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Critical Assessment of Seismic and Geomechanics Literature Related To A High-Level Nuclear Waste Underground Repository

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U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

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The objectives noted above are not mutually independent, and many other performance objectives must be satisfied in terms of equipment operation, ventilation, environmental impact, drainage, scheduling and cost, for example. However, considering the geomechanics objectives separately, they may be realized from a comprehensive knowledge of the geotechnical conditions in the mine area, and a capacity for analysis of the response of the rock mass to excavation activity within it. The adequacy of these practices is affirmed by the success of mining operations under a broad range of site conditions, mining methods, and extraction ratios.

2.2 Special Features of the Mined Geologic Disposal System

Despite the similarity between an underground mine and a mined geologic disposal system, some substantial differences exist in design practice because of the nature of nuclear waste, the time scale required for effective waste isolation, and the legal and regulatory environment in which waste isolation is to be engineered and managed. Sections of Part 60 of Title 10 of the Code of Federal Regulations (10CFR60) direct specific attention to technical criteria, performance objectives and design criteria which impose particular requirements in repository design and performance assessment. Compliance with 10CFR60 Regulations in general leads to a need for more extensive site characterization, consideration of a wider range of factors influencing long-term behavior of the site, and more comprehensive analysis of the performance of the site under both operating and post-closure conditions. These include geomechanics issues which arise from the regulatory environment pertaining mainly to citations concerning performance objectives related to safety, retrievability, system performance and performance of particular barriers after permanent closure. For example, 10CFR60.111(a) cites the need to assure protection, through permanent closure, against radiation exposures and releases of radioactive material. Retrievability of waste is required in the citation 10CFR60.111(b). It specifies that the geologic disposal system should be designed so that any or all of the emplaced waste could be retrieved starting at any time up to 50 years after waste emplacement is initiated. Overall system performance after permanent closure is cited in 10CFR60.112, and required performance of particular barriers after permanent closure is cited in 10CFR60.113. Interaction between the host rock mass and the waste canisters, and long-term geomechanical performance of the host rock mass, impinge directly on these performance objectives. Compliance with the regulatory citations related to safety, retrievability and long-term repository performance therefore requires analysis of the performance of the components of the system. It is generally accepted that numerical analysis will play a major role in performance assessment studies of the type required to demonstrate compliance.

In specifying suitable site conditions for a repository, 10CFR60.122 specifically requires consideration of natural phenomena and site conditions which could adversely affect achievement of the prescribed performance objectives. An important phenomenon which could conceivably affect both the short- and long-term performance of a repository is ground motion due to seismic activity. Similarly, ground motion due to underground nuclear explosions at the Nevada Test Site needs to be evaluated. Conceivably, ground motion from either source could cause rock displacements on the canister-, room- and repository-scales, any or all of which could violate the established repository performance objectives. For example, joint slip in a canister hole associated with seismically-induced ground motion might prevent canister retrievability. Falls of rock in repository emplacement rooms could result in canister damage, and increase staff exposure to radiation. Disruption of the geologic barrier after permanent closure by fault or joint displacement could significantly increase the gross permeability of the rock mass (Obert, 1967).

APPENDIX B. LIST OF ROCK MECHANICS COMPUTER CODES

[From "ISRM: Rock Engineering Software," Int. J. Rock Mech., Min. Sci. & Geomech. Abstr., 25(4), 297-250 (1988)]

		Specific Capabilities													
Code name	Label	Displacement and stress	Seepage flow analysis	Temperature distribution/ heat conduction	Rigid block stability	Evaluation of in situ and test data	Nonlinear material	Large displacement	Three dimensional	Dynamic analysis	Jointed rock	Creep	Rock salt	Construction/ excavation	Mining
FEKOST	2.A.1	X	X				X		(X)		X				
MISES 3	S.A.S	X	X	X			X		X		X			X	X
BEFE	2.AUS.1	X					X		X		X			X	X
ESB	2.AUS.2	X					X				X			X	
FEM 204	2.AUS.3	X					X				X			X	
NLECP	2.AUS.4	X					X				X			X	
QADFIN	2.AUS.5	X					X				X			X	X
GEOFSM	2.CDN.1	X					X					X	X	X	X
RHEO-STAUB	2.CH.1	X					X					X		X	
GJP-1	2.CHINA.1	X							X		X				
JR	2.CHINA.2	X					X				X				
SACRC	2.CHINA.3	X					X				X			X	
CKP	2.CSSR.1	X													X
GE	2.CSSR.2	X					X								
KAVERNA	2.CSSR.3	X					X				X			X	
MEZ-SYSTEM	2.CSSR.4		1			X	X			X			X		
NEPP-3	2.CSSR.5	X					X		X					X	
NE-XX	2.CSSR.6	X		X			X								
ZPR-SYSTEM	2.CSSR.7	X					X	X	X					X	
ASTREA	2.F.1	X		2			X				X	X			
COBEF 2	2.F.2	X													
COBEF 3	2.F.3	X					3		X						
FRAC	2.F.4	X					X	X	X			X			
GEF	2.F.5	X	4				X		X					X	
NON PIEU/GEFPIEU	2.F.6	X					X								
PAM-GEOM	2.F.7	X					X			X	X	X		X	
PLAST 3F/ELFI 3F/ MAVER 3	2.F.8	X					X				X			X	X
PREPELA	2.F.9	X												X	
PPR	2.F.10	X	X	X			X								
ROSALIE/CESAR	2.F.11	X	5	SX			X	6	X	X	X	X		X	
STRE/TLCE	2.F.12	X					X				X				
VIPLEF	2.F.13	X					X	7				X	X		X
ANSALI	2.FRG.1	X		X			X	X	X	X		X	X	XTX	
ESI-GEOMLIB	2.FRG.2	X	1	X			X	8	X	X	X	X	X	X	
FES 03	2.FRG.3	X					X		X	9	X			X	
MAUS	2.FRG.4	X					X					X	X	X	
NONSAP-B	2.FRG.5	X					X	X	X		X				
SGG-STATAN-15	2.FRG.6	X					X		X		X			X	
TUNNEL	2.FRG.7	X					X				X			X	
DAMM 9	2.GDR.1	X					X							X	
CAL-SDGRO	2.GR.1	X					X								
MSAV	2.H.1	X					X								
PFMT	2.H.2	X					X	X						X	
PANEL	2.I.1	X	X												
AXTRE	2.J.1	X					X					X			
BOLT.FORT	2.J.2	X					X							X	
C-117	2.J.3	X					X					X		X	
C-121	2.J.4	X													
C-122	2.J.5	X							X						
C-130	2.J.6	X	10												
CKCINT	2.J.7	X					X				X	X			
CKCREM	2.J.8	X					X					X	X		
COSMOS	2.J.9	X					X					X			
COUPLING	2.J.10	X	X												
EARTH-FEM	2.J.11	X	X	X			X								
ELASTO-PLASTIC	2.J.12	X													
ESPRIT	2.J.13	X					X							X	
EX2ANS	2.J.14	X					X							X	

Code name	Label	Specific Capabilities													
		Displacement and stress	Seepage flow analysis	Temperature distribution/ heat conduction	Rigid block stability	Evaluation of in situ and test data	Nonlinear material	Large displacement	Three-dimensional	Dynamic analysis	Jointed rock	Creep	Rock salt	Construction/ excavation	Mining
FELAN	2.J.15	X								X					
FEM2D	2.J.16	X					X				X			X	
GATUC	2.J.17	X					X								
GEOTECHS	2.J.18	X					X								
LINEAR-VISCOELAST	2.J.19		X					X						X	
NARS	2.J.20	X					X				X			X	
NATM	2.J.21	X					X							X	
ROCK FEM	2.J.22	X					X				X	X		X	
ROCKV9	2.J.23	X					X				X	X		X	
SIGNAS	2.J.24	X	11	X			X			X	X	X		X	
STAK	2.J.25	X					X				X			X	
STEP	2.J.26	X					X		12					X	
STRESS-ANALYSIS	2.J.27	X					X				X			X	
NEE.22	2.P.1	X							X						
NEE.62	2.P.2	X							X	13	X				
COPRESS	2.PL.1	X													
COVDR	2.PL.2	X					X	X							
MES 1	2.PL.3	X	10				X							X	
QUAD	2.RSA.1	X					X								
NOLINA	2.UK.1	X					X		X		X				
ADINA	2.USA.1	X	X	X			X	7	X	X					
BMINES	2.USA.2	X					X		X		X			X	
CIGAP	2.USA.3	X					X		X		X			X	
GEOSYS	2.USA.4	X					X		X		X			X	
JAC	2.USA.5	X					X	X			X	X			
JPLAXD	2.USA.6	X					X				X			X	
PLANE(NL)-2D	2.USA.7	X					X								
SANCHO	2.USA.8	X					X	X				X			X
SPECTROM-21	2.USA.9	X					X					X		X	
SPECTROM-11/ SPECTROM-311	2.USA.10	X					X		X		X			X	
SPECTROM-31	2.USA.11	X					X	X			X	X			
SSTIN-3D/SSTIM-2D	2.USA.12	X					X	X	X	28	X			X	
STRESEEP-2D	2.USA.13	X	X				X							X	
SUBSID	2.USA.14	X					X								
CREEP	2.USSR.1	X					X	X				X		X	X
FA-110	2.USSR.2						X								
FA-120	2.USSR.3	X					X								
FLAME	2.USSR.4	X					X								
BE2D/BE3D	3.AUS.1	X							X						
BIEMR	3.AUS.2	X									X				
BITEMJ	3.AUS.3	X									X				
NFOLD	3.AUS.4	X					14		X					X	X
RMS	3.AUS.5	X					X		X					X	X
THREED	3.AUS.6	X					X							X	X
TESA-1	3.CHINA.1	X							X						
CMN	3.CSSR.1	X							X						X
SERRE	3.F.1	X									15				
CREEP	3.FRG.1	X					X					X	X		
DIGMO	3.FRG.2	X							X					X	X
SCHLAG	3.FRG.3	X													X
SOLMIN	3.FRG.4	X							X				X	X	X
COUPL-3D	3.J.1	X					16		X						
NATM-3D	3.J.2	X					X		X			X		X	
ROCK-BEM	3.J.3	X							X					X	
SETL-3D	3.J.4	X							X			X		X	
TWIN-TUN	3.J.5	X										X		X	
BEM	3.RSA.1	X					X		X						
MBEM	3.RSA.2	X					X		X			X			

Specific Capabilities

Code name	Label	Displacement and stress	Seepage flow analysis	Temperature distribution/ heat conduction	Rigid block stability	Evaluation of in situ and test data	Nonlinear material	Large displacement	Three-dimensional	Dynamic analysis	Jointed rock	Creep	Rock salt	Construction/ excavation	Mining
NURIDE	3.RSA.3	X					X		X		X				
X															
BEMH2-SDEMHY	3.USA.1	X									X				
CAVERN/CAVIEW	3.USA.2	X										X			
FEBE	3/ISA/3	X					X							X	
HYDEBE	3.USA.4	X						17			X		X		
BLOCKS	4.AUS.1				X				X		X				
DSM	4.AUS.2	X			X		X				X				
POLY	4.CH.1				X						X				
GEOPLN	4.CDN.1				X				X		X				
GEOSTB	4.CDN.2				X				X		X				
BLOC	4.F.1	X				X		X		X		X			
TETRAROC	4.F.2		18		X				X		X				
JLWIDER	4.FRG.1		18		X				X		X				
ROCKSS	4.J.1				X						X				
WEDGE	4.RSA.1		18		X				X		X				
DAYLITE	4.USA.1				19						X				
JOINTSIM	4.USA.2				19						X				
PF3/ROTFA	4.USA.3				X										
SLOPESIM	4.USA.4				19						X				
SWARS	4.USA.5				X						X				
SWARS-2MC	4.USA.6				X						X				
SWARS-2PM	4.USA.7				X						X				
GEOSAT	5.CDN.1		X												
GEOSPG	5.CDN.2		X												
ECOUL 2	5.F.1		X												
FISSURE	5.F.2		X				20				X				
HYMEC/HYMECTR1/ MECHYD	5.F.3		X				20		X		X				
HYD 03	5.FRG.1		X						X		X				
C-212	5.J.1		X								X				
C-213	5.J.2		X						X		X				
COUPE	5.J 3		X												
DIFFUSION II	5.J.4		X				X								
GFLOW	5.J.5		X												
HBADM	5.J.6		X												
HEAT 5	5.J.7		22					X							
QUASI	5.J.8		X						X						
SEEP	5.J.9		X												
SEEPAGE	5.J.10		X												
SEEPAGE 3/SEEPAGE 2	5.J.11			X						X					
SEEPAGE-ANALYSIS	5.J.12		X												
STOFF	5.J.13		23												
UNSAF	5.J.14		X												
WAS2	5.J.15		X						X					X	
WASGR2	5.J.16		X												
QSOL	5.RSA.1	24													
FIEL2D	5.USA.1		X												
SEEP2(VM)-2D/3D	5.USA.2		X						X						
SEPROC	5.USA.3		X								X				
SPECTROM-41/ SPECTROM-341	5.USA.4		25				X		X						
SPECTROM-58	5.USA.5		26									X			
EPDSA	6.CHINA.1	X					X			X					
NT6PS	6.CHINA.2	X							X						
DSIM	6.FRG.1	X								X	X				
BRAST	6.J.1	X							27	X		X			
DAYS-2	6.J.2	X					X			X					
DY2	6.J.3	X							X	X					

Specific Capabilities

Code name	Label	Displacement and stress	Seepage flow analysis	Temperature distribution/ heat conduction	Rigid block stability	Evaluation of in situ and test data	Nonlinear material	Large displacement	Three-dimensional	Dynamic analysis	Jointed rock	Creep	Rock salt	Construction/ excavation	Mining
HONDO III	6.USA.1	X					X	X		X		X			
LAYER	6.USA.2	X					X			X					
WONDY	6.USA.3	X					X			X					
ORIENT	7.AUS.1					X									
STRSS1	7.AUS.2					X									
CELULG	7.B.1					X									
GEODAT	7.CDN.1					X									
POLARI	7.11					X									
SASM	7.1.2					X									
SASMR	7.1.3					X									
DBAP	7.J.1	X				X									
BDAP-B	7.J.2	X				X									
FENTE	7.J.3					X									
ROCK TEST	7.J.4					X									
AGRUALL1	7.P.1					X									
AGRUAMIN	7.P.2					X									
DESDIAFR/DEDIFRAI/ DESODIFR	7.P.3					X									
SOMAGRUP	7.P.4					X									
JOINT-ANALYSIS-SYSTEM	7.RSA.1					X									
ROSE	7.RSA.2					X									
FDND	7.USA.1					29				X					
FRACTWO	7.USA.2					X									
JANAL	7.USA.3					X									
ORIENTAN	7.USA.4					X									
PROBE	7.USA.5					X									

1 Coupled consolidation.
2 Can be coupled with nonlinear transient thermal analysis.
3 Extension NOTEM 3.
4 Coupled consolidation or transient seepage (GEFLAP).
5 Including 2-D-elastoplastic consolidation.
6 Two-dimensional.
7 Large displacements and large strains.
8 Large displacements, large strains and slide-lines
9 Special version: FEST D3.
10 Pore pressure considered.
11 Saturated unsaturated seepage, consolidation
12 Plane strain, but 3-D-effects of tunnel face progression being considered in 2-D-scheme.
13 Capability of coupled dynamic interaction with 3-D-reservoirs.
14 Non-elastic crushing, sliding, and separation on mining planes and faults can be considered.
15 Specially designed for fracture propagation problems.
16 Planned.
17 In the discrete element domain.
18 Pore pressure as input.
19 Probabilistic approach.
20 Can be coupled with stress analysis (iteratively).
21 Seepage, diffusion, adsorption and absorption.
22 Heat conduction analysis.
23 Generalized computer code for analysis of solution transport with dispersion.
24 Solute transport can be considered.
25 Conductive and convective heat transfer analysis.
26 Brine transport in rock salt.
27 Plane strain, but 3-D-blasting effects can be considered.
28 Program SSTN (DYN)-2-D
29 Evaluation of displacements of jointed rock mass in form of an idealized cylinder.