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In This Issue . . .

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***Cover photographs*:** (*left*) Unsealed aluminum thermal spray systems tested after 5,040 hours. (a) DHS solution, (b) Prohesion cycle, (c) BOR cycle.

(*right*) Effect of thin seal: Aluminum-Al_2O_3 systems tested in the BOR corrosion test cycle after 5,040 hours. (a) Amercoat seal, (b) Metco, (c) unsealed.

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GEOPHYSICAL SURVEY FOR CANAL SEEPAGE – YUMA AREA DEMONSTRATION PROJECT

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Background

The U.S. Department of the Interior, Bureau of Reclamation (Reclamation) is investigating canal seepage in five water districts within the Yuma Area Office jurisdiction. The canals are part of a large network of unlined irrigation canals fed by the Colorado River. Groundwater in this area typically has a higher salinity level than the relatively fresh water in the canals. In addition to the concern over the loss of fresh water, seepage losses from canals can cause damage to surrounding crops by raising the levels of high-salinity groundwater in localized areas.

The use of surface geophysics has proved effective in locating and characterizing canal seepage. Geophysical surveys can provide a rapid, spatially dense sampling of subsurface conditions in a non-invasive manner. In Australia, geophysical surveys are recommended as the most accurate method for assessing relative seepage in large-scale surveys (IAL, 2008). Electrical resistivity and electromagnetics are the most common geophysical methods used for seepage investigations. Electrical resistivity is a proven, state-of-practice tool for the mapping of canal seepage (IAL, 2008; Wan and Khan, 2007; Engelbert, et al., 1997), and when calibrated, resistivity can provide an estimate of seepage velocity (White, 1994).

Scope

Reclamation's Yuma Area Office retained Technos, Inc. (Technos), to carry out a geophysical investigation as a demonstration project to show how surface geophysics can be utilized for rapid assessment of seepage in irrigation canals. Six unlined canals in five water districts located in Arizona and California were chosen for the demonstration project (table 1).

Marine resistivity data were acquired along a total of 45.3 miles of canals (table 1). The marine resistivity data were used to develop electrical conductivity cross-sections and plan view maps along each of the survey lines. The marine resistivity data were acquired between October 29 and November 6, 2008.

Table 1.—Survey areas

District	Canal	Survey length (miles)
Yuma County Water Users	East Main	8.4
Yuma County Water Users	Central	4.8
Bard	Mohave Lateral	3.5
Imperial	East Highline	11.5
GGMC Admin Board	Gila Gravity	13.9
Colorado River Indian Tribes (CRIT)	73-19-36 (referred to as CRIT in this article)	3.2

Two anomalous locations within each water district site were selected for followup investigations utilizing a land-based resistivity survey. The land-based resistivity data were acquired between December 5 and 12, 2008. Wells were drilled at each location, and alluvium samples were obtained for sieve analysis by Reclamation. Geophysical logs were also acquired within each of the wells by a Reclamation subcontractor.

This report summarizes the methodology, survey parameters, limitations, and results for all resistivity measurements. Correlations are made to quantify the relationship between ground conductivity values and alluvium composition, which can then be used to characterize seepage potential.

Technical Approach

Survey Lines

Survey lines within the canals were defined by Reclamation as shown in table 1. Survey lines within each canal were broken into segments. The segment endpoints corresponded to physical obstructions within the canals such as road crossings, control structures, and gates. Data were not acquired in short segments between structures (<500 feet) due to the length of the marine resistivity array.

Positions within the canals were obtained with a Lowrance LMS-520c differential GPS with a lateral accuracy of +/-3 feet. The GPS positions were recorded with the marine resistivity data at 1-second intervals. Marine resistivity cross-sections are referenced to distance in feet from starting points. Geographic positions along the cross-sections are annotated as latitude and longitude using the NAD-83 datum.

The locations of the land resistivity arrays were established with a Trimble Ag-132 differential GPS with a lateral accuracy of +/-3 feet. Positions along the land resistivity lines are referenced to distance in feet. Data were acquired along survey lines oriented roughly parallel and perpendicular to the canals.

Electrical Resistivity

Overview

Resistivity measurements are made by placing electrodes in contact with the soil or water. A DC electrical current is injected between one pair of electrodes while the voltage across the other pair of electrodes is measured. The resistivity measurement represents the apparent resistivity averaged over a volume of the earth determined by the resistivity of the subsurface materials, along with the electrode geometry and spacing (ASTM, 2005).

In this study, the resistivity data are presented as electrical conductivity (inverse of resistivity) in units of milliSiemens/meter (mS/m). The conductivity of coarse-grained materials such as sand and gravel is generally lower than that of fine-grained materials such as silts and clays. Since coarse-grained materials have a higher hydraulic permeability than fine-grained materials, seepage rates will generally be higher in coarser-grained materials (Reclamation, 1965; Houk, 1956; and Davis, 1952). Therefore, lower electrical conductivity values generally correspond to areas of high potential seepage (Engelbert, et al., 1997). Exceptions to this can occur in areas where the influence of shallow groundwater dominates the measurement.

Marine Data Acquisition

Marine data were acquired with an AGI SuperSting marine system using a cable towed on the water surface with an electrode spacing of 6 meters. The cable was towed upstream to keep the cable straight. An average current of 1 ampere was injected by the nearest two electrodes to the tow point. Eight dipole-dipole measurements were made at approximately 4-second (10-foot) intervals as the cable was towed along the survey lines at an average speed of 1.8 miles per hour. In the East Main, East Highline, and Gila Gravity Canals, the cable was towed by an inflatable boat. Water depths were recorded by the Lowrance LMS-520c and used in the data processing.

In the Central, Mohave, and CRIT Canals, the cable was towed by a vehicle and personnel walking along the adjacent roads. Note that the GPS data were acquired from the vehicle on the adjacent road, and water depths were estimated.

Canal water-specific conductance values were obtained with a YSI 3000 T-L-C meter. The specific conductance and depth of the water were used in the resistivity modeling.

Land Data Acquisition

Land resistivity data were acquired at two locations within each of the five water district study areas. The locations were selected based on the results of the marine data. At each location, measurements were obtained roughly parallel and perpendicular to the canal (except at Gila-Land-2, where an additional parallel line was substituted for the perpendicular line).

Land resistivity data were acquired with an AGI R1IP Sting/Swift system using 56 electrodes spaced 5 feet apart (covering a linear distance of 275 feet). The electrodes were attached to stainless steel stakes hammered into the ground. Water was poured around each stake to improve electrical coupling. Dipole-dipole measurements were made with maximum input currents of 200 or 500 milliamperes depending upon the local soil conditions.

Data Processing

The marine resistivity data were processed with EarthImager software by AGI. Data points having low signal levels (<0.2 millivolts) or discontinuous values were removed from the dataset prior to modeling. An iterative inversion modeling scheme was used to calculate two-dimensional (2D) models of subsurface conductivity to a depth of 45 feet.

The land resistivity data were processed with RES2DINV software by Loke. Noisy data points (>5 percent [%] RMS error) were removed from the dataset prior to modeling. An iterative least-squares inversion was used to calculate 2D models of subsurface conductivity to a depth of 45 feet.

The resulting models were contoured and presented as 2D conductivity cross-sections in SURFER software (Golden Software). The models are shown using a constant conductivity scale to allow direct comparison among the different survey lines. Average conductivity values from the canal bottom to a depth of 45 feet were calculated and shown in plan view to illustrate the general conductivity variations along each canal.

Data Quality and Repeatability

As a quality control measure, resistivity data were acquired twice along a segment of the Gila Gravity Canal. The data were acquired on different days and processed separately. The resulting models confirm that the measurements are repeatable and that small variations in the path of the electrode array do not have a significant effect on the models.

The quality of the marine and land resistivity data is excellent, with generally continuous data having a high signal-to-noise ratio. Marine model RMS errors are less than 5%, indicating a good fit between the calculated model and measured data. Land model RMS errors range between 1.7 and 14.8%, with higher RMS errors generally due to heterogeneities in the near-surface materials.

Marine Model Resolution and Detectability

In wide canals (>45 feet), the conductivity is representative of the water in the canal and the sub-bottom materials. In narrow canals, materials along the sides of the canal can influence the measurements, and therefore, the conductivity is representative of the water in the canal, sub-bottom materials, and materials along the sides of the canals.

The lateral resolution is mainly dependent upon the electrode spacing. The model blocks in the resistivity inversion have widths of approximately 2.5 feet. The model resistivity values were gridded at a 10-foot lateral spacing to show a smooth model. Depending on the resistivity contrast, features smaller than this spacing may be detectable, but their response will be averaged over this 10-foot interval.

The vertical resolution of resistivity measurements decreases with increasing depth. A conservative rule-of-thumb is that the thickness of the modeled layers can only be defined to within 30% of the depth of the strata. It is possible to detect layers that are thinner than 30% of the depth, but unlikely to resolve them into separate layers or calculate their true thickness. The models consist of 16 layers ranging in thickness from 1 foot at the surface to 5 feet at a depth of 45 feet.

Limitations

Resistivity models can contain artifacts due to interference of grounded metal objects such as utility lines, railroad tracks, and fences. These artifacts are annotated on the resistivity cross-sections presented in this report.

Results

General Observations

The unlined canals cut through alluvial sediments consisting of a broad mix of sands, silts, and clays. Table 2 summarizes the general conditions within each of the canals. Specific conductance measurements of the canal water have a median value of 1,010 microSiemens/centimeter (μS/cm) or 101 mS/m, with the lowest

Table 2.—Canal conditions

Canal	Surface conditions	Survey direction (upstream)	Canal water conductivity (µS/cm)	Canal width (feet)	Canal depth (feet)	Ground-water depth (feet)
East Main	Sandy/silty	S → N	1,020	20–50	2–6	4–8[a]
Central	Silty/clayey	W → E	1,040	20–40	2–4 (estimated)	6–8[a]
Mohave	Silty/clayey	S → N	1,000	10–40	1–4 (estimated)	14–18[b]
East Highline	Sandy	N → S	995 (south) 1,030 (north)	100–130	5–9	<5[c]
Gila	Sandy gravel	S → N	1,060 (south) 990 (north)	60–100	9–12	N/A
CRIT	Silty	S → N	800	6–40	2–6 (estimated)	6–11[d]

Sources:
[a] Reclamation, 2008.
[b] Reclamation, 2007.
[c] Keller-Bliesner Engineering, 2007.
[d] CRIT, 2007.

conductance in the CRIT Canal, located well upstream of the others. The specific conductance readings and canal depths were used as fixed model constraints during the marine resistivity data inversion.

Detailed groundwater levels are not available for most of the study areas. However, regional maps and data from nearby piezometers provide a general range of groundwater depths (table 2). The shallowest groundwater is located along portions of the East Main Canal and East Highline Canal. Specific conductance readings of the drainage water adjacent to the East Highline Canal have an average specific conductance of 1,519 µS/cm (Keller-Bliesner Engineering, 2007). It is expected that the groundwater in all of the survey areas has a significantly higher specific conductance than the canal water.

Resistivity Data

The marine resistivity data were acquired along a total of 45.3 miles of canals and are of excellent quality with a high degree of repeatability and lateral continuity. The modeled conductivity cross-sections show a broad range in conductivity values (1–500 mS/m), indicating that there are significant variations in geology (clay, silt, and sand) and possibly groundwater that are influencing the measurements. In most cases, the conductivity values are influenced by more than one factor within the volume of materials measured.

For example, variations in clay and moisture content of the alluvium will both affect conductivity values. Table 3 lists typical conductivity values that are characteristic of various materials encountered in the survey areas.

Table 3.—Characteristic conductivity values

Material	Conductivity (mS/m)
Canal water	80–100
Groundwater	>150
Sand and gravel	<10
Wet clay/silt	50–100

Land Resistivity Measurement Locations

Conductivity anomalies representing a broad range of values within the marine data were selected for followup measurements with land-based resistivity measurements (table 4). The results for each of the canals are discussed in the following sections.

Table 4.—Land resistivity locations

Name	Canal	Section	Station (feet)	Longitude (degrees)	Latitude (degrees)	Conductivity from marine measurements
EMC-Land-1	East Main	A	7,800	-114.6785222	32.5939084	High (~100 mS/m)
EMC-Land-2	East Main	D	3,800	-114.6565474	32.6170710	Low (6–15 mS/m)
Mohave-Land-1	Mohave Lateral	A	750	-114.5344706	32.7728252	Very low (2–10 mS/m) at depths of 10–30 feet
Mohave-Land-2	Mohave Lateral	H	300	-114.5173672	32.8148284	Mid-range values (40–60 mS/m)
EHC-Land-1	East Highline	A	3,300	-115.2922536	32.9239232	Very high (100–500 mS/m)
EHC-Land-2	East Highline	E	6,700	-115.2767350	32.7800946	Mid-range values (40–50 mS/m) to 45-foot depth
Gila-Land-1-West	Gila	D	2,050	-114.4960596	32.7630234	Pockets of very low (<10 mS/m) in generally low area
Gila-Land-1-East	Gila	D	2,050	-114.4956620	32.7629736	Pockets of very low (<10 mS/m) in generally low area
Gila-Land-2-West	Gila	F	9,400	-114.4487262	32.8624478	Pockets of very high (100–500 mS/m) in generally high area
Gila-Land-2-East	Gila	F	9,400	-114.4482456	32.8625864	Pockets of very high (100–500 mS/m) in generally high area
CRIT-Land-1	CRIT	B	1,200	-114.3900946	33.9224254	Thin low (6–10 mS/m) above high (90–100) at depths >20 feet
CRIT-Land-2	CRIT	F	500	-114.3947380	33.9386904	Low (4–10 mS/m) at depths <20 feet

East Main and Central Canals

Marine Data

The conductivity values range between approximately 4 and 200 mS/m with an average value of 52 mS/m below the canal bottoms. The thin upper layer of the models represents the canal water with an approximate conductivity of 100 mS/m. Sub-bottom zones of low conductivity (<15 mS/m) are evident in Section D of the East Main Canal and Sections A and B of the Central Canal. Thin, shallow areas of low conductivity are also evident along portions of Sections C, E, and F of the Central Canal.

Shallow groundwater (< 6 feet) is indicated in the area of low conductivity measured within Section D of the East Main Canal (Reclamation, 2008). However, shallow groundwater is also indicated along Section A of the East Main Canal where there is relatively high conductivity. Also, relatively constant groundwater depths (8 feet) are mapped along the Central Canal where both low and high conductivity were measured. Therefore, groundwater depth variations along the East Main and Central Canals do not correlate with conductivity variations. This lack of correlation indicates that geologic variations (e.g., clay, silt, and sand) are likely the dominant factor in the conductivity measurements.

Land Data

Land resistivity measurements were obtained in both high and low conductivity areas. EMC-Land-1 is located within a broad conductivity high (>100 mS/m), while EMC-Land-2 is located within a broad conductivity low (<15 mS/m).

The conductivity values obtained at EMC-Land-1 correlate well with the marine measurements at this location. A zone of high conductivity (>100 mS/m) lies at a depth of 10 to 30 feet below the canal road and extends up to the ground surface at field level. This high conductivity zone correlates with fat clay identified in the well at this location with 99.4% fines reported in the sieve analysis (Reclamation, 2009).

Mohave Lateral

Marine Data

The conductivity values range between approximately 1 and 100 mS/m with an average value of 23 mS/m below the canal bottom. The upper layer consists of conductivity values in the 40 to 70 mS/m range extending to a depth of approximately 10 feet. Since the canal is shallow (1–4 feet), this layer likely represents an average of the canal water and sub-bottom materials with high clay content. A layer of low to very low (<10 mS/m) conductivity values are centered at depths of 10 to 30 feet within the cross-sections.

The Mohave Lateral has the lowest average conductivity of all the canals surveyed as part of this demonstration project. Groundwater maps indicate a greater depth to groundwater of 14 to 18 feet along this canal (Reclamation, 2007). The less-saturated conditions may be contributing to the lower overall conductivity values.

Land Data

Land resistivity measurements were obtained at two locations: Mohave-Land-1 in an area of very low conductivity (1–10 mS/m) and Mohave-Land-2 in an area of mid-range conductivity values (40–60 mS/m).

Mohave-Land-1 data indicate a zone of low conductivity (<10 mS/m) at a depth of 5 to 30 feet below the canal road and 5 to 15 feet below the field level. The land values are in general agreement with the marine data at this location; however, the low conductivity zone is thinner in the land cross-sections. In all cases, a layer of mid-range conductivity values extend from the surface to a depth of 5 to 10 feet. The upper layer of mid-range conductivity values correlate with clay observed on the surface. The clay overlies a zone of sand and gravel identified in the well at this location, which correlates with the low conductivity zone.

Mohave-Land-2 data indicate heterogeneous conditions in the upper 20 feet, with mid-range conductivity values that are in general agreement with the marine data at this location. The conductivity values at this location are higher than most of the survey line, indicating a transition into materials with higher clay content at the northern end of the survey line. This interpretation is supported by high fines reported in the sieve analysis at this location (Reclamation, 2009).

East Highline Canal

Marine Data

The conductivity values range between approximately 30 and 500 mS/m with an average value of 83 mS/m below the canal bottom. The upper 5 to 9 feet of the models represents the canal water with an approximate conductivity of 100 mS/m. Sub-bottom conductivity values are significantly higher in northern sections of the canal survey area (A, B, and C) compared with southern sections (D and E). In general, a layer with mid-range conductivity values of 30–60 mS/m lies below the bottom of the canal. This layer is variably thick and is generally thicker in the southern sections of the canal survey area. High to very high conductivity values (>>100 mS/m) underlie this layer in much of the northern sections of the canal survey area.

The East Highline Canal has the highest average conductivity of all the canals surveyed as part of this demonstration project. Recent studies have shown a very shallow depth to groundwater (<5 feet) in the immediate vicinity of the canal (Keller-Bliesner Engineering, 2007). Fluid conductivity measurements indicate significantly higher groundwater conductivity compared with the canal water in the northern survey area (Southwestern Exploration Services, LLC, 2009). It is likely that the high to very high conductivity layer in the northern sections of the canal survey area is a result of the shallow groundwater.

Land Data

A high conductivity area (EHC-Land-1) and mid-range conductivity area (EHC-Land-2) were selected for land resistivity measurements.

EHC-Land-1 is located in an area of high to very high conductivity values in the marine data. However, the land cross-sections indicate more complex conditions, with both high and low conductivity areas at this location. A thin layer of high conductivity (>100 mS/m) is evident parallel to the canal from the surface to a depth of approximately 10 feet. This layer pinches out to the west and transitions to low conductivity. Below 10 feet, the conductivity cross-sections indicate a gradual transition from mid-range to high conductivity values with depth. The sieve analysis from a well at this location report sandy silt and clay with a high percentage of fines. It is likely that the high conductivity layer is responding to fines in the alluvium and groundwater conductivity.

EHC-Land-2 is located in an area of mid-range conductivity values in the marine data. Except for some near-surface heterogeneity, the land measurements correlate well with the marine data at this location. Fluid conductivity logs show similar values as the canal water and much lower values than at EHC-Land-1, which indicates that shallow groundwater is not a factor at this location (Southwestern Exploration Services, LLC, 2009). The mid-range conductivity values correlate with silty sand and clay with a high percentage of fines reported in the sieve analysis (Reclamation, 2009).

Gila Gravity Canal

Marine Data

The conductivity values range between approximately 2 and 500 mS/m with an average value of 39 mS/m below the canal bottom. The upper 9 to 12 feet of the models represents the canal water with an approximate conductivity of 100 mS/m.

Sub-bottom pockets of low conductivity (<15 mS/m) are evident throughout the survey area, with the lowest values in portions of Section B, the northern portion of Section C, and the southern portion of Section D. These zones of low conductivity extend from the canal bottom to the maximum depth of the models (45 feet) in many locations. Broad areas of high conductivity values with pockets of very high conductivity (>>100 mS/m) are located in the northern portion of Section F.

Land Data

Land resistivity measurements were obtained at two locations: Gila-Land-1 in an area of very low conductivity (2–15 mS/m) and Gila-Land-2 in an area of very high conductivity (100–500 mS/m). At Gila-Land-1, data were obtained along parallel and perpendicular lines on each side of the canal. At Gila-Land-2, data were obtained along parallel lines along each side of the canal (a perpendicular line could not be obtained at this location due to heavy vegetation).

Gila-Land-1 conductivity cross-sections on both sides of the canal indicate low conductivity values that extend to the ground surface at field level. The low conductivity values are in general agreement with the marine data; however, the land data indicate mid-range conductivity values below 20 feet compared with low conductivity values in the marine data. Slightly lower conductivity values are evident on the eastern side of the canal compared with the western side. The low conductivity values correlate with sand and gravel observed at the surface and within the well at this location (Reclamation, 2009).

Gila-Land-2 conductivity cross-sections on both sides of the canal indicate a zone of low to mid-range conductivity values from the surface to a depth of 20 feet below the canal road. The low conductivity values in the upper 20 feet are likely due to the coarse-grained materials within the canal road. High to very high conductivity values are evident below a depth of 20 feet. The high conductivity areas correlate with the marine data at this location. The fluid conductivity log indicates very high fluid conductivity (Southwestern Exploration Services, 2009), which may be related to a groundwater contaminant plume in this area based on conversations with Reclamation personnel. Sieve analysis show silt and clay with a high percentage of fines (Reclamation, 2009). Therefore, the high conductivity zone is likely due to a combination of fines in the alluvium and groundwater conductivity factors.

CRIT Canal

Marine Data

The conductivity values range between approximately 4 and 200 mS/m with an average value of 38 mS/m below the canal bottom. The upper 2 to 6 feet of the models represents the canal water with an approximate conductivity of 80 mS/m. A thin layer of low conductivity (<15 mS/m) is evident in Sections A, B, and F from the canal bottom to depths of approximately 20 feet. In a portion of Section B, the low conductivity layer overlies an area of high conductivity (90–100 mS/m). Sections C, D, and E show much less lateral variability than the other sections and have mid-range conductivity values of 30–80 mS/m.

Land Data

Land resistivity measurements were obtained at two locations: CRIT-Land-1 in an area of low conductivity (6–15 mS/m) above high conductivity (90–100 mS/m) and CRIT-Land-2 in an area of low conductivity (4–15 mS/m) at depths less than 20 feet.

CRIT-Land-1 data indicate low to mid-range conductivity values, with the lowest values located in the field along the perpendicular survey line. The low conductivity zone extends to depths of 20 feet below field level and correlates well with the marine data at this location. The low conductivity zone correlates with sand and a low percentage of fines (Reclamation, 2009). Below this zone, a layer of high conductivity is likely due to a combination of higher fluid conductivity (Southwestern Exploration Services, LLC, 2009) and clay (Reclamation, 2009).

CRIT-Land-2 data indicate a low conductivity layer from the field level ground surface to a depth of approximately 10 feet. These values correlate well with the marine data at this location and with a low percentage of fines (Reclamation, 2009). Mid-range conductivity values underlie this layer to a depth of 45 feet and correlate with silty-sand and a higher percentage of fines (Reclamation, 2009).

Correlation with Well Measurements

The geophysical logs and sieve analysis obtained at each well provide supporting evidence for the relationship between the conductivity values and alluvium composition. In order to quantify the correlation between surface geophysical data and well measurements, the conductivity models developed from land measurements were sampled at 5-foot depth intervals at the locations of the wells. The correlations between the surface and downhole measurements are presented below.

Geophysical Logs

Geophysical logs were obtained in each of the wells and include natural gamma, dual-induction, fluid temperature and conductivity, resistivity, and neutron measurements (Southwest Exploration Services, LLC, 2009). The fluid conductivity and induction logs have the most significance for this study.

Fluid conductivity measurements in screened portions of the wells show conductivity values ranging between 820 and 10,870 µS/cm. Conductivity values in three of the wells are significantly above the conductivity of the canal water. These high fluid conductivity wells include EHC-1, Gila-2, and CRIT-1. Shallow groundwater is responsible for the elevated readings at EHC-1 and CRIT-1, while a possible groundwater contaminant plume is responsible for the elevated readings at Gila-2. Omitting the data from these three wells, the fluid conductivity values range between 860 and 1,610 µS/cm, which are values similar to the canal water conductivity (table 2). The R^2 correlation coefficient between the fluid conductivity data and the conductivity models developed from land surface measurements is 0.03 after the data from the three high conductivity well locations are removed from the analysis. Therefore, variations in fluid conductivity have little to no impact on the conductivity models, except at locations where high conductivity groundwater or contaminants are within the measurement range of the resistivity survey (~45 feet).

At the three locations where high fluid conductivity is a factor, a sieve analysis shows that the alluvium contains silt and clay with a high percentage of fines. Therefore, we can infer that the canal water is contained within an impervious bottom or sub-bottom at these locations, allowing the high conductivity groundwater to be in closer proximity to the canal.

The induction logs show variations in bulk conductivity that correlate well with the conductivity models developed from land surface measurements. The R^2 correlation coefficient between these two conductivity datasets is 0.74, which improves to 0.82 when the three high fluid conductivity wells are removed from the correlation analysis. Therefore, the conductivity models developed from the land surface measurements are consistent with measurements obtained in the wells. Variations from the linear correlation are due to differences in resolution and volume of measurement between the two methods.

The conductivity models have no apparent correlation with the natural gamma logs. The natural gamma logs should be representative of clay content and, therefore, correlate well with conductivity variations. However, the natural gamma logs show a high degree of variability and different background values at the various well locations. Therefore, the natural gamma log may be impacted by other gamma emitters besides clay in the alluvial sediments.

Sieve Analysis

Reclamation obtained alluvium samples at selected intervals within each of the wells and provided a sieve analysis for each sample (Reclamation, 2009). The percentages of fines, defined as silt and clay passing through the 0.075-millimeter (mm) screen, were compared to the conductivity model values at the well locations. Data from the three wells where high fluid conductivity was measured (EHC-1, Gila-2, and CRIT-1) were omitted from the analysis.

The correlation between the percentage of fines in the alluvium and modeled conductivity values has a moderately high R^2 coefficient of 0.59. Deviations from the linear correlation are due to a couple of factors:

- A group of five samples shows relatively high conductivity values with a low percentage of fines. In each of these five samples, there is a high percentage of fine sand, one screen size larger than the fines cutoff of 0.075 mm. Therefore, it is likely that the relatively high conductivity is responding to higher fines content in the fine sand than represented by the discrete sample within this zone.

- Three samples with a high percentage of fines and high conductivity deviate from the linear correlation. In each of these cases, there is a large percentage of clay in the samples that likely has a nonlinear relationship with conductivity.

The good correlation between the percentage of fines in the alluvium and the modeled conductivity indicate that the conductivity models can be used to identify areas of low fines content, which have a higher potential for seepage. The linear relationship developed from the geophysical data and sieve analysis is:

$$\%\ Fines = (0.66)\ \mathrm{s} + 2.66;$$
where* s *is the modeled conductivity in mS/m.

For water-retaining embankments, soil is generally required to have 25% fines to be considered impervious (Reclamation, 2004). For canals, a conservative threshold of 12% is generally thought to be acceptable to prevent significant amounts of seepage (based on conversations with Reclamation personnel). This 12% threshold equates to approximately 15 mS/m in the correlation analysis. Conductivity values less than 15 mS/m are interpreted in the conductivity cross-sections as areas with less than 12% fines content.

Conclusions

The results of the marine and land resistivity surveys show a broad range of conductivity values (1–500 mS/m) from the surface to a depth of 45 feet. Based on a correlation with well data, the measurements are primarily influenced by grain size, with higher conductivity corresponding to a higher percentage of fines in the alluvium. Shallow, high conductivity groundwater produces higher measured conductivity values at some locations and reduces the measured effect of grain size variations. However, sieve analyses at these locations show alluvium with a high concentration of fines that appear to be sealing the canal water from the groundwater.

In order to assess the potential for seepage using the conductivity data, it is necessary to examine the data in relation to the canal bottom. A conductivity threshold of 15 mS/m or lower corresponds with a 12% or lower concentration of fines in the alluvium. Alluvium with a low concentration of fines (<12%) within 10 feet of the bottom is interpreted as having the highest potential for seepage. These areas comprise approximately 25% of the total survey area, based upon the conductivity data, and are listed in table 5. However, not all of these areas may be currently problematic if alluvium with a sufficient concentration of fines seals the canal sides and bottom (e.g., Central Canal and Mohave Lateral).

Table 5.—Areas with high seepage potential interpreted from conductivity data

Canal	Section with <12% fines within 10 feet of canal bottom	Conditions
East Main	D	Sandy conditions observed on surface and in well.
Central	A, B, C, E, F	Silty and clayey conditions observed at surface may be presently sealing these sections of the canal. However, low conductivity zones (low concentrations of fines) occur within 10 feet of canal bottom.
Mohave Lateral	A, B, C, D, E, F, G	Thin layer of clay (upper 10 feet) presently sealing the canal. However, low conductivity zones correlating with sand and gravel occur within 10 feet of canal bottom.
East Highline	None	Mid-range to high conductivity values indicate high concentrations of fines in alluvium. Sections A and B show very high conductivity due to shallow groundwater. Silt and clay likely sealing the canal water from the groundwater at these locations.
Gila Gravity	B, C, D, E, F	Thick zones of low conductivity correlated with sand and gravel.
CRIT	A, B, F	Thin zones of low conductivity correlate with sand.

Marine resistivity measurements show great promise for rapid assessment of seepage in unlined irrigation canals. The low conductivity areas identified in the data can now be targeted for quantifying seepage rates and possibly installing canal lining to remediate seepage.

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PREVENTING CORROSION ON RECLAMATION STRUCTURES WITH THERMAL SPRAY METALIZING

by: David Tordonato, Ph.D,. P.E.; Allen Skaja, Ph.D., PCS; and Bobbi Jo Merten, Ph.D., Bureau of Reclamation, Technical Service Center, Materials Engineering and Research Laboratory, 86-68180

Metalized/thermal spray coatings (TSCs) were investigated by the Bureau of Reclamation's (Reclamation) Materials Engineering and Research Laboratory. The goal of this study was to evaluate the feasibility of using TSCs for corrosion protection on Reclamation equipment. The focus of this study was on thermal spray materials that are anodic (i.e., corrode preferentially to steel). This study included a literature review and laboratory test programs that evaluated five thermal spray alloys and two sealer systems.

Metalizing is a technology used to provide corrosion protection to steel and concrete engineering structures. It offers several advantages over conventional coating technology.

Advantages include:

- No cure time. The structure can be placed in service immediately following the conclusion of the application.
- No production of volatile organic compounds (VOCs).
- Good impact resistance (compared with epoxy).
- Good ultraviolet (UV) light resistance (compared with epoxy).
- No temperature restrictions for application.
- No humidity restrictions for application.
- Increased service life (up to two times) with less downtime for coating maintenance.

Disadvantages include:

- Not compatible with impressed current cathodic protection systems found on many structures such as buried pipe.

  Higher initial cost, which ranges from 15 to 40 percent depending on the system specified.

- Metalizing heats the substrate that may be unacceptable in certain situations. The surface temperature will be dependent on the process and parameters used.

- Fast-flowing water can, as some studies have shown, decrease coating life.

- Service life in immersion can vary significantly depending on water chemistry and coating material.

Metalizing is not a new technology. It has been in use since the 1930s. Although it has seen limited use in comparison with conventional coatings, this is primarily due to economics. In past years, application rates for metalized coatings have been slow, making the process an expensive alternative to conventional coatings. However, the technology has fostered advances in equipment that result in faster production times due to greater reliability and greater material deposition rates. The average spray rate has increased from 7.5 pounds per hour (lb/hr) to 35 lb/hr for aluminum.

In the polymeric coatings industry, local, State, and Federal regulations are driving market changes by reducing the VOC limits in many States. Facility owners are searching for alternatives to coating systems such as vinyl resins, which were once commonplace in applications that required corrosion protection in fluctuating immersion. Furthermore, coatings are becoming more expensive to purchase and apply. Old coatings systems, such as lead-based paints, were surface tolerant. Modern coating systems have more stringent surface preparation requirements that typically require a near-white metal blast. Plural component systems may require expensive plural component equipment. Not only are these newer coatings systems more expensive to apply, but there is greater chance of applicator error and, hence, premature failure. Many of the newer systems have expected service lives that are much shorter than the coating systems historically used. For example, coal tar enamel, lead-based paint, and vinyl systems have been known to last in excess of 50 years. In contrast, an epoxy system typically has an expected service life of 15–20 years. Due to the challenges associated with these factors, metalizing is becoming an attractive option for corrosion protection.

Our results suggest the best use of metalizing at Reclamation is on radial gates, stoplogs, partially exposed trash racks, and other equipment subjected to a fluctuating immersion environment. Although metalizing has an initial cost premium over a comparable polymer coating system, life cycle costs may be substantially lower. Other applications where metalizing should be considered include severe atmospheric service environments such as bridges and aboveground piping.

The lab tests were performed utilizing various accelerated weathering techniques that included the following: Prohesion, BOR, and Immersion. The Prohesion test consisted of alternating salt spray and UV light exposure. The BOR test consisted of alternating salt spray, UV light exposure, and immersion testing in a corrosive mixture known as a "Dilute Harrison Solution" (DHS). Immersion testing took place in either DHS, deionized (DI) water solution, or a high-velocity DI solution (DIFT). Following testing, each system was evaluated for coating performance.

Testing revealed that alloy composition and exposure condition significantly affect corrosion protection performance. Of the systems tested, the pure aluminum system is believed to offer the best combination of corrosion protection and expected service life in immersion or fluctuating immersion. The system works well if the water has a pH between 4.0 and 8.5. In addition, aluminum is easy to apply, relatively low in cost, and exhibits greater adhesion strengths compared to the other alloy systems. Aluminum-sprayed panels tested under several conditions are shown in figure 1.

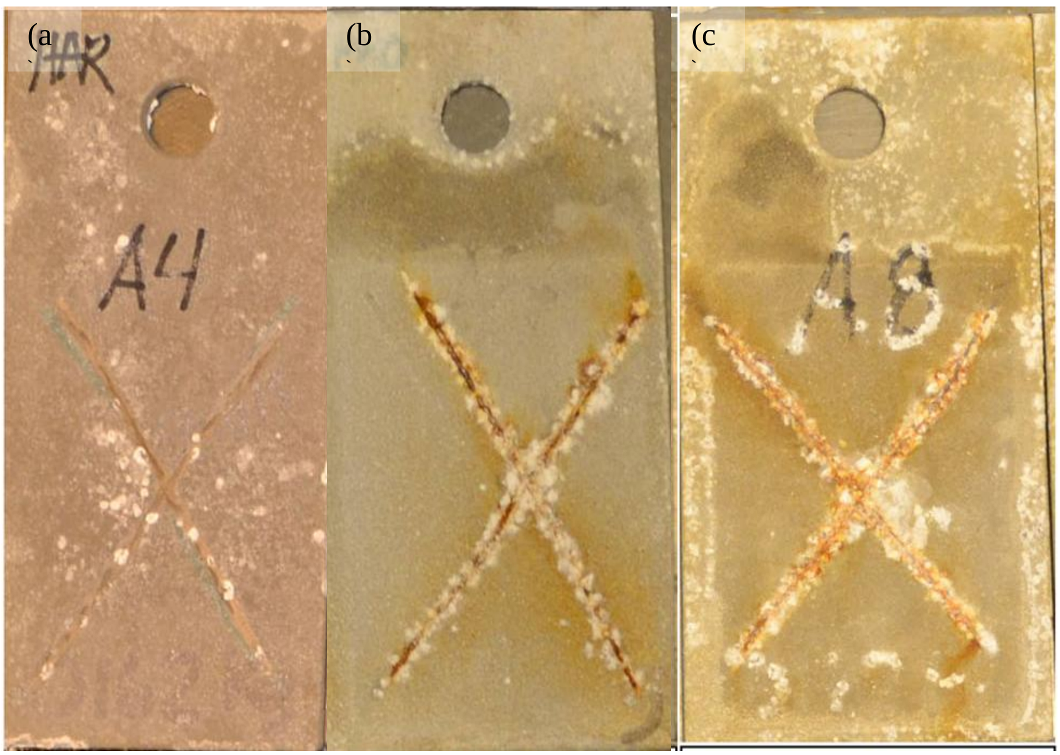


Figure 1.—Unsealed aluminum thermal spray systems tested after 5,040 hours. (a) DHS solution, (b) Prohesion cycle, (c) BOR cycle.

The zinc system provided the highest level of corrosion protection performance by protecting the bare steel in the scribe area. However, pure zinc experienced rapid deterioration during immersion testing in DHS. Use of zinc metalizing should therefore be avoided when frequent or prolonged immersion in corrosive environments is expected.

The 85/15 zinc-aluminum system offered good corrosion protection as well as a more stable oxide that was not easily damaged or removed. However, the system experienced blistering during prolonged immersion in both DHS and DI water solutions and is therefore not recommended.

90/10 aluminum-aluminum oxide (AA) and 95/5 aluminum-magnesium (AM) systems are variations of the pure aluminum TSC that are intended to provide increased abrasion resistance and increased galvanic protection. Neither of these systems is recommended. The AA system experienced more extensive oxide formation than other systems, and both AM panels blistered in the BOR test. In addition, locating feedstock for both of these systems was difficult. The AA system was not readily available in wire form, so a powder was mixed and applied using a combustion system.

The use of a polymer seal coat over the TSC system appeared to offer little in terms of increased corrosion protection unless the material was applied in greater thickness, in which case it was considered to be more of a topcoat. A comparison of sealed and unsealed panels is shown in figure 2.

Figure 2.—Effect of thin seal: Aluminum-Al_2O_3 systems tested in the BOR corrosion test cycle after 5,040 hours. (a) Amercoat seal, (b) Metco, (c) unsealed.

For more information, the full report will be made available on Reclamation's Science and Technology Web site at: http://www.usbr.gov/research/science-and-tech/projects/detail.cfm?id=9818.

ARC FLASH HAZARDS

by Gary Cawthorne, P.E., Bureau of Reclamation, Technical Service Center, Hydropower Diagnostics and SCADA Group, 86-68450

This and the next photograph are grabs from a video taken by a camera that shoots 30,000 frames per second. This is one of those frames. In this picture are two electricians (mannequins). One is near the equipment, and the other is near the right side of the photo. This test was performed by Bussman.

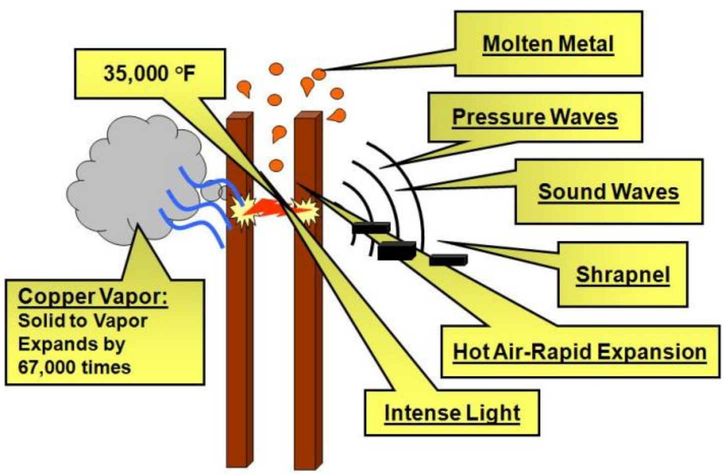
Working with electricity has always been dangerous. When you think about electrical injuries, most people think of injuries due to shock. Shock and electrocution have long been recognized as risks to those who work around electricity. In recent years, additional emphasis has been placed on the dangers associated with arc flash and arc blast energy. This risk arises not from the passage of electric current through the body but from the concentrated energy during an arcing fault. Of all the electrical injuries that occur, approximately 80 percent involve burns from an arc flash and burning clothing. Every year, there are over 2,000 people admitted to burn centers with severe electrical burns. The most severe burns are caused by the ignition of clothing after an arc flash incident, not from the arc flash itself.

In this picture, the arcing fault has been generated. This test was performed by Bussman.

An arc flash hazard is a dangerous condition associated with the release of energy caused by an electric arc. People working on energized electrical equipment have the potential for personal injury from arcing faults by conditions such as tools contacting electrical buses, equipment failures, insulation failures, loose connections, improper work procedures, impurities/dust buildup, corrosion, condensation, etc. Arcing faults can reach temperatures of 34,000 ^{o}F.

This happens to be the approximate temperature of the surface of the sun. This temperature will vaporize metal, burn skin, and ignite clothing. When clothing ignites, it can greatly increase the amount of skin area burned and the chance of a fatality. The metal that is most prevalent in our electrical equipment is copper, which, when vaporized, expands 67,000 times its original volume. This expansion of vapor can produce a pressure wave carrying molten copper and shrapnel. This pressure wave is called an arc blast.

The heat generated by an arc flash is expressed as energy, which is measured in calories per square centimeter (cal/cm^2). The factors that have the most effect on the amount of energy a worker will be exposed are distance to the arc, the fault current, and how long the worker is exposed to the arc (also known as the clearing time of the fault). If you can decrease any one of these factors, the heat energy the worker will be exposed to will lessen.

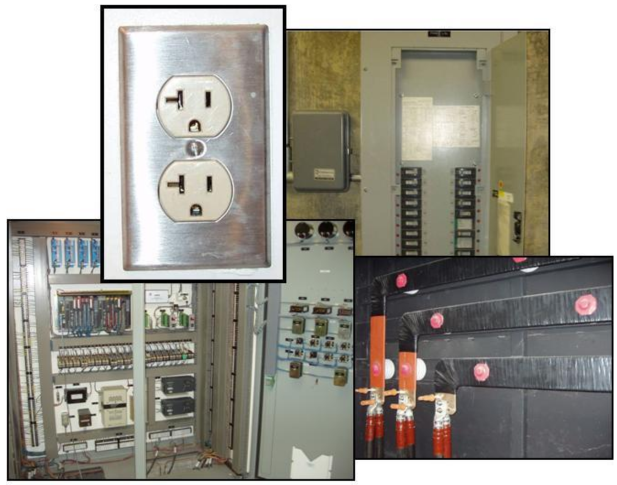


Anatomy of an arc flash.

In 1979, the National Fire Protection Association (NFPA) introduced NFPA 70E, Standard for Electrical Safety in the Workplace. This standard covers methods to protect workers from harm due to exposure to electrical systems and devices. In 1995, NFPA 70E was revised to help protect individuals from arc flash dangers. The Occupational Safety and Health Administration has since stated that it will enforce the requirements of NFPA 70E. The Bureau of Reclamation (Reclamation) started the process of instituting arc flash protection when it revised Reclamation Safety and Health Standard in 2001.

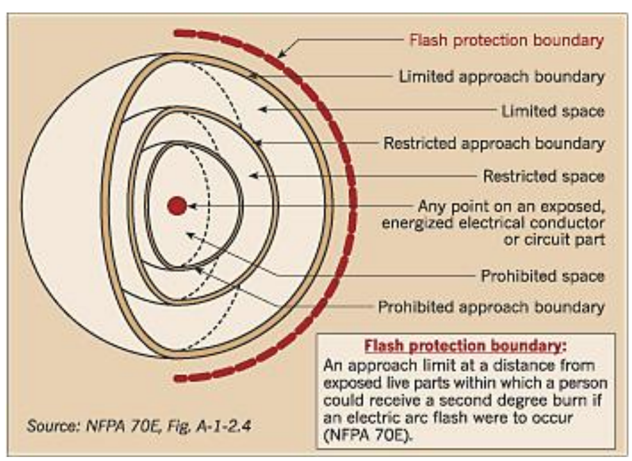
Arc flash hazards.

In order to best protect workers from arc flash hazards, a program must be developed that will identify how an office plans to deal with arc flash hazards. The first step is to start protecting the worker from arc flash hazards using Tables 130.7(C)(15)(a) and 130.7(C)(15)(b) of the 2012 version of NFPA 70E. These are task-based look up tables that will give both the arc flash hazard/risk category level, specific personal protective equipment (PPE), and an estimated arc flash boundary. The arc flash boundary is discussed in more detail below. These tables are a good place to start, but they have some serious downfalls. They make some assumptions about the nature of the protective devices that may or may not be true, so the worker may find that he is underprotected. Therefore, it is imperative that a qualified engineer either verifies that the protective equipment meet the assumptions made in the table or performs an arc flash hazard analysis.



Some of the equipment where there is a potential arc flash hazard.

An arc flash hazard analysis is really the best and most complete way to ensure that the worker is safe. The arc flash analysis will provide a more realistic assessment of the arc flash energy levels and the arc flash boundaries for the equipment being worked on. It can point out areas where the amount of PPE is considerably less than that required by the task-based tables. In some cases, the task-based table may require a hazard/risk category 4 arc-rated (AR) switching outfit to perform a task that may actually require Hazard/Risk Category 2 AR clothing by the arc flash hazard analysis. There may be areas where the analysis finds that the task-based tables are deficient as well. The arc flash hazard analysis will also show areas within a facility where the arc flash energy levels can be improved. In any case, it is imperative that an office do something to meet the requirements of NFPA 70E as soon as possible. If nothing else, follow the requirements of the NFPA 70E task-based tables, but remember, unless these tables are verified by a qualified engineer, workers may be put into a hazardous situation of being underprotected.



The shock and arc flash boundaries.

Unfortunately, it is not always possible to mitigate all arc flash hazards. So, the most effective way is to eliminate the hazard by de-energizing the electrical equipment prior to maintenance activities. However, it is very important to remember that equipment is considered energized until it has been verified that it is de-energized. Understanding arc flash hazards is key in preventing and surviving an arc flash incident. Training is extremely important to fully understand an arc flash hazard and how to spot hazardous conditions.

In order to protect a worker from electrical hazards, both shock and arc flash, boundaries were created to assist in determining the level and type of PPE to be used while performing work on energized equipment. Shock hazard approach boundaries are used to reduce the risk of shock hazards, and the arc flash boundary is used to reduce the risk from an arc flash hazard.

There are many different techniques used to alert workers of an arc flash boundary. The simplest technique is with caution tape as shown here.

The shock hazard approach boundaries consist of three specific boundaries: limited, restricted, and prohibited approach boundaries. These boundaries can be found within 2012 NFPA 70E, Table 130.4(C)(a) and are dependent on the voltage of the electrical parts that are exposed. The shock hazard approach boundaries are independent of the arc flash boundary and are applicable where people are exposed to energized electrical conductors or circuit parts.

The arc flash boundary is different from a shock hazard boundary in that it is not dependent on voltage. Instead, the arc flash boundary is the distance from a worker's face and chest to a prospective arc source within which a person could receive a second degree burn (1.2 cal/cm^2 is the amount of energy that will result in a second degree burn on unprotected skin). The arc flash boundary is applicable only when work is being performed on exposed energized electrical conductors or circuit parts. The main focus of NFPA 70E and other standards that focus on arc flash hazards is to ensure that the incident energy level to which a worker's skin is exposed does not exceed 1.2 cal/cm^2.

Work clothing within the arc flash boundary was found to be a large portion of the problem in many of the severe burn cases caused by an arc flash. Workers were wearing polyester or polyester/cotton blend clothing while working on electrical equipment. Unfortunately, if the worker was exposed to an arc flash, this material would instantly burn and melt to the skin, greatly increasing the severity of the burns. While performing work within an arc flash boundary, extreme care must be taken when choosing the material to be worn within an arc flash boundary. It all must be of a non-melting material, including sweaters, jackets, rainwear, high visibility vests, etc.

Conductive articles of jewelry and clothing (i.e., large belt buckles, watchbands, bracelets, rings, key chains, necklaces, cloth with conductive thread, metal headgear, or metal frame glasses) when worn within a flash protection boundary can also increase the significance of a burn or cause an arc flash. Conductive articles of jewelry and clothing, as well as conductive articles in pockets, must be removed prior to entering an arc flash boundary.

Hazard/risk category level 0 covers arc flash energy levels to 1.2 cal/cm^2.

To protect the worker from an arc flash, five hazard/risk category levels were created for NFPA 70E. These category levels relate directly to the thermal performance of work and AR clothing and the types of PPE to protect a worker when exposed to an arc flash. The five hazard/risk category levels are categories 0, 1, 2, 3, and 4. The differences between the category levels is mainly the types of PPE required. Hazard/risk category levels 1–5 require AR clothing.

Hazard/risk category 0 covers arc flash energy levels to 1.2 cal/cm^2. When working within an arc flash boundary with a category level of 0, the required clothing consists only of a long-sleeved shirt of non-melting material with untreated, denim cotton, blue jeans. However, the blue jeans cannot contain metal rivets or metal buttons for the fly. A metal zipper is acceptable. A hard hat and safety glasses or goggles are required. If the worker's head will be within the arc flash boundary, ear plugs must be worn. If the worker will be working on energized parts, insulated gloves with leathers must be worn.

Hazard/risk category 1 covers arc flash energy levels to 4 cal/cm^2.

Hazard/risk category 1 covers arc flash energy levels to 4 cal/cm^2. When working within an arc flash boundary with a category level of 1, the required clothing consists of an AR long-sleeved shirt and AR pants. Also, AR coveralls may be used in place of the AR shirt and pants. A hard hat, safety glasses, and hearing protection are required. If the worker will be working on energized parts, insulated gloves with leathers must be worn.

Hazard/risk category 2 covers arc flash energy levels to 8 cal/cm^2. When working within an arc flash boundary with a category level of 2, the required clothing consists of an AR long-sleeved shirt. If the AR shirt is rated less than

Hazard/risk category 2 covers arc flash energy levels to 8 cal/cm^2.

8 cal/cm^2, a t-shirt of non-melting material must be worn under the AR shirt. AR pants must also have an AR rating of no less than 8 cal/cm^2. Alternately, AR coveralls rated no less than 8 cal/cm^2 may be used in place of the AR shirt and pants. A switching hood or a balaclava and an AR face shield that also covers the side of the head must be worn. A hard hat, safety glasses or goggles, leather gloves, and hearing protection are required. If the worker will be working on energized parts, insulated gloves with leathers must be worn as well.

Hazard/risk category 3 covers arc flash energy levels to 25 cal/cm^2.

Hazard/risk category 3 covers arc flash energy levels to 25 cal/cm^2. When working within an arc flash boundary with a category level of 3, the required clothing consists of an AR long-sleeved shirt and pants with an AR rating of no less than 25 cal/cm^2. Alternately, AR coveralls rated no less than 25 cal/cm^2 may be used in place of the AR shirt and pants, or an AR flash suit rated no less than 25 cal/cm^2 may be worn. A switching hood, rated no less than 25 cal/cm^2, is also required. A hard hat, safety glasses or goggles, AR gloves, and hearing protection are required. If the worker will be working on energized parts, insulated gloves with leathers must be worn as well. Leather gloves are OK when used with insulated gloves.

Hazard/risk category 4 covers arc flash energy levels to 25 cal/cm^2.

Hazard/risk category 4 covers arc flash energy levels to 40 cal/cm^2. When working within an arc flash boundary with a category level of 4, the required clothing consists of an AR long-sleeved shirt and pants with an AR rating of no less than 40 cal/cm^2. Alternately, AR coveralls rated no less than 40 may be used in place of the AR shirt and pants, or an AR flash suit rated no less than 40 cal/cm^2 may be worn. A switching hood, rated no less than 40 cal/cm^2, is also required. A hard hat, safety glasses or goggles, AR gloves, and hearing protection are required. If the worker will be working on energized parts, insulated gloves with leather gloves must be worn as well. Leather gloves are OK when used with insulated gloves.

All AR clothing may be worn alone or integrated with flammable, non-melting, or other AR apparel of a lesser AR rating. Layering is a very effective way to increase the level of protection from an arc flash hazard. However, only the energy level of the garment with the highest AR rating can be used to meet the arc flash energy level of the equipment.

A worker racking in or out a breaker. This is one of the most hazardous tasks that can produce an arc flash.

Levels above hazard/risk category 4 are determined to be extremely dangerous, and there is no PPE that will protect a worker from an arc flash of this energy level. This is due to another hazard of an arcing fault, the arc blast. When the arc flash energy level becomes greater than 40 cal/cm^2, the arc blast becomes so extreme that the heat is no longer the largest hazard, the arc blast is. Above 40 cal/cm^2, the arc blast can become so severe that no level of AR switching outfits will protect the worker. Current PPE does not address protection against physical trauma injuries that could occur other than exposure to the thermal effects of an arc flash. Therefore, just because a worker is wearing PPE over 40 cal/cm^2, it does not mean that he is protected from an arc flash over 40 cal/cm^2. It may be tempting to buy an AR switching outfit with an AR rating that is well over 40 cal/cm^2 to protect yourself from some of these areas that may have extremely high energy levels, but the problem with these outfits is that they are extremely bulky and uncomfortable. Furthermore, AR clothing and switching outfits will not protect a worker from electric shock, and when the outfits are designed for high energy levels, it becomes very hard to see and move, making electric shock a very real threat. To deal with hazards of arc flash energy levels over 40 cal/cm^2, local procedures must be developed for situations requiring work within the arc flash boundary. Also, engineering controls or fixes may be able to mitigate some of these hazards as well.

Example of more AR garments. Note the tag showing the arc rating of the garment.

When purchasing AR clothing, the fit is very important to the safety of the worker. When the surface of AR clothing is heated, heat is conducted through the material, and any AR clothing touching the skin can result in a burn. To minimize this, AR clothing must fit loosely to provide additional thermal insulation, but must not fit so loose that it interferes with the worker's movements. This is where layering becomes very useful. It will provide that extra bit of protection to prevent the burns that can be caused by the AR material. The ability of the worker to see in the necessary direction must not be restricted. One size does NOT fit all. The clothing must be selected such that risk of an incident is not increased as a result of the fit. When AR clothing is worn, it must cover and prevent all ignitable clothing (including undergarments) from igniting and burning. In past years, the clothing was referred to as flame resistant (FR) to protect the worker from an arc flash. However, this became confusing since there are FR clothes that are not manufactured to protect a worker from an arc flash. Therefore, clothing that will protect a worker from an arc flash must be labeled as AR. All AR protected equipment and clothing contains a label or other mark on the garment that describes the maximum incident energy rating of the PPE.

An option to assist in the procurement of AR clothing is furnish just two levels of protection as described within the 2012 version of NFPA 70E, Section H.2 rather than four. This is the simplified, two-category AR clothing system that allows an office to perform work with only two category levels of PPE: hazard/risk category level 2 and 4. Most arc flash energy levels fall below 8 cal/cm^2; therefore, hazard/risk category level 2 clothing can be used for most cases. Anything above 8 cal/cm^2 would wear the hazard/risk category level 4 AR switching outfits.

It is imperative that AR clothing and other AR PPE be maintained in a clean and sanitary condition. The AR clothing and PPE must be cleaned and maintained as defined by the clothing manufacturer's instructions. Two items that must not be used while cleaning AR clothing and other AR PPE are bleach and fabric softener. Each of these will affect the protective properties of the garments.

This article barely touches on the subject of arc flash and arc flash hazards. There is a wide variety of literature that is available on the subject. Reclamation's Facility Instructions, Standards, and Techniques (FIST) Volume 5-14, "Arc Flash Hazard Program," is a sample of what Reclamation is doing to protect the worker. This FIST can be obtained at http://www.usbr.gov/power/data/fist_pub.html.

Remember, the first step is to recognize the importance and the dangers of arc flash hazards. The next step is to do something about it.

Contact Information:

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Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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