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ELECTRIC GROUNDING STUDY FOR FFTF

C. S. BUCHOLZ

AUGUST 1968

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ELECTRIC GROUNDING STUDY FOR FFTF

Prepared for PNL/FFTF
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August 1968

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ELECTRIC GROUNDING STUDY FOR THE FFTF

C. S. Bucholz

PART I - INTRODUCTION

The purpose of this study is to 1) investigate and recommend a design basis for the area electric grounding system, 2) consider the grounding requirements for the reactor containment sphere, and the stainless steel piping and vessels, and 3) investigate the feasibility of a separate and independent grounding system for the reactor instrumentation. Because the grounding conductors have a direct bearing on corrosion control and cathodic protection of other underground facilities, some comments on this subject are included.

DESCRIPTION OF THE SITE

The proposed site of the FFTF is about 4 miles north and 2 1/2 miles west of the 300 Area (Figure 1). Hanford coordinates of the centerline of the reactor are approximately S-6400, W-0400. The terrain is nearly level at an elevation of about 440 ft (Figure 2). It is a square area, about 1000 ft on each side (Figure 3).

The surface soil at this location is known as Rupert sand⁽¹⁾ (formerly Winchester sand in the 1919 Soil Survey). The surface is a brown to grayish brown coarse sand grading to a dark grayish brown sand at about 36 in. in depth.⁽¹⁾

The Appendix to this report contains the log of the nearest existing well⁽²⁾ (No. 669-S6-E4C) located about 1 mile east of the FFTF area. At this location, layers of sand and gravel extend to the 117-ft level. Ground water, encountered at 76 ft, subsequently rose to within 52 ft of the surface (see Reference 3, Map of Ground Water Contours).

FIGURE 1. Site Study Map

SK-3-12443

FIGURE 2. Site Plan North of 300 Area

SK-3-12981

FIGURE 3. Plot Plan of Building Plan XVIII

PART II - AREA GROUNDING SYSTEM

The protection afforded to personnel and equipment by adequate electrical system grounding has been thoroughly documented.^(4,5)

The grounding system must provide for:

- The ground connection for grounded neutral power systems
- The discharge path for lightning arrestors
- A return path to operate relays for clearing of ground faults
- Protection of personnel and equipment from dangerous electric potentials caused by faults, static accumulation, or lightning discharges by insuring that noncurrent-carrying parts such as equipment frames are always at ground potential
- Positively discharging and de-energizing feeders or equipment before proceeding with maintenance
- Fire alarm system grounding
- Communication and instrumentation system grounding.

The grounding requirements for personnel protection and for other purposes are not necessarily compatible. Personnel protection requires that a low voltage gradient at the earth and between the earth and exposed metallic objects be maintained. An example is the difference of potential between the foot of a person standing on the earth, and the hand touching a metal building, fence, or piece of equipment. Low impedance and high current capacity grounding systems are desirable for most other applications. Recommended resistances to earth for grounding systems are 1 Ω for large substations, and 5 Ω for small substations and industrial plants.⁽⁵⁾ It is assumed that large, as used in Reference 5, means physically large in extent, since the fault currents are greater in lower voltage systems of the same kVA capacity. The maximum ground resistance permitted by the National Electric Code (250-48) is 25 Ω .

Considering the complexity of equipment, the intrinsic hazards, and the monetary value of the FFTF complex, plus the exposure of the site to lightning, a grounding system resistance to earth of not more than 1 Ω would appear reasonable.

THE ELECTRIC POWER SYSTEM

Present design concepts provide for two sources of 115 kV primary power to the FFTF by 1) re-routing the existing BPA Benton to Midway line through the FFTF substation, and 2) providing two sectionalizing circuit breakers in the station.⁽⁶⁾

Two, 115 to 13.8 kV, 20 MVA transformers will be connected delta-wye with the neutral of the wye grounded through resistors. Five (one spare) 13.8 to 2.4 kV transformers will also be located at the primary substation to supply power for the large pump and blower motors. These transformers are to be delta-delta connected with grounding transformers to limit the ground fault current to about 400 A. Two lightning arrestors will be installed in the primary substation.

Two 13.8 kV to 480 V substations will be located adjacent to the reactor building for all other power requirements. Each station will have four 1500 kVA transformers connected delta-wye with solidly grounded neutrals⁽⁷⁾ (see Figure 4).

THE 115 kV SUBSTATION

The 115 kV Substation at the FFTF site will include a fenced enclosure and a switchgear building. It is understood that the Bonneville Power Administration (BPA) will participate in the design and construction of the station. Their design standards⁽⁸⁾ for grounding outdoor substations employ the conventional grid and ground rod layout, with a perimeter cable outside the fence similar to Hanford Standard D-3-5. Apparently, BPA uses copper grounding conductors (see Reference 8, p. 11). The substation grid will necessarily be interconnected

SK-3-12835

FIGURE 4. One Line Diagram of 13.8 kV Feeders,
2.4 kV and 480 V Switchgear

with all other FFTF buried grounding conductors by galvanized steel cables in accordance with Hanford Standards and Design Criteria. Two referenced IEEE papers^(9,10) describe the difficulties in attaining an adequate cathodic protection potential on buried iron and steel where copper grounding systems are used. Of course, corrosion is even more severe where no cathodic protection is installed.

Therefore, it is strongly recommended that galvanized steel grounding materials be used in the substation in accordance with Hanford Standards. Details shown on the standards can be modified, if necessary, to suit BPA requirements.

The BPA substation design manual⁽⁸⁾ outlines the method used for design of matts or grids based on "step" and "touch" potentials (the potential differences between the feet when walking and the hand and feet when touching a grounded object). Grids are not designed for a specific resistance. The resistance is measured after installation and, presumably, the grid is modified if the resistance is too high.

EARTH RESISTIVITY AT THE FFTF SITE

The resistance of a buried, bare conductor to the earth is expressed by^(11,12)

$$R = \frac{\rho}{2\pi C}$$

where ρ is the resistivity of the earth, and C is the capacitance of the conductor in air.

All equations for the resistance of grounding configurations are based on the above combined with a solution of, or an approximation to, the capacitance problem. However, in every case, the resistance is directly proportional to the earth resistivity. The resistivity in these expressions is assumed to be constant (homogeneous earth) and the earth to be of infinite extent, that is, with no other connected conductors in the vicinity.

Of course, it is recognized that the resistivity is not uniform, particularly near the surface, because the moisture content of the soil has a very great effect. The curves in the Appendix of this report, show the variation of resistivity with moisture content for several soils. Note that a reduction of moisture from 15 to 5% increases the resistivity by a factor of about 10 and that the resistivity levels off at around 5000 Ω -cm at 40% moisture content. Change beyond that point is negligible. Completely dry soil has a resistivity greater than 10^9 Ω -cm.⁽⁵⁾ A minimum resistivity of 5900* Ω -cm for gravel, sand, and stones with little clay or loam⁽⁵⁾ compares well with the curves. The plot on the same page shows resistivity variation with temperature, and explains why conductors must be buried below the frost line. While Hanford Standards specify a minimum of 18 in. deep, this depth should not be much exceeded (except under buildings) if maximum benefit in equalizing potentials at the surface is to be realized.

The extreme variation of the earth resistivity within several feet of the surface makes it difficult to estimate a safe value. For the same reason, resistivity measurements at the surface are practically meaningless. There is very little data available for the conductance or the minimum moisture content of Hanford soils at various depths. A resistivity of 5000 Ω -cm for average Hanford soil was developed in a study of soil corrosion⁽¹³⁾ but this was at the depth of pipe line burial, i.e., 3 ft or more. Since the ohmic value of any grounding arrangement is directly dependent on the resistivity, an investigation of soil conductivity at the FFTF site during the dry season would be very worthwhile. A resistivity of

* The 59000 Ω value listed in Reference 5 is obviously in error (10 times too high) as can be seen by comparing the rod resistances based on the resistivity values shown.

100,000 Ω -cm is used in the subsequent calculations for a grounding grid buried 18 in. below grade without ground rods. This figure may seem high, but the average value for sand and gravel shown in Reference 5 is 94,000 Ω -cm, so that 100,000 may even be low.

The average ground water conductivity from 10 wells in the southerly part of the Hanford Area is 296 $\mu\text{mho/cm}$ at 25 C⁽¹⁸⁾ equivalent to 3380 Ω -cm (conductivity is the reciprocal of resistivity). However, soil resistivity is not the same as water resistivity even though the soil may be saturated. The sand and gravel particles may be thought of as insulators in the conduction path provided by the water. In subsequent calculations, soil with a moisture content of 40% or more is estimated at 6000 Ω -cm, but this figure is also suspect and should be investigated by actual soil sampling.

LIGHTNING PROTECTION

Because the FFTF site is isolated from any natural barriers, it is vulnerable to direct lightning strokes (the ground level rise of 60 ft to an elevation of 500 ft about 1 mile west is too far to be of any consequence). There has been an average of 10 thunderstorm days per year at Hanford⁽¹⁹⁾ during the period 1945 through 1967. These storms, while comparatively few in number, can be severe.

In considering the area layout (Figure 3) with respect to lightning, concern is immediately centered on the metal reactor containment sphere, the stack, and the 115 kV substation. Adequate grounding must be provided for the containment and stack, and the stack equipped with air terminals according to accepted practice.⁽¹⁴⁾ The steep wave front of the current surge from a lightning discharge requires a low impedance path for effective grounding. The conductors should be as short and direct as possible, and without sharp bends.

The containment sphere is almost entirely surrounded by support buildings and a peripheral buried grounding conductor around these buildings is necessary for personnel protection during lightning discharges, if for no other reason.

Reference 14 states that the primary zone of lightning protection about a mast (or other high structure) is a cone whose base radius is equal to its height, and a secondary protective zone of base radius twice the height. Although the FFTF building layout shown in Figure 3 is tentative, the primary zone afforded by the sphere appears to include nearly all of the presently planned buildings immediately adjacent to the reactor, while the secondary zone will cover the air blast heat pumps, the sodium unloading building, the liquid gas storage, and most of the area reserved for future building facilities. The secondary stack zone (assuming a 200 ft high stack) will embrace the steam plant, sodium disposal facility, filter vault, retention basins, and part of the radioactive liquid waste facility.

UNDERGROUND PIPE LINES

Most industrial areas, as well as those at Hanford, depend to a considerable extent on the connection of grounding systems to underground (UG) lines to reduce the total ground resistance. However, most UG lines for the FFTF will be comparatively small and short, while others may be encased in concrete ducts. An exception is a proposed 8 in. cast iron water main from the 300 Area. Cast iron piping, however, is of little value for grounding because of the many high resistance joints. From the standpoint of cathodic protection, an insulating coating for all UG piping (except galvanized steel and cast iron) and tanks would be very desirable. Thus, UG piping is considered to have only a small effect on the resistance of the proposed grounding systems. However, all UG piping to buildings should be grounded in accordance with accepted practice for safety reasons.

RESISTANCE TO EARTH OF GROUNDING CONFIGURATIONS

Equations for the approximate resistance to ground of rods, wires, and plates in various simple configurations have been developed and are widely referenced and published in the literature (11,12). While calculation of the resistance of grids or mats is more difficult, several empirical methods have been devised. In the Appendix of this report is an IEEE (formerly AIEE) paper written by A. J. McCrocklin and C. W. Wendlant describing the method used here for grids. An accurate determination of the resistance of a grid with many attached ground rods is practically impossible even though the earth resistivity is assumed to be uniform.

Ground grids are usually installed with attached ground rods with the expectancy that the rods will penetrate to soil of better conductivity (higher moisture content) than that at the depth of the grid. Thus, personnel protection (the grid) and a low resistance to ground (the rods) can usually, but not always, be obtained with this combination. A reasonable number of rods, unless contacting soil of appreciably lower resistivity, will reduce the resistance of a large grid only slightly below that obtainable from a grid without rods.

Assume then that a grid will be required for the reactor and attached buildings (some of the other smaller buildings will probably also have grids) with a perimeter cable outside the building walls. The irregular shape of the perimeter can be approximated with a grid 300 ft square. The grid spacing may be 30 to 40 ft each way, but there is no particular reason to extend the cross ties under the reactor sphere foundation. In other words, the grid may have a large circular hole in its center. A grid spacing of 50 ft will be used to compensate for a grid of closer spacing with the hole. Also, Hanford standards require a double 5/8 in. peripheral cable. While there is no way to consider this requirement in the calculations, the heavier conductor will tend to reduce the resistance.

RESISTANCE OF GROUNDING GRID - REACTOR BUILDINGS

The method described in the Appendix will be used with corresponding symbols. The grid, without ground rods, has the following dimensions:

length (L) = width (W) = 300 ft,
 grid spacing (A) = 50 ft,
 depth of burial (S) = 18 in.,
 diameter of conductor (d) = 5/8 in., and
 resistivity of soil (ρ) assumed at 100,000 Ω -cm.

From the Appendix, Equation 6

$$R_g = \frac{\rho K_1 K_2}{10.16 \pi W}$$

From Appendix Figure 1, $K_1 = 5.5$, where $L/W = 1.0$, and
 $S/W = 0.005$

From Appendix Figure 2, $K_2 = 1.22$, where $L/W = 1.0$, and
 $A/W = 0.167$.

Then,

$$R_g = \frac{100,000 \times 5.5 \times 1.22}{10.16 \pi \times 300 \times 12} = 5.85 \Omega$$

By extrapolation of the data in the last paragraph of the referenced Appendix, a correction factor of about 1.2 for a W/d ratio of 5760 must be applied to the foregoing so that

$$R_g = 5.85 \times 1.2 = 7.0 \Omega$$

To check the 7 Ω value for the grid, the following configurations, roughly the size of the grid, were calculated using Sunde's equations⁽¹²⁾ with the same resistivity (100,000 Ω -cm).

Horizontal round plate of:

radius (a) = 150 ft, and

depth of burial (d) = 18 in., where $d \ll a$

$$R = \frac{\rho}{4a} \left(1 - \frac{4d}{\pi a}\right) = 5.4 \, \Omega$$

Circular ring of wire of:

radius (r) = 150 ft,

depth of burial (d) = 18 in., and

wire radius (a) = 5/16 in.,

$$R = \frac{\rho}{2\pi^2 r} \ln \frac{8r}{\sqrt{2ad}} = 9.3 \, \Omega$$

The resistance of the plate is lower than 7 Ω and the resistance of the ring is higher than 7 Ω , as they should be.

COMBINED RESISTANCE OF GRID WITH GROUND RODS

A 300 ft square with grid wires spaced at 50 ft both ways and with ground rods at all intersections would have 49 rods or, for convenience, 50 rods. Hanford Standard rods are 5/8 in. in diameter by 8 ft long.

As mentioned previously, the calculation of the combined resistance of a grid with rods is complicated by the mutual resistance effects between the rods and the grid wires, and thus can be only approximated.

To calculate the resistance of the rods alone, consider 50 rods arranged in a circle, circumscribed about a 300 ft square, of radius $\sqrt{2 \times (150)^2}$, or 212 ft, connected by insulated wire. The circumference of the circle is about 1330 ft, and the rod spacing is then 1330/50 or about 27 ft. Sunde's⁽¹²⁾ equation for the combined resistance of the rods on a circle is

$$R_r = \frac{1}{n} \frac{\rho}{2\pi L} \left(\ln \frac{4L}{a} - 1 + \frac{2L}{S} \ln \frac{2n}{\pi} \right),$$

where,

- 'n' is the number of rods,
- 'L' is the length of rods,
- 'a' is the radius of the rods, and
- 's' is the spacing.

A resistivity of 45,000 Ω -cm is used for the region of the rods -- 1-1/2 to 9-1/2 ft below the surface. This is simply a guess, and is the mean of the difference between 100,000 at a depth of 18 in. and perhaps 10,000 at 9-1/2 ft. Although the equation R_r applies to rods driven flush with the surface, the fact that the top of the rods are 18 in. below grade at the surface of the grid will have little effect on the result due to the high soil resistivity of the upper layer.

From the foregoing equation, the combined resistance of the 50 rods, approximating those in a grid, is 4.8 Ω . As a check, the calculated value of 50 individual rods in parallel is 3.6 Ω . The higher figure is the result of interference effects (mutual resistance).

The resistance of the grid without rods was calculated at 7.0 Ω in the foregoing section. The combined resistance of two interfering grounding arrangements is given by⁽¹²⁾

$$R_t = \frac{R_g R_r - R_m^2}{R_g + R_r - 2R_m},$$

where,

- ' R_g ' is the resistance of the grid,
- ' R_r ' is the resistance of the rods, and
- ' R_m ' is their mutual resistance.

This form is identical to the expression for the total inductance of two coils in parallel with coupled fields. If the mutual resistance is small and can be neglected, the equation reduces to that of two resistances in parallel.

According to Sunde,⁽¹²⁾ the mutual resistance can be obtained by taking the average potential along the length of the rods due to current in the wire. If the wire length (L_w) is much greater than the rod length (L_r), the potential varies logarithmically with the separation. The average potential is then obtained by using an equivalent separation L_r/e in place of (a), the conductor radius, in the equation for the resistance of a ring of wire, which then becomes

$$R_m = \frac{\rho}{\pi L_w} \left(\ln \frac{4eL_w}{\pi L_r} \right) = \frac{\rho}{\pi L_w} \left(\ln \frac{1.27 L_w}{L_r} + 1 \right)$$

With the same constants, the result for the mutual resistance is 2.24 Ω .

Now the three resistances may be substituted in the equation for the total resistance.

$$R_t = \frac{7 \times 4.8 + (2.24)^2}{7 + 4.8 + (2 \times 2.24)} = 3.9 \Omega$$

This value is higher than desirable for the total ground resistance. However, the actual values derived in this section may be grossly in error because of the resistivity assumption, but the equations are included to illustrate the method employed herein. Of course, the three individual resistances can be adjusted in direct proportion for other resistivity values based on better information.

RESISTANCE OF GROUNDING WELLS

Wells driven into permanent ground water are commonly used for low-resistance grounding. A well casing, if the joints are welded, may be used as the ground conductor and electrode. Such a ground was installed by the U. S. Army Signal Corps for the BY telephone exchange at the time of the original construction at Hanford. A well is used for grounding at the telephone exchange for the 200 Areas.

Many wells have been drilled at the Hanford project for geo-chemical and geophysical research,⁽²⁾ most of which have 8 in. diameter steel casings.

As previously pointed out, the ground water level is about 75 ft below the surface at the FFTF site. Then, a well drilled to about 115 ft, would be 40 ft in saturated soil. It is estimated that the soil would contain 40% moisture at least half-way above ground water. Thus, the well would be in 80 ft of earth having 40% or more moisture.

The equation for a single, vertical, ground rod or pipe is^(11,12)

$$R = \frac{\rho}{2\pi L} \left(\ln \frac{4L}{a} - 1 \right) ,$$

where,

$$L \gg a .$$

For a well casing with an effective length (L) of 80 ft, a radius (a) of 4 in., and an estimated resistivity of 6000 Ω -cm for soil of 40% or more in moisture content, the resistance of a single well is

$$\begin{aligned} R_w &= \frac{6000}{2\pi \times 80 \times 12 \times 2.54} \left(\ln \frac{4 \times 80 \times 12}{4} - 1 \right) \\ &= 0.39 (6.87 - 1) = 2.29 \Omega . \end{aligned}$$

In reality, the result should be smaller because the equation is for a vertical rod at the surface, but the effective top of the well is assumed to be 35 ft below the surface.

Wells provide a short and direct ground for lightning protection. If one well were located near the stack and one adjacent to the 115 kV substation (about 1000 ft distant), the combined resistance may be calculated from Sunde's equation⁽¹²⁾ for two ground rods where the spacing (s) is much greater than the length, as follows:

$$R_{2w} = \frac{\rho}{4\pi L} \left(\ln \frac{4L}{a} - 1 + \frac{L}{S} \right)$$

Using the same constants, the resistance of two wells is 1.16 Ω . Half the value for a single well is 1.145, so that the mutual resistance effect is very small at the 1000-ft spacing.

RESISTANCE OF GRID AND WELLS

Although the mutual resistance of the grid and wells can be approximated as in a previous section for grid and rods, it would be meaningless to proceed with that refinement considering the assumptions made. Simply combining the parallel resistances of the grid (7 Ω) and the two wells (1.16 Ω) results in a total resistance of slightly less than 1 Ω . Mutual effects will tend to increase this figure, but other interconnected grids and underground piping will decrease it.

USE OF GROUNDING WELLS

As was previously pointed out, it is impossible to arrive at a definite value for the resistance of any grounding electrode configuration. Grids are necessary but are unreliable for low resistance. The use of wells, interconnected with the grids, is recommended as an effective and economical means to provide a dependable grounding system of constant ohmic value.

If ground wells are incorporated, ground rods are relatively unimportant and only a minimum number need be installed to reinforce the grids at critical points such as corners. If ground wells are not provided, grids should be designed for the full complement of rods in accordance with Hanford Standards as the minimum requirement.

At least two connections, each of double 5/8 in. steel cable, should be made to well casings. Connections should be above ground, accessible for inspection, and be easily disconnected for testing. Grounding conductors must not be run in steel conduit (this does not apply to equipment grounds in conduit with power conductors).

The corrosion of the steel casings of grounding wells should be of no concern because water samples from many Hanford wells drilled 20 or more years ago have only a small corrosion product content, and the casings are apparently in good condition. Cathodic protection systems, if used, would protect the well casings as well as other underground facilities.

It is probable that several wells will be drilled at the site in connection with foundation studies, and these might be used for grounding. The only requirement is that they have steel pipe (schedule 30 or 40) casings with the lengths welded together.

CATHODIC PROTECTION

It is expected that an impressed current (rectifier) cathodic protection system will be installed for corrosion protection of underground facilities at the FFTF. The exposed area of these facilities will probably not be as extensive as that of the grounding system so that the grounding electrodes will unavoidably collect a large part of the cathodic current. While this will benefit the grounding system, other facilities to be protected may suffer because of their proximity to the grounds.

Deep anode installations have become widely used in recent years and have certain obvious advantages. If, for instance, the anode assembly were placed at about the center of the FFTF area and at a depth of about 325 ft (above the first layer of basalt [see page A-1 of Appendix]), then the entire area might be protected from this single anode installation. One can visualize the protective current as being supplied from underneath instead of from the side as in usual systems with anodes near the surface. The deep anode location should be as far as practical from the grounding wells so that the latter will not absorb a disproportionate share of the protective current.

Deep ground anodes are usually an assembly of several silicone iron anodes fastened to a length of rail or I beam. The assembly is then lowered into a well and sometimes driven deeper than the end of the well casing. If the anode assembly (assuming it is below the water level) is contained within or is in contact with the well casing, the casing will become a secondary anode and eventually be destroyed. For this purpose, the casing must not be connected to the anode circuit or to the grounding system. Plastic pipe has been used for anode well casings. Construction details for several types of deep anodes are shown in Reference 15.

However, if the cathodic protection requirements are minor and localized, a deep anode installation would be impractical. In this case, one grounding well should be located near the reactor and conventional cathodic protection anodes installed as required.

With the reactor containment sphere resting on a thick concrete foundation, no corrosion problems from earth moisture would be expected. However, any water seepage between the sphere and the concrete could result in a serious corrosion problem, and cathodic protection would be ineffective in this region.

PART III - GROUNDING OF CONTAINMENT SPHERE,
AND STAINLESS STEEL PIPING AND VESSELS

All grounding connections to stainless steel equipment and piping should be made to stainless "stingers" or saddles welded to the equipment to avoid contamination and possible corrosion of the stainless material. This method for piping is shown on Hanford Standard D-5-4. Connections should be accessible and preferably above ground. Thermite weld connections are preferred. Where the galvanizing on cables has been burned off by welding, the surface should be cleaned and regalvanized with a low-temperature, self-fluxing galvanizing material. Above ground welds should be given one coat of chromate primer and a finish coat of aluminum paint. Underground connections should have an asphaltic compound applied to the joint and for a distance of 6 in. on each side. Two or more grounding connections are required for large equipment, where unusual hazards are present, or where the object is exposed to lightning.

Grounding the containment sphere should be of no particular concern. It is required that an equipment ground conductor be included in all power circuits entering the sphere, and these will provide a direct metallic path for fault currents. However, several (perhaps six) heavy connections should be carried to the grounding system for dissipation of lightning strokes. It is suggested that steel studs extending a few inches inside and outside the sphere be welded into the enclosure. Then the external ground connections and the interior grounding system could be attached to the same studs. Where buildings attach to the sphere, the ground connections and the sphere itself should be protected from contact by personnel. The outside of the shell could be a dangerous area during lightning storms, but personnel and equipment will be perfectly safe inside the containment.

Penetrations of the independent instrumentation grounding conductors, as discussed in Part III, must be insulated from the containment sphere.

LIGHTNING PROTECTION

Because the deep anode well, if used, will be near the reactor, a spark gap lightning arrestor could be connected between the containment shell and a metallic anode well casing to provide a more direct and low impedance ground for lightning strokes to the sphere. The arrestor should have a low breakdown voltage and high current capacity, and must have a very high resistance in the normal state.

Another, but more costly, method for lightning dissipation is the installation of towers and static wires over the vulnerable buildings and equipment. This practice is commonly employed for large substations. To be effective, the towers and static wires would require connection to a low resistance grounding system.

Telephone cables, whether aerial or underground, should not be located in the region of the 115 kV substation, parallel to 115 kV lines, near main grounding electrodes, or in proximity to other structures vulnerable to lightning strokes.

A schematic sketch showing the essential parts of the proposed grounding and cathodic protection systems is shown in the Appendix.

PART IV - INSTRUMENTATION GROUNDING SYSTEM

Differences in potential between various points in a grounding system are not uncommon. These differences are caused by the flow of stray currents of any origin in the system such as faults or transients on electric power equipment. If low signal-level instrumentation has multiple connections to the ground, either intentional or accidental, these potential differences can result in instability of the instruments. Difficulties of this kind have been experienced at Hanford, and the cause is sometimes difficult to locate and correct.⁽¹⁶⁾ For these reasons, an independent instrument grounding system (IGS) has been proposed for the FFTF reactor instrumentation. While the concept of an independent IGS has some advantages, it will not eliminate capacitive coupling or leakage resistance to ground that may result in ground-loop currents and consequent noise in instrumentation circuits.⁽¹⁷⁾

The final design of instrumentation grounding methods will depend on several factors, particularly the types of equipment to be used, and the entire subject will require continued effort and study as the design progresses. To obtain satisfactory operation, intricate instrumentation systems almost always require some, and oftentimes extensive, modifications of grounding connections after the equipment is installed.

To facilitate future changes of this kind, it is suggested that a reasonable degree of adaptability be designed into the IGS as follows:

- The IGS should be entirely separate from the power grounding system and should include one or more grounding wells for that purpose only (a separate IGS well is shown on Appendix Page A-6). The main grounding conductors should be not smaller than 4/0 Awg copper cable. All connections should be above ground in an accessible location and

easily disconnected for testing. A lockable knife switch and an ohmmeter could be installed in main ground connection, then the presence of extraneous grounds on the IGS could be determined quickly by opening the switch and noting the meter reading. A resistor could be shunted across the switch if complete lifting of the instrumentation ground is undesirable.

- Several separate areas or zones of instrumentation, divided as to the type and location, should be provided with individual grounding busses or conductors that could be either connected to the IGS or left floating as operating experience dictates.

The use of an IGS will require that all instrumentation be constructed with the signal grounds insulated from frames, chassis, power supply grounds, etc., and terminated at IGS points. Separation of the two grounding systems will involve some difficult practical problems. For example, any sensor, amplifier, or other component normally grounded to its housing will require special construction.

A method for identifying the IGS conductors will be needed. Insulation of the equipment grounding wires, of course, is always green and all insulated grounding conductors in building wiring must be of the same basic green in accordance with NEC requirements. However, black is the accepted color for ground leads in electronic wiring. The ninth conductor in control cables, as per IPCEA color coding standards, is green with a black tracer, and this is suggested as a possible color combination for the IGS wires. A black band could be used on green wire at all IGS terminal points. Usually, the ground conductor will be the shielding or drain wire of shielded cables and no further identification will be required.

In all other respects, IGS conductors would be subject to equipment grounding requirements in accordance with Hanford Standards and the NEC. In brief, green-insulated copper conductors one trade size smaller than the largest power conductor serving the equipment, but not lighter than No. 12 Awg, must be installed. To minimize thermal EMF's, conductors of dissimilar metals should not be interconnected.

The instrumentation systems referred to in this section do not include the communication or fire alarm systems.

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* Available from Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia.

APPENDIX A

GEOLOGIC LOG OF WELL 699-S6-E4C

The altitude of land surface is approximately 430 ft, and the top of casing is 1.8 ft above land surface.

<u>Materials</u>	<u>Deposit Thickness, ft</u>	<u>Depth of well, ft</u>
Glaciofluvial and fluvial deposits:		
Gravel, fine to coarse, sandy, largely basaltic.	15	15
Sand, coarse, gray-tan, gravelly . . .	7	22
Sand, fine, tan, gravelly.	7	29
Gravel, fine, sandy, very permeable . .	36	65
Ringold formation:		
Sand, gravelly; water table at 76 ft depth.	19	84
Sand, gravelly and silty	33	117
Silt, gray-blue, with beds of sand and gravel. Gravel ranges from 1/4 in. to 4 in. in diameter. Beds cave badly, and in places are sulfurous.	68	185
Sand, gravel, and a few silt beds . . .	12	197
Silt, green with fine sand, gravel, and thin clay beds.	36	233
Gravel, sandy.	4	237
Clay, black, sandy, with basalt gravels .	18	255
Silt, blue-green, sandy and gravelly with some gravel up to 3-1/2 in. diameter .	20	275
Sand, fine, tan, gravelly.	6	281
Clay, black, silty, containing basalt chips and gravel up to 4 in. in diameter . .	2	283
Gravel, fine to coarse, sandy, cemented. Basalt pebbles have rinds	12	295
Silt, clayey, gray-black, containing some wood between 300 and 305 ft depths . .	10	305
Gravel, fine to medium, sandy	2	307

<u>Materials</u>	<u>Deposit Thickness, ft</u>	<u>Depth of well, ft</u>
Silt, clayey, gray-black, containing some gravel in the 307-310 ft zone. .	15	322
Undifferentiated, probably of Ringold age:		
Silt, blue, alternating with gravel and sand beds	7	329
Basalt, black, boulders. Water rose from 76 to 52.7 ft below load surface upon penetrating 2 ft into bed.	5	334
Silt, sandy, green, with embedded gravel up to 3/4 in. diameter.	3	337
Silt, sandy and clayey, green, with some medium to fine gravel and some sandstone. Gravel up to 4 in. diameter occurs in the 337-367 ft zone	30	367
Claystone, silty, gray, with alternate beds of yellow-green clay and some sand beds.	3	370
Basalt, black, boulders	15	385
Gravel, sandy	10	395
Silt, sandy, green.	19	414
Columbia River basalt:		
Basalt, soft, reddish-brown.	26	440
Basalt, black, vesicular.	15	455
Basalt, black, dense	6	461

FIGURE A-1. *Variation of Soil Resistivity With Moisture and Temperature*

Determination of Resistance to Ground of Grounding Grids

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EQUATIONS and curves have been published for determining the resistance to ground of many ground configurations.¹ This information, however, is lacking on the resistance to ground of grounding grids. Even the curves plotted for effectiveness of a large number of ground rods in parallel, distributed over a given area, omit the effectiveness of the connecting grid. In many ground installations, the effect of this grid must be omitted because in these cases the connecting grid is located above the permanent moisture level of the ground. However, in many cases the connecting grid may be a good ground without necessitating the purchase and installation of ground rods.

The authors became aware of the need for information on ground grids when one

of them was confronted with the problem of grounding a hydroelectric power plant located in a canyon on the Colorado River in Texas. There was no appropriate place available at this site where ground rods could be driven. Their installation would have required the drilling of holes in the rock, an expensive procedure. The authors decided that an effective ground could be established in

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the water above the dam by use of a grounding grid or plate. Equations and curves are available for determining the resistance to ground of buried strips or parallel horizontal wires at various depths below the surface, and for isolated plates of various length and width ratios.²

Equations

The mathematical solution of the resistance to ground of grids is very complex, and even an approximate solution is not obtained easily. Only as an alternative method, the authors obtained experimental test data by measuring the resistance to ground of different-sized grids and plates in the water of Lake Austin. Each plate and grid was measured at different depths under the surface, with a total of about 200 measured resistances to ground of grids and plates having definite length-width ratios and depth width ratios.

The resistance to ground of any isolated ground is given by²

$$R = \frac{\rho}{4\pi C} \quad (1)$$

where

Figure 1 (left). The variations of the reciprocal of the capacitance to ground per centimeter of width given as K_1 with variation of depth - width ratio. S = depth in inches, W = width in inches, and L = length in inches

Figure 2 (above). The resistance to ground in ohms of grids 2 feet by 4 feet and a 2-foot by 4-foot plate plotted against depth below surface of water. A = spacing between wires of grid in inches, $A=0$ is the plate, and ρ of water = 2,150 ohms per centimeter cube

R = resistance to ground in ohms
 ρ = resistivity of surrounding medium in ohms per centimeter cube
 C = capacitance to ground of the grounding unit in statfarads

The problem then is the determination of the capacitance to ground of the grounding grid or plate.

The reciprocal of the capacitance of an isolated thin rectangular plate, as presented by H. B. Dwight,² using the average-potential method, which is an approximate solution that gives results about 8 per cent too high, is given by the following equation

$$\frac{1}{C} = 2 \left[\frac{1}{a} \log_e \frac{a + \sqrt{a^2 + b^2}}{b} + \frac{1}{b} \log_e \frac{b + \sqrt{a^2 + b^2}}{a} + \frac{a}{3b^2} + \frac{b}{3a^2} - \frac{(a^2 + b^2)\sqrt{a^2 + b^2}}{3a^2b^2} \right] \quad (2)$$

where

a = length of plate in centimeters
 b = width of plate in centimeters

For a constant width-length ratio, that is $W/L = k$, where

W = width of plate in inches
 L = length of plate in inches

equation 2 becomes

$$\frac{1}{C} = \frac{2}{2.54} \left(\frac{1}{L} \right) \left[\log_e \frac{1 + \sqrt{1 + k^2}}{k} + \frac{1}{k} \log_e (1 + \sqrt{1 + k^2}) + \frac{1}{3k^2} + \frac{k}{3} - \frac{(1 + k^2)\sqrt{1 + k^2}}{3k^2} \right] \quad (3)$$

$$\frac{1}{C} = \frac{2}{2.54} \left(\frac{1}{W} \right) \left[k \log_e \frac{1 + \sqrt{1 + k^2}}{k} + \log_e (1 + \sqrt{1 + k^2}) + \frac{1}{3k} + \frac{k^2}{3} - \frac{(1 + k^2)\sqrt{1 + k^2}}{3k} \right] \quad (4)$$

So, for any isolated plate, the capacitance varies as the length or width where the length-width ratio is held constant. If the plate is half-submerged, the electric field on the lower side is the same as it would be if the plate were isolated, because of the plane of symmetry of the field lying in the center plane of the plate. Thus, when half-submerged, only one-half of the field of an isolated plate is useful in allowing the flow of current. Therefore the resistance to ground of the plate when placed at the surface should be exactly twice the resistance to ground of the same plate when the plate is treated as an isolated plate.

Since equations 3 and 4 show that the

capacitance is proportional to the length or width as long as the length-width ratio is held constant, small ground grids can be used to obtain data that may be applied to other sizes. The sizes of the plates and grids used were 2 feet by 2 feet, 2 feet by 4 feet, 2 feet by 6 feet, and 2 feet by 8 feet. The grids used were made of number 22 American Wire Gauge copper wire crossing at right angles and forming squares with sides of 3 inches, 6 inches, 12 inches, and 24 inches. The wires were soldered at all cross points.

The resistance to ground of these grids was measured in the water of Lake Austin. The plates and grids were suspended in water about 50 feet deep and 150 feet from a surface object or exposed earth. Because of additional dams above Lake Austin, the conductivity of the water is practically constant at 470 micromhos per centimeter cube. Actual samples of water obtained when any ground resistance readings were made give a variation of 460 to 510 micromhos per centimeter cube. The re-

Figure 3. A plot of the ratio of resistance of grid to resistance of plate of the same size expressed as K_2 against ratio of spacing between the wires of the grid to width of the grid. All openings in grids are squares, and the ratio of width of the grid to wire diameter is 945

sistance measurements were made using a multirange 0 to 3-, 0 to 30-, 0 to 300-, 0 to 3,000-, 0 to 30,000-ohm Biddle "Ground Megger," serial no. 259178, using the 3-electrode method. The current electrode was the trash rack on the intake to the two hydroelectric units. The potential electrode was a 6-inch pipe on the intake of the water supply to the office building cooling system. This intake pipe was submerged to a depth of approximately 20 feet below normal water level. Contact to the grid under test was made at a cross point when ever possible and corrections were always made for lead resistance.

Using equation 1 and the test results, the capacitance of the ground plates and grids may be calculated. However, the results of the tests are presented in the form of curves, using ratios. Figure 1 gives a plot of K_1 against depth expressed as S/W for solid plates when W is width of plate in inches, and S is depth in inches. The values of K_1 at large values of S/W approach approximately one-half the value at $S/W = 0$ on each curve. This is in agreement with theory and the value of C at the larger values of S/W ratios check very closely with corrected calculated values given by Dwight for plates of the same size as used in the tests.²

The resistance measurements on the grids show a close relation between all grids and plates of same over-all dimensions. The actual resistance of a set

of grids and plates of the same size is given in Figure 2. The ratio of the resistance of the grids to the plate of the same size at a fixed depth, or the reciprocal of the ratio of the respective capacitance, is given as K_2 in Figure 3. For any S/W ratio, K_2 is nearly constant for each value of L/W . This value of K_2 is plotted for $L/W = 1, 2, 3$, and 4 for the grid spacing-width ratio of 0 to 1.

The curves in Figures 1 and 3 can be used to find the resistance to ground of the grounding grids and plates of varying sizes.

The resistance to ground of ground plates is given by

$$R = \frac{\rho K_1}{10.16\pi W} \quad (5)$$

where

R = the resistance of the plate to ground in ohms

ρ = the resistivity of the surrounding medium in ohms per centimeter cube

W = the width of the plates in inches

K_1 = obtained from the curves in Figure 1 for a particular value of S/W and L/W

L = the length of plate in inches

S = the depth the plate is below the surface in inches

The resistance to ground of the grid is

$$R = \frac{\rho K_1 K_2}{10.16\pi W} \quad (6)$$

where K_2 is a constant obtained from Figure 3 for a desired value of A/W and L/W . The letter A is the spacing between wires in the grid in inches.

Equations 5 and 6 have the restriction that $W/d = 945$ where d is diameter of the wire in inches. The two-foot width with the number 22 wire gives a W/d ratio that is near the value that might be used in ground grids. The equation, $W/d = 945$ corresponds to a grid 64 feet wide, made of 500,000-circular-Mil cable or a grid 44 feet wide when made of number 0000 cable. Further tests⁵ by C. W. Wendlandt, however, show that the wire size has a very small effect upon the resistance. A ratio of $W/d = 650$ gives a resistance which is 5 per cent below the value obtained for $W/d = 945$, and a ratio of $W/d = 1,500$ gives a resistance which is 5 per cent higher.

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FIGURE A-2. Schematic Diagram of Basic Grounding and Cathodic Protection Systems for the FFTF

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