carlsbad, NM: Carlsbad Field Office. DOE/WIPP 09-3424.

U.S. DOE. 2014. Title 40 CFR Part 191 Subparts B and C Compliance Recertification Application for the Waste Isolation Pilot Plant, Carlsbad, NM: Carlsbad Field Office. DOE/WIPP 2014-3503.

U.S. DOE. 2019. Title 40 CFR Part 191 Subparts B and C Compliance Recertification Application for the Waste Isolation Pilot Plant, Carlsbad, NM: Carlsbad Field Office. DOE/WIPP 2019-3609.

U.S. Environmental Protection Agency (U.S. EPA). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. Federal Register, vol. 58: 66398–416.

U.S. EPA. 1998a. CARD No. 44: Engineered Barriers. Compliance Application Review Documents for the Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR 191 Disposal Regulations: Final Certification Decision (May 18, 1998) (pp. 44-1 through 44-36). Washington, DC: Office of Radiation and Indoor Air.

U.S. EPA. 1998b. 40 CFR Part 194: Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the Disposal Regulations: Certification Decision; Final Rule. Federal Register, vol. 63 (May 18, 1998): 27353–406.

U.S. EPA. 2022. 2022 – Emplacement Inspection Report Inspection of the Waste Isolation Pilot Plant May 24-26, 2022. Washington, DC: Office of Radiation and Indoor Air. Docket: EPA-HQ-OAR-2001-0012-0767.*

WIPP Specification (WIPP). 2023. Specification for Prepackaged MgO Backfill. Revision 13. February 28, 2023. D-0101. Carlsbad NM: Carlsbad Field Office.*

WTS. 2009. Engineering Change Order (ECO) 12137. January 15, 2009. Carlsbad, NM: Washington TRU Solutions.