OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT ANALYSIS/MODEL COVER SHEET

Complete Only Applicable Items

1. QA: N/A

2. ☒ Analysis — Check all that apply

Type of Analysis	☒ Engineering ☐ Performance Assessment ☐ Scientific
Intended Use of Analysis	☐ Input to Calculation ☐ Input to another Analysis or Model ☒ Input to Technical Document ☐ Input to other Technical Products

Describe use:

Update electrical system to current configuration

3. ☐ Model — Check all that apply

Type of Model	☐ Conceptual Model ☐ Abstraction Model ☐ Mathematical Model ☐ System Model ☐ Process Model
Intended Use of Model	☐ Input to Calculation ☐ Input to another Model or Analysis ☐ Input to Technical Document ☐ Input to other Technical Products

Describe use:

4. Title:

ELECTRICAL SUBSURFACE GROUNDING ANALYSIS

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

BABFAA000-01717-0200-00109 REV 01

6. Total Attachments:

1

7. Attachment Numbers - No. of Pages in Each:

I-2

		Printed Name	Signature	Date
8.	Originator	J. M. Calle	[signature]	10/11/00
9.	Checker	W. J. Reed	William J. Reed	11/01/00
10.	Lead/Supervisor	W. J. Reed	William J. Reed	11/01/00
11.	Responsible Manager	L. R. Morrison	Lawrence R. [signature]	11/1/00

12. Remarks: None

EDITORIAL COMMENTS ON PAGE 5 AND PAGE 14 WR 12/4/00

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

Complete Only Applicable Items

2. Analysis or Model Title:

ELECTRICAL SUBSURFACE GROUNDING ANALYSIS

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

BABFAA000-01717-0200-00109 REV 01

4. Revision/Change No.	5. Description of Revision/Change
00	Issued to LRC.
01	The entire analysis was revised because the changes were too extensive as indicated in detail below. In addition, the analysis was revised to meet the requirements of procedure AP-3.10Q. Section 4, Inputs, was entirely revised because the input data became available and because it was based on versions of the ESFDR that have since been superseded. Section 5, Assumptions, many of the items in this section were deleted. Section 6, Analysis, was extensively revised because the calculations were performed using the ETAP program.

CONTENTS

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FIGURES

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ACRONYMS AND ABBREVIATIONS

Acronyms

ECRB	Enhanced Characterization of the Repository Block
ESF	Exploratory Studies Facility
ETAP	Electrical Transient Analyzer Program
MPC	mine power center
NEC	National Electrical Code
NTS	Nevada Test Site
SSPC	subsurface power center

Abbreviations

A	amp
AWG	American wire gauge
ft	foot
in.	inch
kcmil	kilo circular mils
kV	kilovolt
kW	kilowatt
m	meter
MVA	megavolt ampere
V	volt
XFMR	transformer

1. PURPOSE

The purpose and objective of this analysis is to determine the present grounding requirements of the Exploratory Studies Facility (ESF) subsurface electrical system and to verify that the actual grounding system and devices satisfy the requirements.

2. QUALITY ASSURANCE

No quality assurance controls apply to the items or activities addressed in this design analysis. The items addressed in this design analysis are temporary and are therefore not classified in accordance with QAP-2-3, *Classification of Permanent Items*, nor are any activities subject to the quality assurance requirements found in *Determination of Importance Evaluation for the Subsurface Exploratory Studies Facility* (CRWMS M&O 1999b). This design activity has been evaluated in accordance with AP-2.16Q, A*ctivity Evaluation*, and has been determined to not be subject to the requirements of *Quality Assurance Requirements and Description* (DOE 2000). QA: N/A.

This design analysis has been prepared in accordance with AP-3.10Q, *Analyses and Models*, which lists the requirements, additional project documents, definitions, responsibilities, etc., to be considered in the preparation of this analysis.

3. COMPUTER SOFTWARE AND MODEL USAGE

The Electrical Transient Analyzer Program (ETAP) Nuclear Version revision 7.35N produced by Operation Technology, Inc. was used to perform ground grid design calculations. This program is suitable for this application.

The ETAP program was purchased by the project and is controlled and managed by the Information Technology Department. The ETAP tracking number is 602299.

4. INPUTS

4.1 PARAMETERS

The main configuration of the ESF electrical system is displayed on the one-line diagram shown in Figure 1. The electrical parameters are actual values extracted from equipment nameplates and from the *Subsurface Mine Power Centers Operations and Maintenance Manual* (CRWMS M&O 1995). Following is a description of the ESF electrical system and its major components.

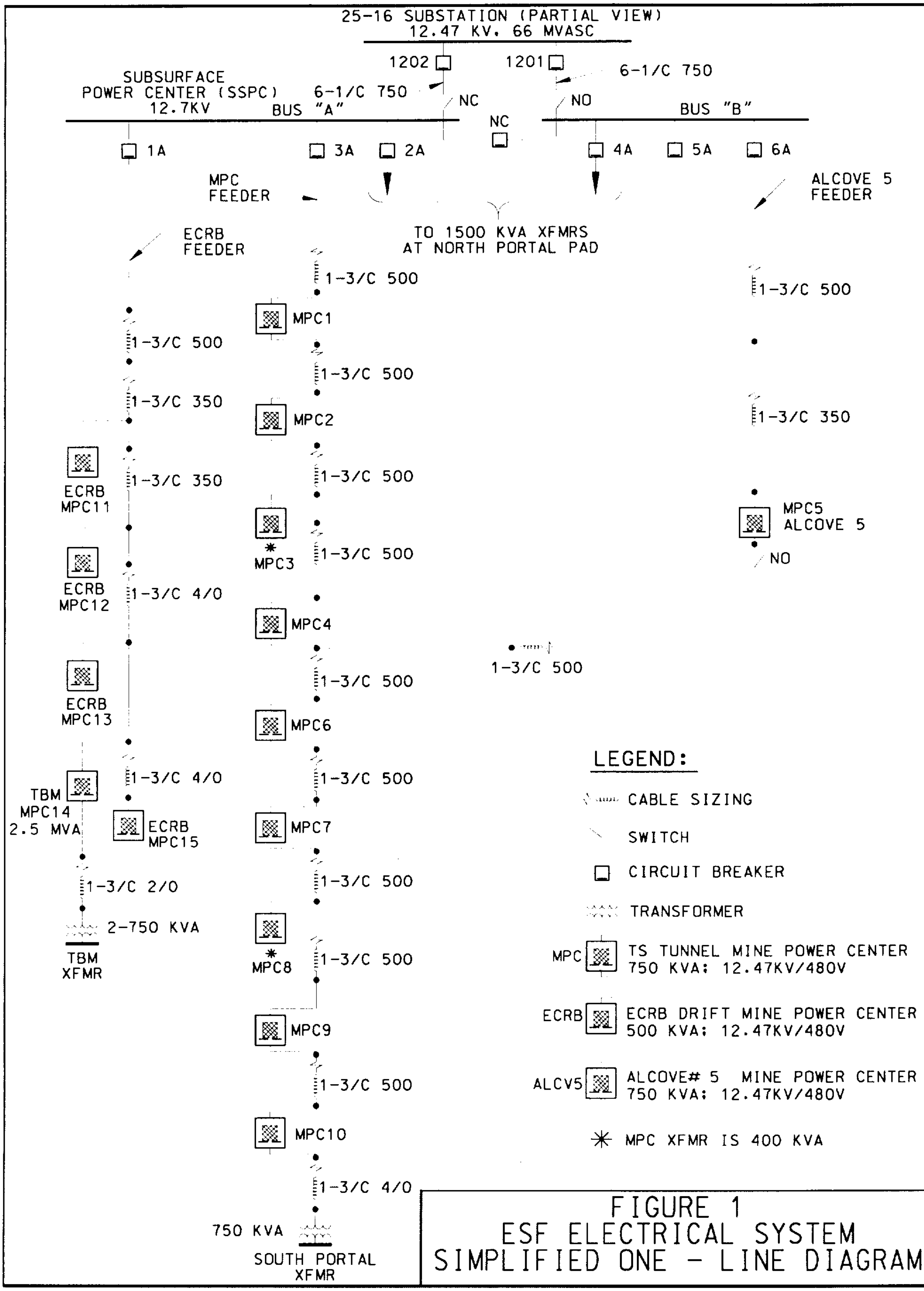

FIGURE 1
ESF ELECTRICAL SYSTEM
SIMPLIFIED ONE - LINE DIAGRAM

4.1.1 Nevada Test Site (NTS) Power Service: The NTS 69-kV feeder originates from Canyon Substation. This feed provides power to the north portal 25-16 substation. At this substation, NTS's 69-kV transmission system voltage is stepped down to 12.47 kV through a 10-MVA transformer. Two 12.47-kV feeders from breakers 1201 and 1202 provide power to the north portal subsurface power center (SSPC), which houses the subsurface distribution switchgear.

4.1.2 Subsurface Power Distribution System: All electrical power for the subsurface drifts and the north and south portal areas originates from the medium-voltage switchgear housed in the SSPC. Three mine power feeders leave the SSPC at 12.47 kV. These three feeders are referred to as the mine power center (MPC) feeder, the Enhanced Characterization of the Repository Block (ECRB) feeder, and the Alcove 5 feeder. The MPC feeder provides power to the Topopah Spring tunnel, its alcoves/niches, and the south portal; the ECRB feeder provides power to the ECRB cross-drift and its alcoves/niches; and the Alcove 5 feeder provides power to the Alcove 5 Heated Drift Test, which has backup power from the north portal standby generators.

These feeders provide power primarily to MPCs, which are mine-type substations used for tunnel construction. The MPC characteristics were extracted from the *Subsurface Mine Power Centers Operations and Maintenance Manual* (CRWMS M&O 1995). The MPCs step down the subsurface distribution voltage of 12.47 kV to the utilization voltages needed to run electrical equipment, such as motor loads, mini-power centers, and tunnel lighting loads, at 480 V. Alcove 5 also has low-voltage automatic transfer switches that transfer Alcove 5 test loads to the MPC feeder when power is lost on the normal Alcove 5 feeder. The SSPC also provides 480-V power at the north portal pad for some of the conveyor drives, trailers, portal lighting, and other miscellaneous equipment.

4.1.3 MPC transformers supplying mobile equipment and the 2500-kVA transformer supporting the ECRB TBM have their secondary neutral grounded through a resistor. All these resistors are connected to a 4/0 AWG grounding wire that is installed along the tunnel. The grounding wire originates at the safety-grounding grid, which is buried on the north portal pad approximately 67 m (220 ft) from the tunnel entrance.

4.1.4 The safety-grounding grid has a rectangular configuration. Its overall dimensions are 30.5 m (100 ft) by 9.15 m (30 ft); the grid is built with medium-hard copper 4/0 AWG conductors spaced approximately 3 m (10 ft) apart. Ten ground rods are located along the perimeter of the grid. The ground rods are copper-clad steel 3 m (10 ft) long by 0.0191 m (3/4 in.) in diameter and the grid is buried approximately 0.6 m (2 ft) below grade.

4.1.5 Short-circuit currents available at the ESF electrical system were obtained from the *Electrical Subsurface Short Circuit Analysis* (CRWMS M&O 2000).

4.1.6 Soil electrical resistivity data are included in "ESF Site Grounding Soil Resistivity Test Data" (Reed 2000), *Design Coordination Routing for YMP North Portal Grounding Mat (Markiewicz* 1993a), and *Yucca Mountain Project – Bureau of Reclamation Electrical Resistivity Survey Field Data Record* (Markiewicz 1993b).

4.2 CRITERIA

The following criteria were developed to respond to the requirements presented in the *Exploratory Studies Facility Design Requirements* (YMP 1997) and *Title III Evaluation Report for the Surface and Subsurface Power System* (CRWMS M&O 1999a). These criteria specifically apply to this analysis. The applicable requirements are cited for each statement.

4.2.1 Suitable switching and protective devices shall be provided in the electrical system to prevent damage to the equipment in case of power failure or faults (YMP 1997, Section 3.8.2.2.1.D). Ground-fault currents shall be routed directly to the earth through a permanent grounding system.

4.2.2 The ESF non-permanent items shall be designed for a 25-year maintainable service life (YMP 1997, Section 3.2.1.2.2.A). The ESF grounding system shall be inspected and tested periodically.

4.2.3 The ESF grounding system shall be designed to comply with the applicable requirements of DOE Order 6430.1A (YMP 1997, Section 3.2.1.2.4.C). All electrical systems shall comply with the National Electrical Code (NEC). Section 250-188 of the NEC (NFPA 70-1998) establishes specific requirements for grounding of systems supplying portable or mobile equipment.

4.2.4 A grounding system shall be provided for personnel safety and equipment protection (YMP 1997, Section 3.8.2.2.1.G). The ESF electrical system shall be connected to earth in a manner that will limit the voltage imposed by abnormal situations such as transient overvoltage, lightning strikes, and short-circuit faults.

4.2.5 Underground high-voltage (1000 volts or more) feeders supplying mobile equipment shall have a ground check circuit to continuously monitor the grounding circuit to ensure continuity (YMP 1997, Section 3.8.2.2.1.M). Medium-voltage cable feeders shall include a ground check conductor, and ground check relays must be installed in the distribution switchgear.

4.2.6 Utility lines, steel supports, and other conducting structures supporting electrical systems shall be electrically bonded and reliably connected to the subsurface electrical safety grounding network (YMP 1997, Section 3.8.2.2.1.O). Connection to ground shall be accomplished in a manner that safely limits the voltage level on these components.

4.3 CODES AND STANDARDS

4.3.1 INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS

ANSI/IEEE 80-86 — *Guide for Safety in AC Substation Grounding*, 1986

ANSI/IEEE 81-83	*Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System*, 1983
ANSI/IEEE 142-91	*Recommended Practice for Grounding of Industrial and Commercial Power Systems*, 1991

4.3.2 NATIONAL FIRE PROTECTION ASSOCIATION

NFPA 70 1998	*National Electrical Code*, 1999 Edition

4.3.3 U.S. DEPARTMENT OF ENERGY

DOE Order 6430.1A	*General Design Criteria for DOE Facilities*, April 6, 1989 (DOE Order 6430.1A was canceled by DOE Order 420.1).

5. ASSUMPTIONS

The following assumptions have been used as input data required to run the ETAP computer program (Attachment I).

5.1 Normally, two-level strata have decreasing resistivities from the upper level to the lower level. However, field measurements from 1992 and 1993 indicate that the resistivity increases with depth; therefore, it is assumed that adopting the highest values of resistivity encountered will ensure conservative results (used in Section 6.2).

5.2 The U.S. Bureau of Reclamation's 1992 resistivity measurements (Markiewicz 1993b) were verified by new measurements in 1993 (Reed 2000). The latter measurements were obtained using a calibrated earth-resistivity meter, and the testing was performed after the excavation and fill work had taken place at the ESF north portal pad. Consequently, for this analysis, earth-resistivity values were extracted from the new measurements (Reed 2000) (used in Section 6.2).

5.3 Soil moisture content was not considered for this analysis. The amount of moisture present on the day that measurements were collected in 1992 (Markiewicz 1993b) and 1993 (Reed 2000) is negligible when paralleling upper and lower ground paths at significant distances and averages out (used in Section 6.1).

5.4 The calculations are based on data resulting from soil surveys made by others, and it is assumed that ground resistance measurements in the field were made in accordance with applicable standards, such as ANSI/IEEE 81-83 (used in Section 6.2).

5.5 The safety-grounding grid was constructed as specified in the previous revision of this document. The grid consists of a 30.5-meter by 9.15-meter grid made of 4/0 AWG conductor spaced 3 meters apart. Ten 3-meter-long and 0.0254-meter-diameter rods, which are embedded in 20-cm-diameter holes backfilled with conductivity-enhancing material, are welded to the perimeter of the grid, as depicted in Figure 2. The grid is buried 0.6 meter below grade (used in Section 6.1).

6. ANALYSIS

6.1 The ESF electrical system supplies power mainly to mine-type equipment such as tunnel-boring machines (TBMs), road-headers, drills, etc., which the NEC defines as mobile equipment. NEC (NFPA 70 1998) Section 4.2.3 provides specific requirements for grounding the electrical system supplying power to mobile equipment. These requirements also include the criteria in Section 4.2. Subsequent paragraphs discuss the means by which the ESF grounding system complies with the criteria requirements.

MPC transformers supplying mobile equipment and the 2500-kVA transformer supporting the ECBR TBM have their secondary neutral grounded through a resistor. All these resistors are connected to a 4/0 AWG grounding wire that is installed along the tunnel. The grounding wire originates at the safety-grounding grid, which is buried on the north portal pad approximately 67 m (220 ft) from the tunnel entrance, as shown in Figure 2. The safety-grounding grid is isolated and separated at least 7.62 m (25 ft) from any grounding system attached to the utility substation grounding grid.

All of the exposed noncurrent-carrying metal parts of the mobile equipment are connected to the same 4/0 AWG grounding conductor to which the neutral resistors are connected and thus connected to the remote safety-grounding grid.

The safety-grounding grid has a rectangular configuration, as illustrated in Figure 2. Its overall dimensions are 30.5 m (100 ft) by 9.15 m (30 ft); the grid is built with medium-hard copper 4/0 AWG conductors spaced approximately 3 m (10 ft) apart. Ten ground rods are welded to the perimeter of the grid, as shown in Figure 2. The grid is buried approximately 0.6 m (2 ft) below grade, and the ground rods are copper-clad steel 3 m (10 ft) long by 0.0127 m (3/4 in.) in diameter.

The 12.47-kV distribution feeders are mine-type cables, which include grounding conductors as well as a ground pilot conductor to monitor the continuity of the returning path. Ground check relays installed in the SSPC continuously monitor the continuity of the feeder grounding conductors, so that the grounding conductor's 12.47-kV power circuit is de-energized if the grounding conductor path is interrupted.

Lightning protection is provided at the tunnel entrances of the north and south portals. At each location there are three lightning air terminals placed in high poles to protect the area adjacent to the portal, including the safety-grounding grid, from lightning strikes.

The safety-grounding grid was designed and implemented to provide a low resistance to earth. ANSI/IEEE 142-91 Section 4.1.2 recommends that the resistance to earth to be between 1 and 5 ohms. The following section includes calculation method and results.

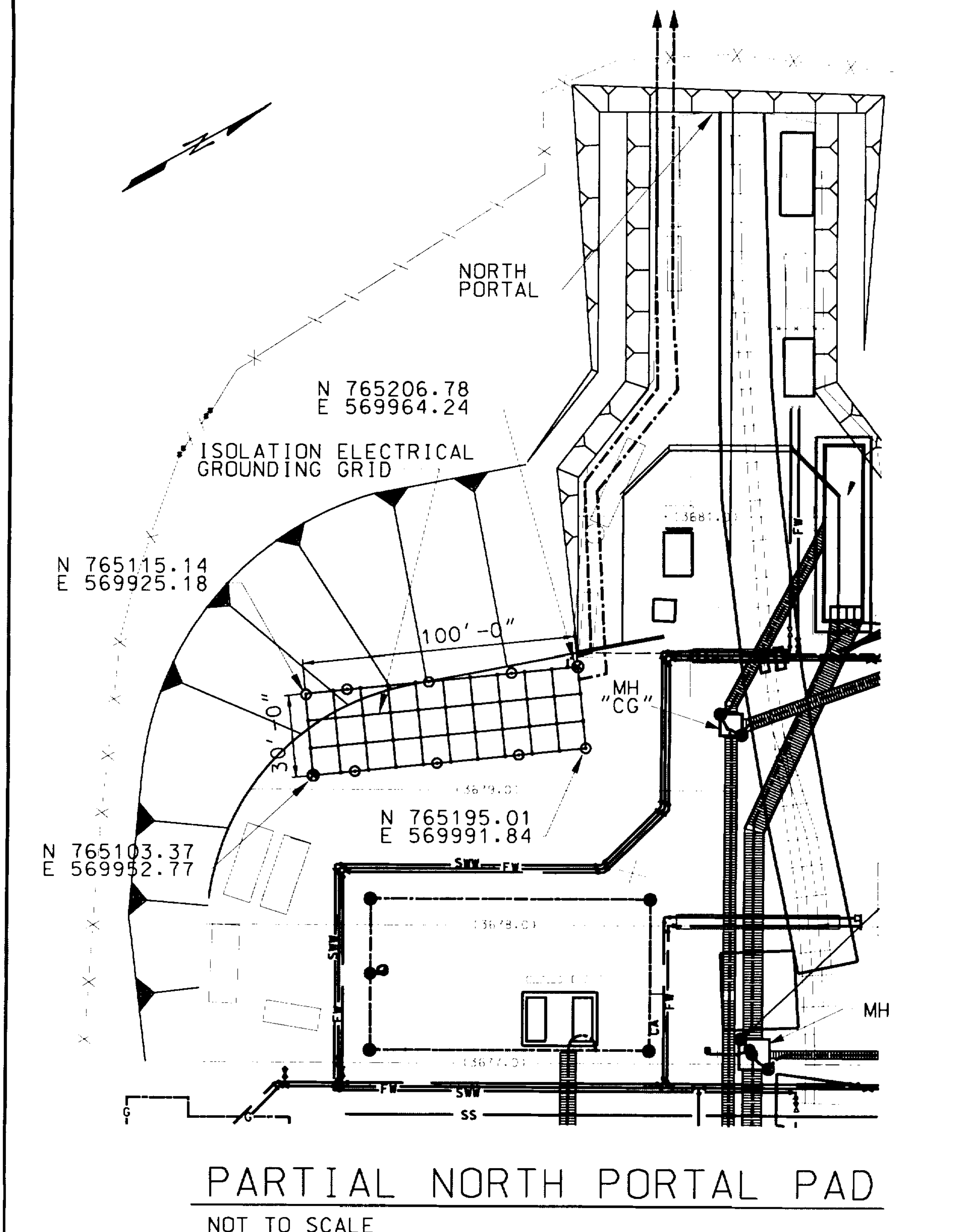

FIGURE 2
ESF SUBSURFACE SAFETY-GROUNDING GRID LOCATION

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6.2 The resistance calculation for the safety-grounding grid was performed using ETAP version 7.35N. The ETAP calculation method is based on the algorithm described in ANSI/IEEE 80-86 Section 12.

Input data for the ETAP calculation program includes the soil resistivity, grounding material characteristics, and the geometrical configuration of the grid. Another critical factor is the short-circuit current expected on the electrical system.

The soil resistivity values and testing methods used are contained in "ESF Site rounding Soil Resistivity Test Data," with attachments (Reed 2000), *Design Coordination Routing for YMP North Portal Grounding Map* (Markiewicz 1993ba), and *Yucca Mountain Project – Bureau of Reclamation Electrical Resistivity Survey Field Data Record* (Markiewicz 1993b). The average soil resistivity determined for this calculation is 150 ohm-m, which is based on values measured at locations P4, P5, and P7 near the north portal.

Grid wire and ground rod characteristics, as well as the safety grid geometrical configuration, which are described in Section 6.1 above, were introduced into the ETAP program.

The short-circuit current available from the electrical system was extracted from the *Electrical Subsurface Short Circuit Analysis* (CRWMS M&O 2000). The short-circuit current available at the 12.47-kV SSPC switchgear was chosen as the worst-case scenario, even though larger short-circuit currents at 480 V were calculated. The 480 V circuits are localized within small areas diminishing any effects of voltage gradients.

ETAP calculation result for the grid-to-earth resistance is 3.99 ohms. To comply with the recommendations of ANSI/IEEE 142-91 that the safety ground to earth should be between 2 and 5 ohms, the latter value shall not be exceeded. Consequently, the grounding conductor resistance from any point in the subsurface electrical system to the safety-grounding bed shall not exceed 1 ohm.

The 4/0 bare copper ground conductor extends 7,877 meters (25,843 feet) from the north portal to the south portal. NEC (NFPA 70 1998) Table 8 shows the direct-current resistance of 4/0 copper wire equal to 0.0626 ohms/1,000 feet or 1.62 ohms. Therefore, to reduce this value to less than 1 ohm, an additional 4/0 copper wire should be installed from the north portal to the south portal. This conductor should be bonded to the existing 4/0 copper wire at intervals not exceeding 304.9 meters (1,000 feet).

7. CONCLUSIONS

The ETAP calculated ground resistance of 3.99 ohms included in Attachment 1 is within the range recommended in Section 6.1.

7.1 The grid-to-earth resistance value of 3.99 ohms does not include any adjustment that could be made for using chemical compounds around the electrodes to lower the soil resistivity. Therefore, this result should be considered as a conservative value

7.2 To comply with the recommendations of ANSI/IEEE 142-91, the 4/0 AWG grounding conductor that extends from the safety-grounding grid to the electrical equipment installed throughout the subsurface facility should be upgraded by adding another 4/0 conductor in parallel to reduce the resistance to ground to 1 ohm and to increase the grounding system reliability. This conductor should be bonded to the existing 4/0 AWG cable at intervals not exceeding 304.9 meters (1,000 feet).

7.4 Periodical testing of the grid-to-earth resistance is recommended to verify that the resistance values remain within the 5-ohm criteria throughout the life of the ESF.

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

8. REFERENCES

8.1 DOCUMENTS CITED

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1995. *Subsurface Mine Power Centers Operations and Maintenance Manual.* BABFAA000-01717-6300-16475-VD-16 REV 0. Las Vegas, Nevada: CRWMS M&O. ACC: DRC.19960925.0139.

CRWMS M&O 1999a. *Title III Evaluation Report for the Surface and Subsurface Power System.* BAB000000-01717-5705-00015 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990915.0114.

CRWMS M&O 1999b. *Determination of Importance Evaluation for the Subsurface Exploratory Studies Facility.* BAB000000-01717-2200-00005 REV 07 ICN 03. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990728.0282.

CRWMS M&O 2000. *Electrical Subsurface Short Circuit Analysis.* BABFAA000-01717-0200-00104 REV 01. Las Vegas, Nevada: CRWMS M&O. URN-0486.

DOE (U.S. Department of Energy) 2000. *Quality Assurance Requirements and Description* DOE/RW-0333P, Rev 9. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19991028.0012.

Markiewicz, R. 1993a. *Design Coordination Routing for YMP North Portal Grounding Mat.* Data from R. Markiewicz to USGS, February 23, 1993. ACC: MOL.19980115.0161.

Markiewicz, R. 1993b. *Yucca Mountain Project – Bureau of Reclamation Electrical Resistivity Survey Field Data Record.* Data from R. Markiewicz to USGS, February 23, 1993. ACC: MOL.19980115.0162.

Reed, W.J. 2000. "ESF Site Grounding Soil Resistivity Test Data." Interoffice correspondence from W.J. Reed (CRWMS M&O) to Mary Woods (CRWMS M&O), June 15, 2000, LV.TFDS.WJR.06/00-42, with attachments. ACC: MOL.20000616.0250.

YMP (Yucca Mountain Site Characterization Project) 1997. *Exploratory Studies Facility Design Requirements*. YMP/CM-0019, REV 02 ICN 01. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.19980107.0544; MOL.19960926.0065.

8.2 CODES, STANDARDS AND PROCEDURES

ANSI/IEEE 80-86. *Guide for Safety in AC Substation Grounding*, 1986. New York, New York: Institute of Electrical and Electronic Engineers. TIC: 6557.

ANSI/IEEE 81-83. *Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System,* 1983. New York, New York: Institute of Electrical and Electronic Engineers. TIC: 232605.

ANSI/IEEE 142-91. *Recommended Practice for Grounding of Industrial and Commercial Power Systems*, 1982. New York, New York: Institute of Electrical and Electronic Engineers. TIC: 235220.

AP-3.10Q, Rev. 2, ICN 3. *Analyses and Models.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000918.0282.

AP-2.16Q, Rev. 0, ICN 0. *Activity Evaluation.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000207.0716.

DOE Order 420.1, Change 2. 1996. *Facility Safety.* Washington, D.C.: U.S. Department of Energy. Readily available.

DOE Order 6430.1A. 1989. *General Design Criteria for DOE Facilities.* Washington, D.C.: U.S. Department of Energy. Readily available.

NFPA 70 1998. *National Electrical Code* 1999 Edition. Quincy, Massachusetts: National Fire Protection Association. TIC: 240528.

QAP-2-3, Rev. 10. *Classification of Permanent Items.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990316.0006.

9. ATTACHMENTS

Attachment	Title
I	ETAP COMPUTER PRINTOUT

ATTACHMENT I

ETAP COMPUTER PRINTOUT

GROUND GRID DESIGN - IEEE 80 METHOD

Project: ESF ELECT SYSTEM GND GRI	ETAP 7.35	Page: 1
Location: Nevada Test Site, NV		Date: 10-12-2000
Contract: 3969F644		SN: 91MKC00625
Engineer: J. Calle	Study Case: Gnd Grid	File: ESFGNGRI

Safety ground grid calculation for the ESF subsurface electrical system.

SYSTEM PARAMETERS:

Frequency	= 60 Hz	Short Circuit Current	= 3100 amperes
Avg. Weight of Worker	= 50 kg	Short Circuit Time	= 0.08 seconds
Ambient Temperature	= 50 øF	X/R ratio	= 9.9

GROUND INFORMATION:

	Resistivity (ohm-m)	Depth (ft)
Surface Material:	150	0.60
Upper Layer:	150	1.00
Lower Layer:	150	

GRID DATA:

	Length (ft)	No. of Parallel Conductors
Longer side:	100.0	4
Shorter side:	30.0	11

Grid Depth = 1.64 ft Total Conductor Length = 730.0 ft

CONDUCTOR DATA:

Size = 210.00 kcmil Material: Annealed Soft Cu

Maximum Allowable Current Before Melting: 111130 amperes

RODS:

Number of Rods = 10 Diameter = 0.750 in

Average Length = 10.0 ft Arrangement: Rods on grid perimeter

RESULTS:

	Actual	Tolerable
Touch Potential (volts)	2191.9	502.4
Step Potential (volts)	2700.3	779.2

Resistance of Ground System = 3.985 ohm

Ground Potential Rise (GPR) = 14152 volts

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