GJBX-267(81)

National Uranium Resource Evaluation

LOGGING CALIBRATION MODELS FOR FISSION NEUTRON SONDES

Bendix Field Engineering Corporation
Grand Junction Operations
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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Nuclear Energy
Grand Junction Office, Colorado

This report is a result of work performed by Bendix Field Engineering Corporation, Operating Contractor for the U.S. Department of Energy, as part of the National Uranium Resource Evaluation. NURE is a program of the U.S. Department of Energy's Grand Junction, Colorado, Office to acquire and compile geologic and other information with which to assess the magnitude and distribution of uranium resources and to determine areas favorable for the occurrence of uranium in the United States.

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ABSTRACT

Six cylindrical concrete borehole models have been constructed at the Department of Energy (DOE) Grand Junction facility for the calibration of fission neutron-based uranium logging tools. Three of these models contain one uniform uranium-enriched (ore) zone surrounded by upper and lower barren zones. Two of the models feature upper and lower ore zones separated by a barren zone. The four ore zones of the two latter models are approximately identical in uranium grade but vary in other important parameters: One ore zone has a high bulk density, another has a high formation average thermal neutron cross-section, and the other two have high and low porosities. The remaining model has a graded uranium ore zone situated between upper and lower barren zones.

Various combinations of model ore zones supply the following sets of calibration parameters:

1. three ore zones with different uranium grades, for determination of tool response as a function of grade;

2. two ore zones with approximately the same uranium grade but different formation average thermal neutron cross sections, for investigation of the formation thermal neutron cross-section effect on tool response;

3. two ore zones with approximately the same uranium grade, but different bulk densities, for investigation of the effect of the bulk density on tool response;

4. three ore zones with approximately the same uranium grade, but different porosities, for determination of the effect of porosity on tool response; and

5. one graded ore zone.

Each model has a single 4.5-inch (11.4 cm) diameter vertical borehole aligned along the model cylinder axis. The boreholes are normally water-filled but can be pumped for dry-borehole logging.

This report describes the design and construction of these models and gives preliminary assignments for the various calibration parameters.

INTRODUCTION

Evaluation of uranium deposits through natural gross gamma-ray logging has the advantages of cost effectiveness and a well-developed technology. However, problems can be encountered with this method when accurate appraisals of low-grade deposits are desired. For example, significant spurious gamma-ray fluxes can arise from concentrations of potassium or thorium, which are commonly present in uranium deposits. Furthermore, uranium nuclei emit relatively few gamma rays during decay, and these are of low energy. The major contributor to a uranium gamma-ray flux anomaly is usually not uranium, but ^{214}Bi, a daughter (the 9th) of ^{238}U. Since ^{214}Bi is chemically dissimilar to uranium and distant in the decay chain from the ^{238}U parent, it is always possible that geochemical processes have separated the sought-after uranium from the signal-generating ^{214}Bi. This possibility is further enhanced by the fact that the decay chain from ^{238}U to ^{214}Bi includes ^{222}Rn, an inert gas which often migrates over appreciable distances.

Coring and chemical assay may be used to verify the presence of uranium in formations where logs reveal gamma-ray anomalies, but where disequilibrium (separation of uranium from its daughters) is suspected. However, coring is quite expensive, and ore tonnage estimates based on chemical analysis of core material may be inaccurate because a core represents only a tiny fraction of the formation volume of interest. These factors have stimulated research to develop logging tools capable of detecting uranium directly.

Several probes for direct uranium detection utilize the fission reactions that uranium nuclei undergo under neutron bombardment. During logging, a neutron generator or other source (e.g., ^{252}Cf) is used to charge the formation with neutrons. The source is then withdrawn or turned off, and detectors interrogate the borehole neutron population. Anomalously high values for the (prompt) epithermal neutron flux or the (delayed) thermal neutron flux indicate that the formation neutron population has been augmented by fission reactions. Detailed information about these logging methods can be found in the bibliography and references.

At the present time, a delayed fission neutron tool is commercially available, and other fission neutron probes are under development by several companies. Various research firms are also developing fission neutron tools under subcontract to Bendix Field Engineering Corporation, the prime contractor for the U.S. Department of Energy (DOE) National Uranium Resource Evaluation program. The logging models described in this report were designed to serve for the calibration and evaluation of prototype tools, for research into the effects of formation porosity, bulk density, and average thermal neutron cross-section on the neutron signal, and for the calibration of industrial probes, as their use becomes routine.

PHYSICAL DESCRIPTION

Each fission neutron model is a concrete right circular cylinder of 6-foot diameter and 15-foot height. A 4.5-inch diameter unlined vertical borehole runs along the cylinder axis of each model, and a 15-foot runpipe extends below each model. The models are buried so that only the upper circular end is exposed. Model labels and locations on the DOE/GJO facility are shown in Figure 1. Model section views are shown in Figure 2. Appendix I summarizes the arguments used to establish the model diameters.

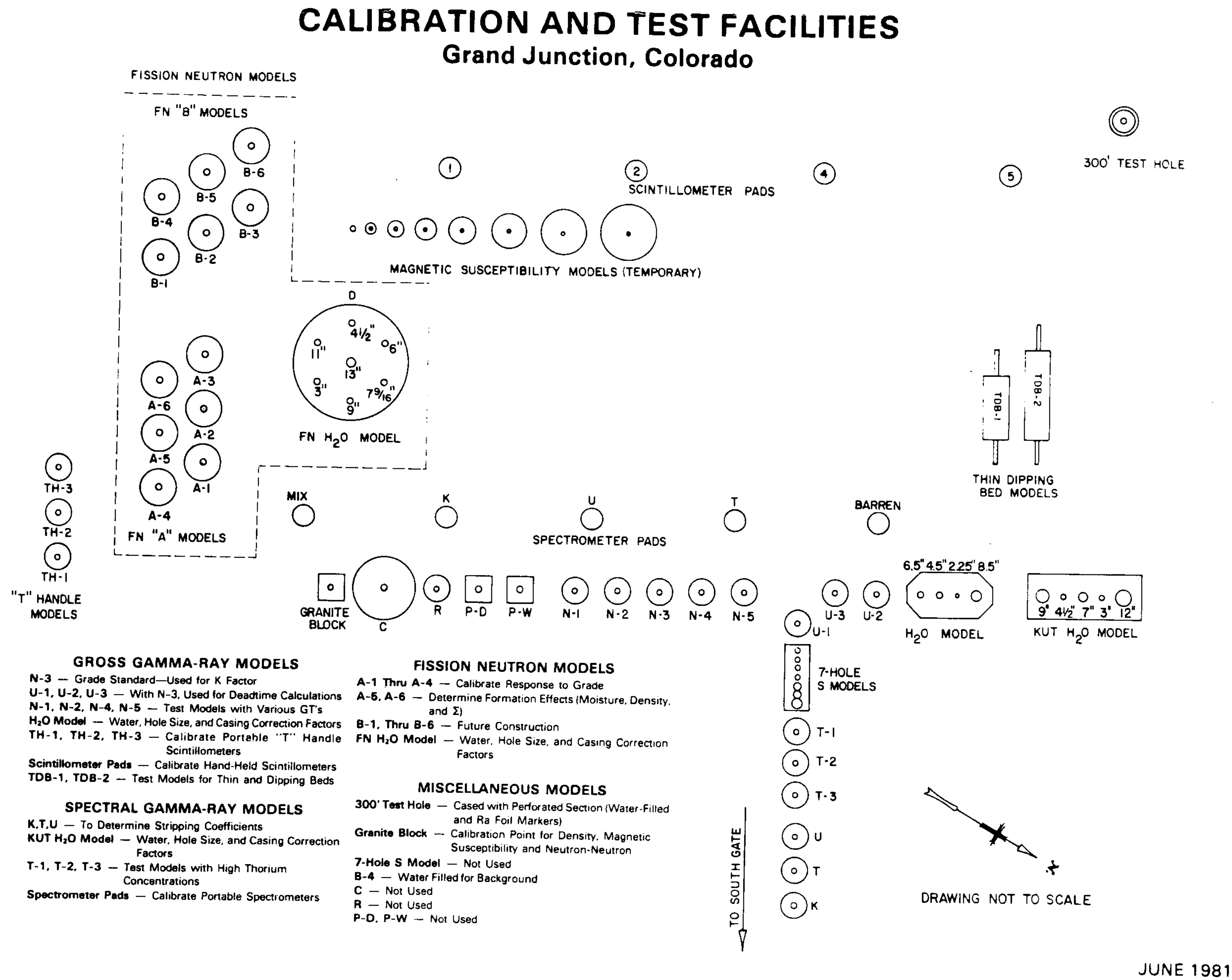

Figure 1. Location of Fission Neutron Calibration Models.

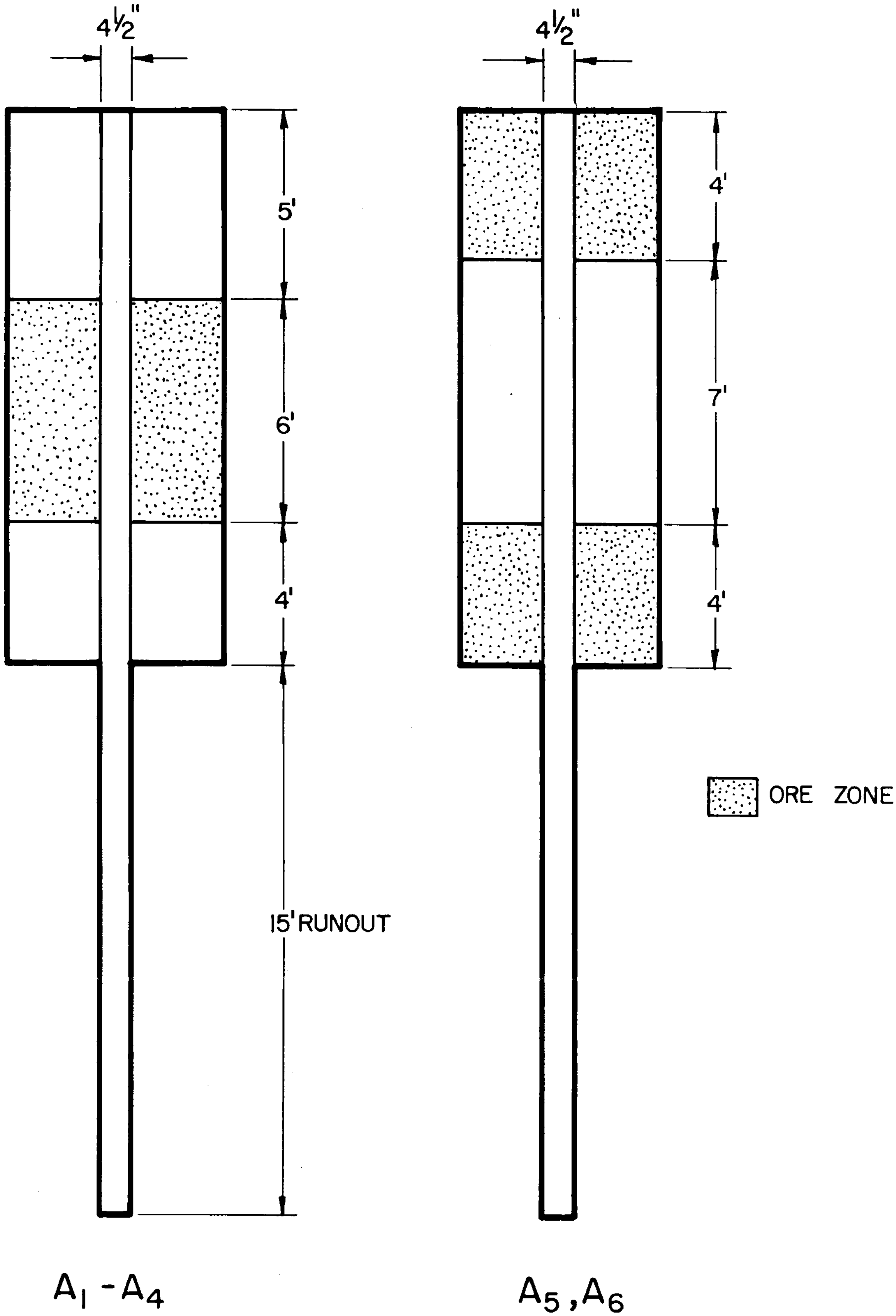

Figure 2. Zone Configurations for Fission Neutron Calibration Models.

As indicated in Figure 2, models A_1, A_2, and A_3 feature a uniform 6-foot (1.83 m) thick ore zone located between a 5-foot (1.52 m) thick upper barren zone and a 4-foot (1.22 m) thick lower barren zone. The design grades for the A_1, A_2, and A_3 ore zones were 0.03, 0.08, and 0.16 percent U_3O_8, respectively. In the construction of these ore zones, every attempt was made to minimize the variations among models of bulk density, porosity, and trace element composition. The major variable is uranium grade, and these three models are intended to serve for the determination of fission neutron tool response as a function of uranium grade.

Model A_4 also contains a 6-foot (1.83 m) thick ore zone, a 5-foot (1.52 m) thick upper barren zone, and a 4-foot (1.22 m) thick lower barren zone. The ore grade is not uniform; it increases from approximately 0.17 percent U_3O_8 at the bottom to approximately 0.35 percent U_3O_8 at the top. The variation of grade with depth was not planned. It resulted from an inadequate concrete mixing technique, which is described in the last paragraph of the section on Concrete Mixing Techniques. Model A_4 should not be used for calibration purposes until the uranium grade as a function of depth is established.

Models A_5 and A_6 contain a 4-foot (1.22 m) thick upper ore zone and a 4-foot (1.22 m) thick lower ore zone. A 7-foot (2.13 m) barren zone separates the ore zones. All four ore zones had a design grade of 0.08 percent U_3O_8. The physical parameters of these ore zones differ from the A_2 ore zone in that the lower zone of A_5 has a higher bulk density and the upper zone has a higher average thermal neutron cross section. The lower zone of A_6 has a low porosity, and the upper zone has a high porosity. Together with the A_2 ore zone, the A_5 and A_6 ore zones therefore furnish two bulk density values, two average formation thermal neutron cross section values, and three porosity values.

The effect of borehole size on tool response can be investigated in the recently completed Fission Neutron Water Factor Model.

CONSTRUCTION

The model concretes are contained within steel cylinders that were fabricated by Doughty Steel and Machine Works of Delta, Colorado. Each model cylinder has a diameter of 6 feet (1.83 m) and a length of 15 feet (4.57 m). The bottom of each cylinder is sealed with a circular steel end plate. A circular hole in the center of each end plate allows logging tools to pass into a 15-foot (4.57 m) long steel runpipe that extends below the model. See Figures 3 and 4. The steel cylinders with attached runpipes were installed in the ground before the model concrete zones were emplaced. Installation of the empty cylinders was accomplished by the following procedures.

Excavation work was done by Caissons, Incorporated, of Denver, Colorado. A large auger, shown in Figure 5, was used to drill six holes, each approximately 9 feet (2.74 m) in diameter and 30 feet (9.14 m) deep. Conventional mud drilling methods were employed. Figure 6 shows drilling in progress; the hole is filled with drilling mud.

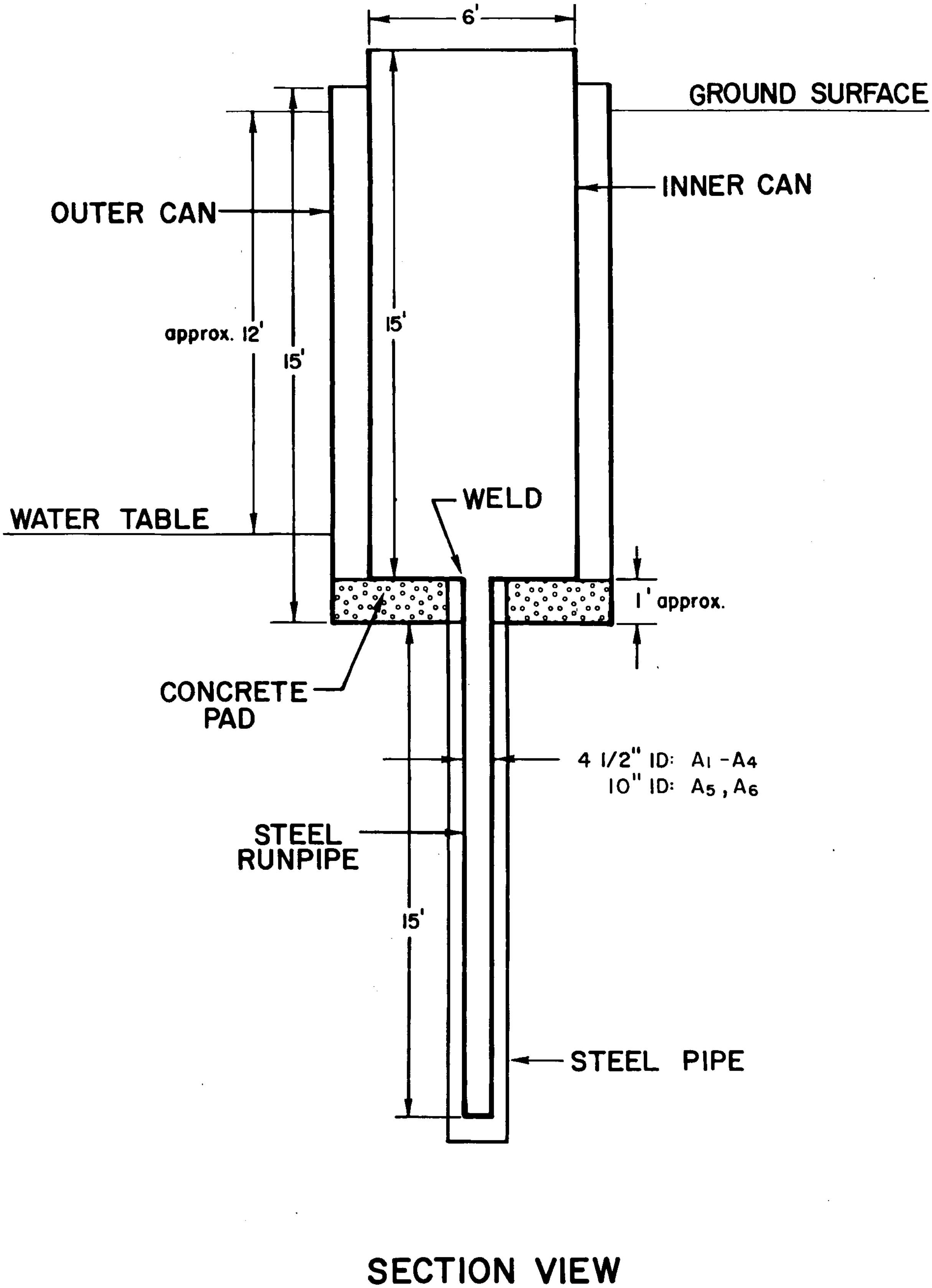

Figure 3. Container Specifications for Models.

Figure 4. Model Cylinder with Runpipe.

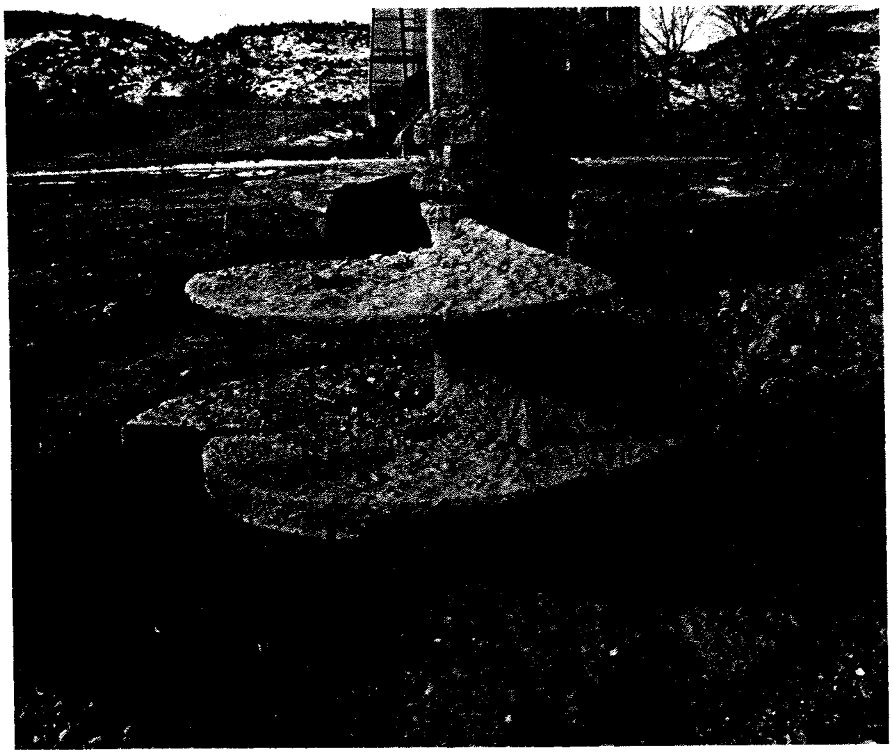

Figure 5. Auger used for Model Hole Excavation.

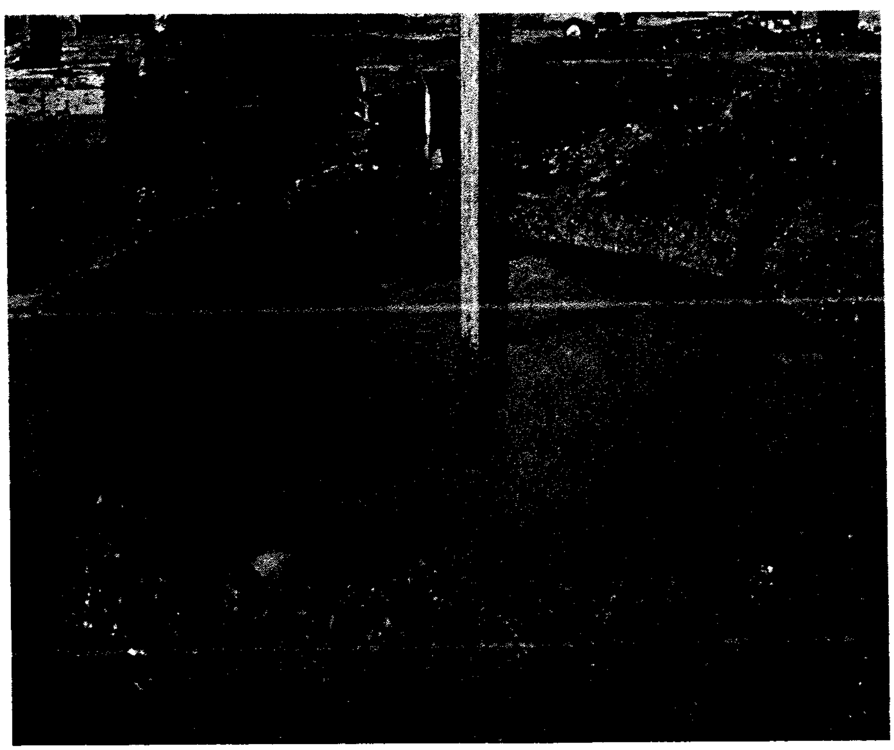

Figure 6. Hole Filled with Drilling Mud.

After each hole was drilled, a 9-foot (2.74 m) diameter temporary casing was set in the hole to minimize infiltration of water (Figure 7). This was required because the hole penetrated about 3 feet (0.91 m) below the water table. Mud and water were bailed from within the temporary casing (Figure 8). Next, a steel pipe of 12-inch (0.30 m) diameter and 15-foot (4.57 m) length was set vertically at the center of the hole bottom. Fourteen feet of backfill were then placed in the hole and leveled. This left only the upper 1 foot of the 12-inch diameter steel pipe exposed, and reduced the depth of the hole to about 16 feet. An 8-foot (2.44 m) diameter, 15-foot (4.57 m) long steel outer cylinder (see Figure 3) was installed in the hole, and a 1-foot (0.30 m) thick pad of reinforced concrete was poured inside of this. The concrete pad lay on top of the backfill and around the protruding 1 foot of the 12-inch diameter steel pipe. A temporary cap kept concrete from entering the steel pipe. Next, the temporary casing was removed (Figure 9). Left in the ground was the outer cylinder with its inner concrete pad and 12-inch diameter steel pipe extending below the pad.

After each hole was prepared as described above, the empty model cylinders were lowered into the 8-foot diameter outer cylinders. This step is illustrated in Figure 10. The 1-foot thick concrete pads formed level bases for the model cylinders, and the 12-inch diameter steel pipes accommodated the model runpipes. At this point, the model cylinders were ready for the addition of model concrete.

Concrete emplacement for models A_1 through A_4 was accomplished according to procedures established during previous model construction projects. That is, zones in a given model were poured one at a time, with at least an overnight cure between successive pours. Smooth pipes of 4.5-inch outside diameter were used to cast the boreholes.

The model runpipes for A_1 through A_4 have inside diameters of 4.5 inches. One end of the casting pipe was inserted into a model runpipe and supported in a vertical position with wooden braces (Figure 11a). A thin coating of grease was applied to the casting pipe. The joint between the casting pipe and runpipe was sealed with a bead of caulk. The lower barren zone concrete was then poured around the casting pipe. The casting pipe was rotated approximately 2 hours later, to prevent it from seizing in the concrete. The pipe was rotated several more times, then removed from the concrete on the next day. It was then re-supported vertically and re-greased, in preparation for the ore zone pour. A bonding agent ("Concrete Bond" by Dri Mix of Denver, Colorado) was applied to the surface of the lower barren zone and the joint where the casting pipe emerged from the lower barren zone was sealed with a bead of caulk. (This caulk seal is especially important in ore zone pours, because it prevents ore zone fluid from contaminating the surface of the previously-cast barren zone borehole.) After the ore zone concrete was poured, the casting pipe was rotated, removed, re-supported, and re-greased, as before. The upper barren zone pour was done in exactly the same manner as the ore zone pour. The finished surface of the upper barren zone was slightly domed, so rainwater would flow away from the borehole. See Figures 11b and 11c.

After a 3-week cure time, the boreholes were filled with water; they have since been kept filled at all times, except during dry hole logging runs.

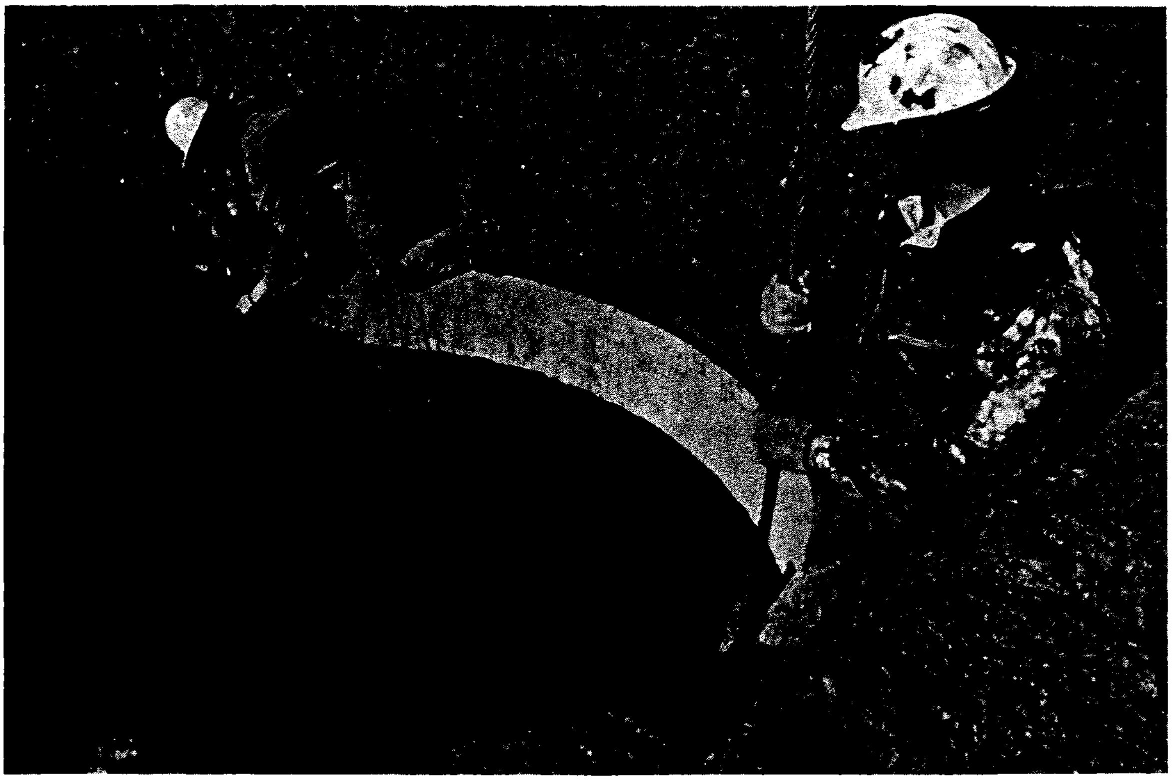

Figure 7. Installation of Temporary Hole Casing.

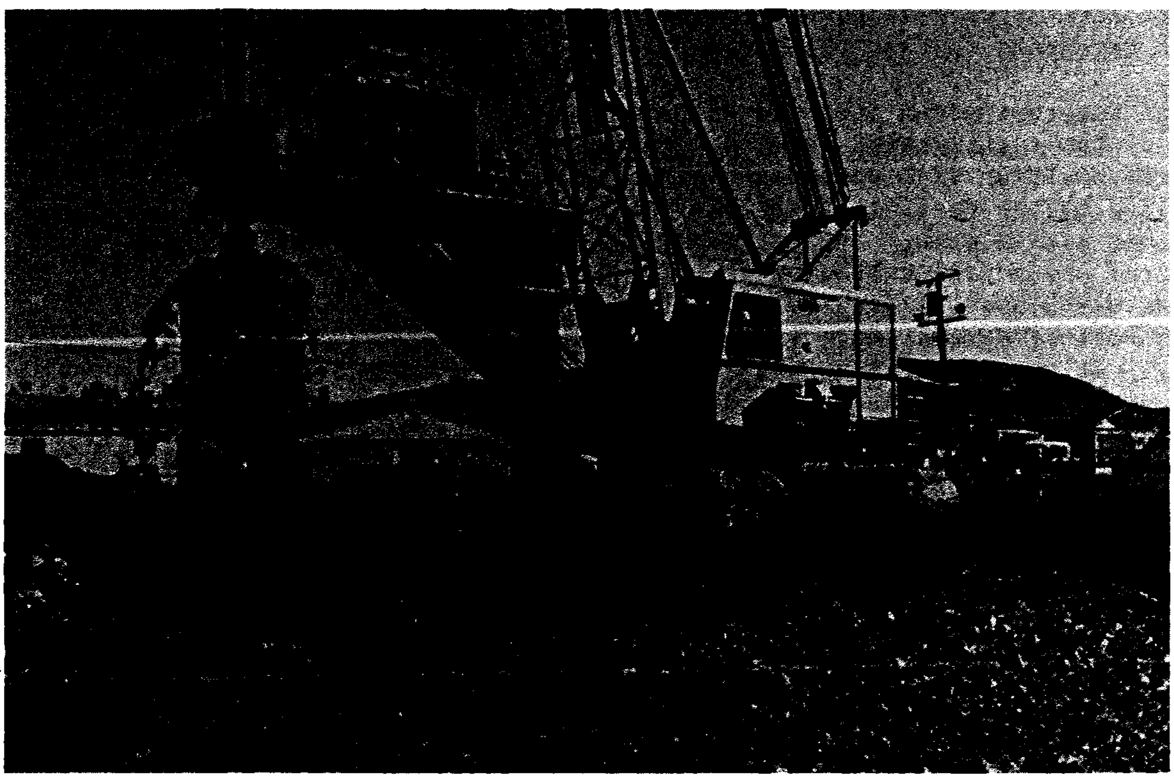

Figure 8. Removal of Drilling Mud.

Figure 9. Removal of Temporary Hole Casing.

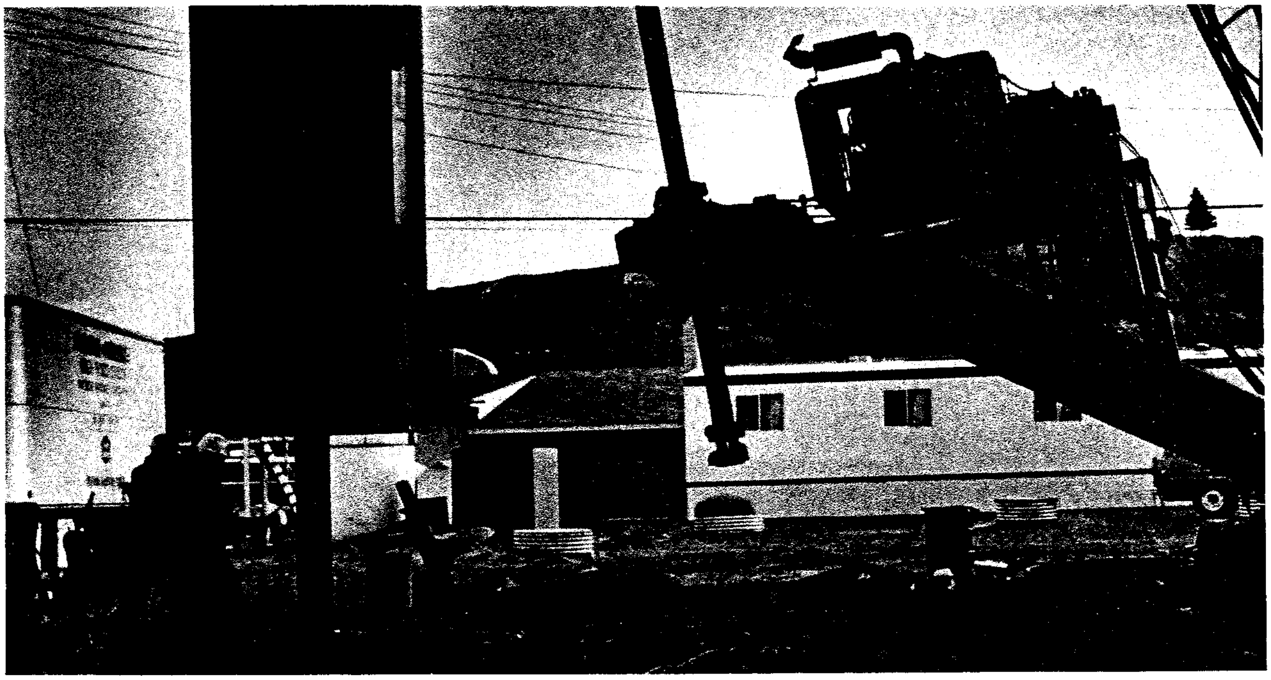

Figure 10. Installation of Model Cylinder.

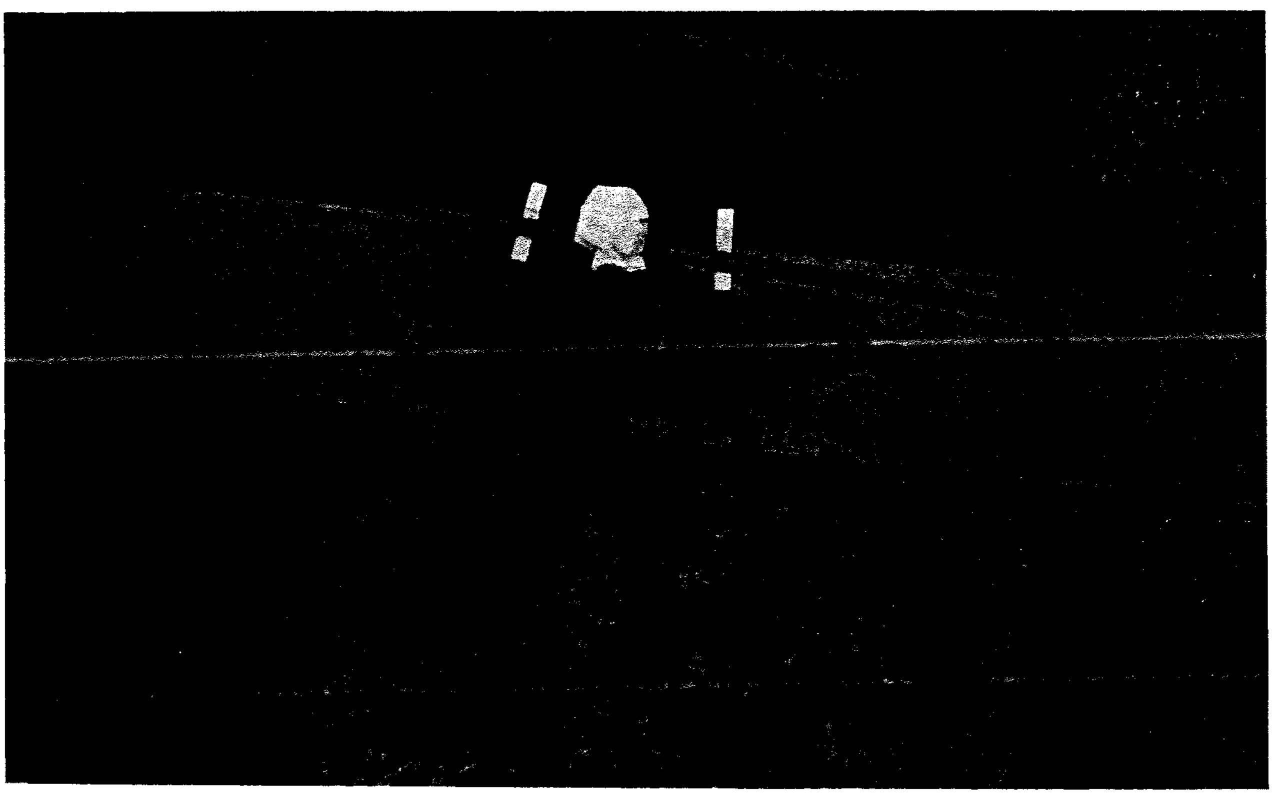

Figure 11a. Pipe for Casting the Model Borehole.

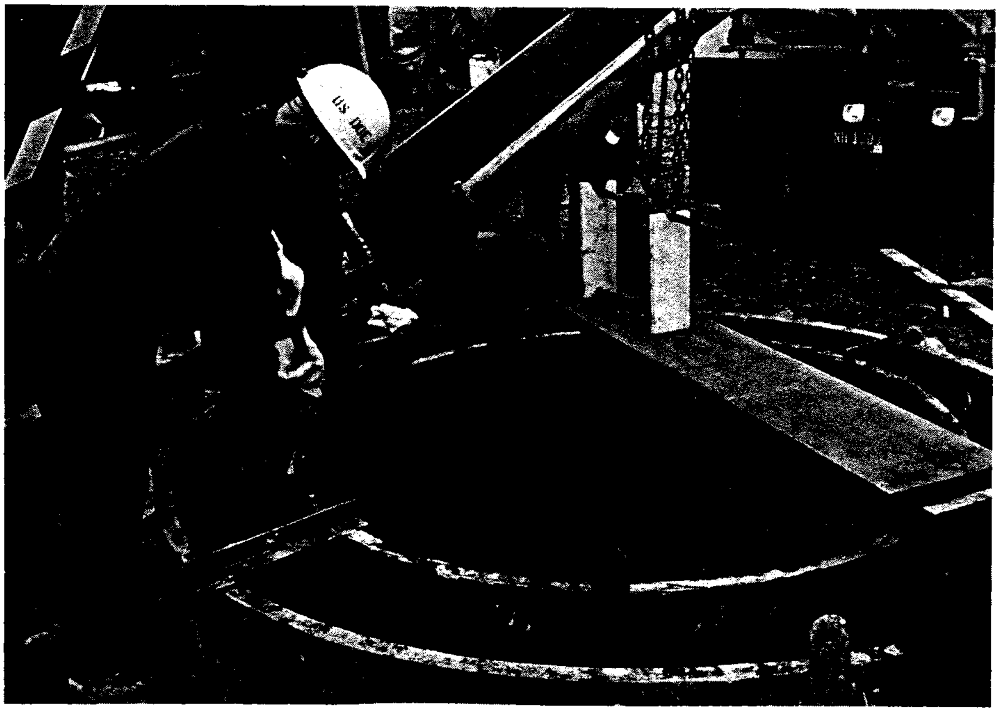

Figure 11b. Emplacement of Model Concrete.

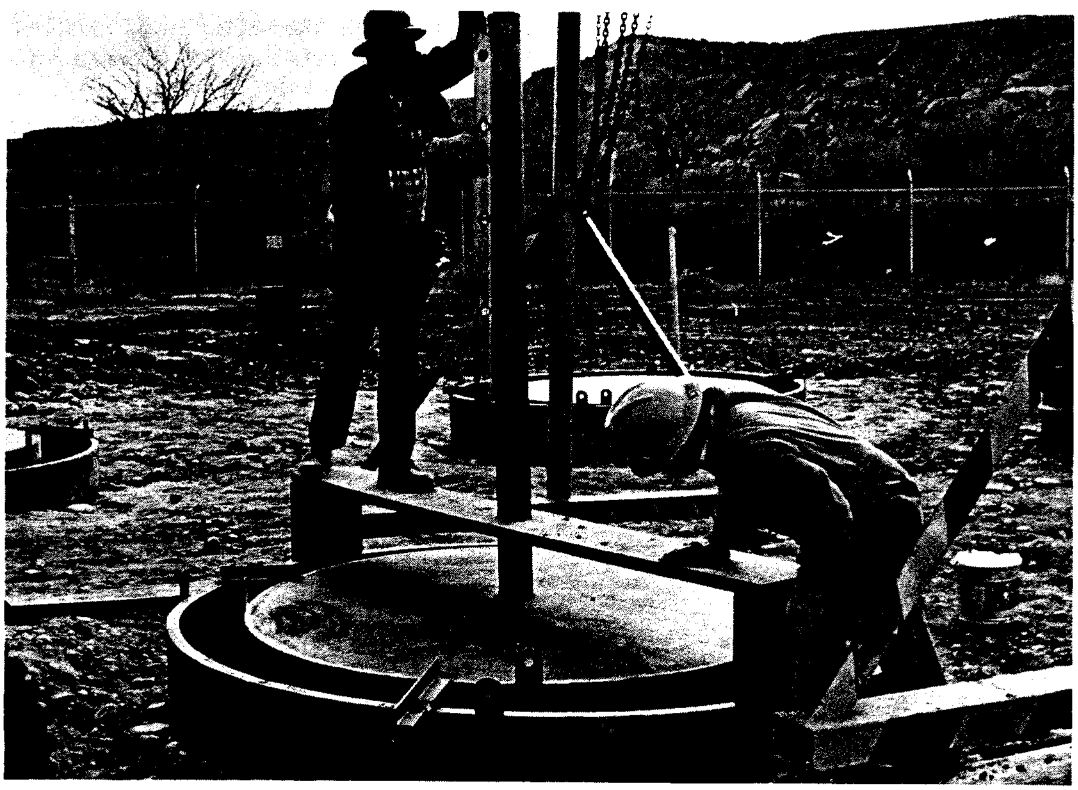

Figure 11c. Model at Completion of Concrete Pour.

An experimental concrete pouring technique was developed for models A_5 and A_6, in response to concern over the following points. If concrete in a model zone is poured, then allowed to cure for a day or more before the next zone is poured, a crack is certain to develop between the two zones. This crack would then fill with water upon addition of water to the borehole. Since water is an excellent neutron moderating medium, the possibility exists that such a water-filled crack in a fission neutron model might produce an undesirable perturbation on the model neutron transport properties. (The gamma-ray transport effect is virtually negligible.) The following description of the A_6 concrete pour illustrates the experimental construction procedures that were developed to avoid, insofar as possible, the formation of cracks between concrete zones.

The A_6 (and A_5) model runpipe is 10 inches in diameter and 15 feet long. This runpipe was filled with barren zone concrete. A few days later, the lower ore zone was poured. This zone was allowed to cure for only 2 hours (approximately), then the barren zone was poured. No bonding agent was placed between zones. After a 2-hour barren zone cure time, the upper ore zone was poured and the surface was domed. Thus, all of the model concrete (except for the runpipe concrete) was poured in a single day's operation. It was hoped that this method would produce firm bonds between zones. (At the very least, curing and shrinking at different rates between zones would be minimized.) Comments on the outcomes of these construction experiments appear in the section on "Problems Addressed Through Core Studies."

After a 6-week cure period, the boreholes for models A_5 and A_6 were core drilled by Himes Drilling Company of Grand Junction, Colorado. Model A_6 was air-cored and model A_5 was water-cored; in both cases efforts were made to recover as much of the drilling dust as possible, thereby holding radioactive contamination of the area to a minimum. A 15-foot (approximately) runout was drilled by coring the concrete column in the 10-inch diameter, 15-foot runpipe. Upon completion of coring, the boreholes were filled with water. They have been kept water-filled ever since, except during occasional dry hole logging runs.

In the final construction phases, the above-ground portions of all of the model outer cylinders were removed with an acetylene torch, and the voids between the inner and outer cylinders were filled with soil. Then the entire construction area was graded and graveled.

DETERMINATION OF CONCRETE FORMULAS

The basic concrete formula for the Fission Neutron Calibration Models was adapted from a formula used by the Colorado Highway Department. The formulas for 1 cubic foot and 1 cubic meter of finished concrete are shown in Table 1.

Table 1
Concrete Formulas

Concrete Volume	Dry Masonry Sand	Dry 3/4-inch Rock	Type II Cement	Water
1 ft^3	45.0797 lb	66.8523 lb	21.2820 lb	11.8060 lb
1 m^3	722.108 kg	1070.871 kg	340.905 kg	189.114 kg

The formulas in Table 1 were used for all barren zone concretes.

The ore zone concrete formulas for models A_1, A_2, A_3, and A_4 were derived by the following method. The ore zone volume was calculated, and a 15 percent safety factor was added to insure against the possibility of mixing a concrete batch with volume insufficient to complete the pour. The entries of Table 1 were then used to calculate the required amounts of sand, rock, cement, and water. The amount M of uranium ore needed was determined from the ore grade G_o and the model design grade G_d:

$$G_d = \frac{MG_o}{\text{sand mass} + \text{rock mass} + \text{cement mass}},$$

or

$$M = \frac{G_d}{G_o}\left(\text{sand mass} + \text{rock mass} + \text{cement mass}\right).$$

This mass M of uranium ore was then incorporated into the concrete formula by removing mass M of sand. That is, the total mass of the ore zone materials was kept constant; sand was replaced by an equivalent mass of ore.

Some of the aggregate materials were not available in a dry condition. In these cases, the moisture content of each aggregate had to be measured, then the dry aggregate and water specifications had to be adjusted to reflect these moisture contents. The amounts of aggregates actually used in the model concretes are listed in Tables 2 and 6, and the aggregates are further described in the section "Model Material Descriptions."

As described in the "Physical Description" section, the four ore zones of models A_5 and A_6 feature variations in average thermal neutron cross section, bulk density, and porosity. The methods by which these variations were attained are described below.

Table 2

Barren Zone Mix Contents

Model	Zone	Whitewater Masonry Sand	3/4-inch Rock	Cement	Water
A_1	Upper barren	7,013 lb (3,181 kg)	10,400 lb (4,717 kg)	3,309 lb (1,501 kg)	1,905 lb (864 kg)
	Lower barren	6,125 (2,778)	9,139 (4,145)	2,888 (1,310)	1,695 (769)
A_2	Upper barren	7,017 (3,183)	10,400 (4,717)	3,309 (1,501)	2,104 (954)
	Lower barren	5,615 (2,547)	8,321 (3,774)	2,647 (1,201)	1,626 (738)
A_3	Upper barren	7,017 (3,183)	10,400 (4,717)	3,309 (1,501)	2,038 (924)
	Lower barren	5,615 (2,547)	8,321 (3,774)	2,647 (1,201)	1,626 (738)
A_4	Upper barren	7,013 (3,181)	10,400 (4,717)	3,309 (1,501)	1,864 (845)
	Lower barren	6,125 (2,778)	9,076 (4,117)	2,888 (1,310)	1,653 (750)
A_5	Center barren	9,824 (4,456)	14,561 (6,605)	4,634 (2,102)	2,885 (1,309)
A_6	Center barren	9,824 (4,456)	14,561 (6,605)	4,634 (2,102)	2,927 (1,328)

A5--Upper Ore Zone

This zone was designed to have a uranium grade of 0.08 percent U_3O_8 and an average thermal neutron capture cross section (per atom), $\langle\sigma_{th}\rangle$, of four times the normal concrete value. The uranium grade and the high $\langle\sigma_{th}\rangle$ were attained by substituting, respectively, uranium ore and boron carbide (B_4C) for part of the sand. The ^{10}B isotope, which comprises 18.83 percent of naturally-occurring boron, has a thermal neutron absorption cross section (σ_{th}) of 3,840 barns. The required amount of boron carbide was established as follows.

The second and third columns of Table 3 list elements and elemental concentrations (N) found in typical type 02-A concrete (9.1 percent water by mass) to which has been added (n) number of molecules of boron carbide per cubic centimeter.

Table 3
Thermal Neutron Cross Section Data for Model Elements

Material	Element[1]	N[1]	σ_{th}	(N)(σ_{th})
Concrete (dry)	Mg	1.238×10^{20} atom/cm^3	5.05×10^{-2} barn/atom	6.25x10 cm
	Al	1.740×10^{21}	1.86×10^{-1}	3.24x10
	Si	1.661×10^{22}	1.29×10^{-1}	2.14x10
	K	4.619×10^{20}	1.73	7.99x10
	Ca	1.502×10^{21}	3.47×10^{-1}	5.21x10
	Fe	3.449×10^{20}	2.05	7.07x10
	C	1.153×10^{20}	2.71×10^{-3}	3.12x10
	O	3.902×10^{22}	1.43×10^{-4}	5.58x10
	^{10}B	0.753 n	3.07×10^{3}	2.31x10
	^{11}B	3.247 n	4.01×10^{-3}	1.30x10
	C	n	2.71×10^{-3}	2.71x10
Water (in formation)	H	1.374×10^{22}	2.66×10^{-1}	3.65x10
	O	6.885×10^{21}	1.43×10^{-4}	9.85x10

Column 4 of Table 3 gives thermal neutron cross sections calculated by averaging the neutron absorption cross sections over a Maxwellian spectrum for energies from 0 to 0.1265 eV, and over an inverse energy spectrum for energies from 0.1265 eV to 0.4140 eV (Woolson and Gritzner, 1977). The fifth column of Table 3 lists the products of atomic concentration and thermal neutron capture cross section for each element.

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[1]Reactor Physics Constants, USAEC Report ANL-5800, Argonne National Laboratory, 1958.

The average thermal neutron capture cross section per atom for a model zone is:

$$\langle\sigma_{th}\rangle = \frac{\Sigma(N)\ (\sigma_{th})}{\Sigma\ N},$$

where the sums (indicated by Σ) are taken over all of the elements in the model zone. For concrete and water with no boron carbide (n=0 in Table 3),

$$\langle\sigma_{th}\rangle_{n\,=\,0} = 0.1012 \text{ barn} = 1.012 \times 10^{-25} \text{ cm}^2.$$

If boron carbide is present, then

$$\langle\sigma_{th}\rangle_{n\,\neq\,0} = \frac{8.154 \times 10^{-3} \text{ cm}^{-1} + 2.31 \times 10^{-21} \text{ n cm}^2}{8.054 \times 10^{22} \text{ cm}^{-3} + 5\text{n}},$$

and the ratio of the average thermal neutron capture cross section with boron carbide to the average thermal neutron capture cross section without boron carbide is

$$\frac{\langle\sigma_{th}\rangle_{n\,\neq\,0}}{\langle\sigma_{th}\rangle_{n\,=\,0}} = \frac{\left(\dfrac{8.154 \times 10^{-3} \text{ cm}^{-1} + 2.31 \times 10^{-21} \text{n cm}^2}{8.0543 \times 10^{22} \text{ cm}^{-3} + 5\text{n}}\right)}{1.012 \times 10^{-25} \text{ cm}^2}.$$

The design objective was

$$\frac{\langle\sigma_{th}\rangle_{n\,\neq\,0}}{\langle\sigma_{th}\rangle_{n\,=\,0}} = 4.$$

This requires a boron carbide concentration of

$$n = 1.06 \times 10^{19} \ (B_4C \text{ molecules/cm}^3).$$

The ore zone volume is

$$V = 113.1 \text{ ft}^3 = 3{,}203 \times 10^6 \text{ cm}^3,$$

so the quantity of B_4C required is

$$m = \left(\frac{1.06 \times 10^{19} \text{ molecules}}{\text{cm}^3}\right)\left(\frac{9.18 \times 10^{-23} \text{ gram}}{\text{molecule}}\right)(3.203 \times 10^6 \text{ cm}^3),$$

or

$$m = 6.9 \text{ lb} = 3.12 \text{ kg}.$$

The 15 percent ore zone overestimate safety factor (mentioned earlier in this section) brings the boron carbide specification to about 8 lb (3.6 kg). The amounts of materials used in this ore zone are listed in Table 6, and detailed descriptions of the aggregates appear in the "Model Material Descriptions" section.

A5--Lower Ore Zone

This ore zone design called for a uranium grade of 0.08 percent U_3O_8, but a higher bulk density, ρ_B. It is difficult to accomplish a density change while keeping such factors as $<\sigma_{th}>$, $<Z>$, $<Z/A>$, and porosity constant, but an excellent solution was suggested by D. C. Moore of Bendix Field Engineering Corporation. It was suggested that the silicon dioxide (SiO_2, density of approximately 2.6 gram/cm^3) of sand be replaced by the chemically similar, but much denser aluminum oxide (or corundum, Al_2O_3, density of approximately 3.7 gram/cm^3). Silicon dioxide and aluminum oxide are further compared in the "Model Material Descriptions" section.

The corundum requirement was established by setting the corundum volume equal to the volume of the replaced sand:

$$\text{corundum volume} = \frac{\text{corundum mass}}{3.7\ \text{gram/cm}^3} = \text{sand volume} = \frac{\text{sand mass}}{2.6\ \text{gram/cm}^3}$$

or

$$\text{corundum mass} = \left(\frac{3.7}{2.6}\right)\ (\text{sand mass}).$$

A sand-like mixture of grain sizes was obtained by blending 6,805 lb (3087 kg) of -36 mesh corundum with 1,856 lb (841.9 kg) of -180 mesh corundum. After several experiments indicated that a competent concrete could be made with corundum instead of sand, an ore zone specification was established in which sand was completely replaced by corundum. The desired uranium grade was attained by replacing part of the corundum with uranium ore. The amounts of materials used are listed at the end of this section, and the corundum properties are described in the "Model Material Descriptions" section.

A_6--Upper Ore Zone

This ore zone was designed to have a uranium grade of 0.08 percent U_3O_8 and a moderately high porosity. A porosity (ϕ) of approximately 30 percent can be attained in concrete if coarse aggregate is omitted. The concrete mix of Table 4 was developed for Bendix Field Engineering Corporation by Armstrong Engineers and Associates of Grand Junction, Colorado.

Table 4
Basic Concrete Formula for Model A_6

Volume	Dry Masonry Sand	Type II Cement	Water
1 ft^3	84.5558 lb	24.6403 lb	17.4101 lb
1 m^3	1354.454 kg	394.700 kg	278.883 kg

If the porosity is described by

$$\phi = \frac{\left(\begin{matrix}\text{grain}\\\text{density}\end{matrix}\right) - \left(\begin{matrix}\text{bulk}\\\text{density}\end{matrix}\right)}{\left(\begin{matrix}\text{grain}\\\text{density}\end{matrix}\right) - \left(\begin{matrix}\text{fluid}\\\text{density}\end{matrix}\right)} ,$$

and the grain, bulk, and fluid densities are approximately 2.6 gram/cm^3, 2.0 gram/cm^3, and 0 (air), respectively, then

$$\phi \simeq \frac{2.6 - 2.0}{2.6} = 23\%$$

As before, part of the sand was replaced by an equivalent mass of uranium ore to attain the desired ore zone grade.

<u>A_6--Lower Ore Zone</u>

This ore zone was intended to have a uranium grade of 0.08 percent U_3O_8 and a low porosity. The low porosity concrete was designed in the following way.

Samples of masonry sand, 3/8-inch rock, and 3/4-inch rock were air dried and individually packed into containers of known volumes. The masses were recorded. Then water was added to the container until all of the pore space was filled. The volume of water and the total mass (water plus aggregate) were recorded.

It was next assumed that a good approximation for ϕ could be calculated under the assumption that the water penetrated only the pore space between grains. Then,

$$\phi = \frac{\text{volume of water added}}{\text{volume occupied by dry aggregate}} .$$

The volumes and dry masses of the aggregates could be used to estimate the bulk densities:

$$\rho_\beta = \frac{\text{mass of dry aggregate}}{\text{volume occupied}} .$$

Once the porosities and bulk densities of the aggregate masses were known, the grain densities could be calculated from the following:

$$\rho_G = \frac{\rho_B - \phi\rho_{fluid}}{1 - \phi},$$

Since ρ_B is the dry bulk density, $\rho_{fluid} = \rho_{air}$. This was taken as zero for these approximation calculations. The calculated porosities, dry bulk densities, and grain densities are displayed in Table 5.

Table 5
Aggregate Parameters

Aggregate	Porosity (%)	Dry Bulk Density (gram/cm^3)	Grain Density (gram/cm^3)
Masonry sand	33	1.54	2.30
3/8-inch rock (pea gravel)	40	1.41	2.35
3/4-inch rock	40	1.41	2.35

Next, the mass of 3/4-inch rock needed to fill the 113.1 cubic foot ore zone was determined:

$$M = (\text{bulk rock density})\ (113.1\ \text{ft}^3),$$

or

$$M = 9944\ \text{lb} = 4510\ \text{kg}.$$

But an ore zone filled with only 3/4-inch rock would contain 40 percent pore space. That is,

$$\text{pore space} = (40\%)\ (113.1\ \text{ft}^3) = 45.2\ \text{ft}^3 = 1.28\ \text{m}^3.$$

This pore space can be filled with a mass M' of 3/8-inch rock:

$$M' = (\text{rock bulk density}) \ (45.2 \ ft^3) = 3{,}978 \ lb = 1804 \ kg.$$

Again, 40 percent of the 3/8-inch rock volume is pore space. That is,

$$\text{pore space} = (40\%) \ (45.2 \ ft^3) = 18.1 \ ft^3 = 0.513 \ m^3.$$

This pore space can in turn be filled with a mass M'' of masonry sand:

$$M'' = (\text{sand bulk density}) \ (18.1 \ ft^3) = 1.739 \ lb = 788.8 \ kg.$$

Since 33 percent of the sand volume is pore space, the remaining ore zone pore space is approximately

$$(33\%) \ (18.1 \ ft^3) = 6.0 \ ft^3 = 0.17 \ m^3,$$

and the theoretical ore zone porosity is

$$\phi = \frac{6 \ ft^3}{113.1 \ ft^3} = 5.3\%.$$

The masses of the 3/4-inch rock and 3/8-inch rock were augmented by 15 percent, to provide a margin of safety. The sand mass was increased by 15 percent for a margin of safety and by an additional 10 percent to fill any excess pore space. The desired uranium ore grade was attained through the replacement of part of the sand with uranium ore. Amounts of various materials used are given in Table 6, and aggregate properties are described in the "Model Material Descriptions" section.

Additional remarks on all of the ore zones discussed in this section appear in the section on "Grade and Other Model Parameter Assignments."

The following tables indicate actual amounts of various materials used in the Fission Neutron Calibration Models. Because the excess concrete that remained after each pour was discarded, the figures represent quantities that were mixed, not quantities of concrete in the models.

Table 6

Ore Zone Mix Contents

Model	Zone	Dri-Mix Masonry Sand	3/4-inch Rock	Type II Cement	Water	Uranium Ore	Uranium Ore Grade	Other
A_1	Center ore	11,136 lb (5,051 kg)	16,867 lb (7,651 kg)	5,367 lb (2,434 kg)	3,294 lb 1,494 kg)	347 lb (157 kg)	2.90%eU_3O_8	-
A_2	Center ore	10,305 (4,674)	15,544 (7,051)	4,920 (2,232)	3,115 (1,413)	222 (101)	11.14	-
A_3	Center ore	10,050 (4,559)	15,537 (7,047)	4,918 (2,231)	3,115 (1,413)	472 (214)	10.44	-
A_4	Center ore	8,516 (3,863)	13,616 (6,176)	4,333 (1,965)	2,396 (1,087)	754 (342)	10.79	-
A_5	Upper ore	5,544 (2,515)	8,330 (3,778)	2,651 (1,202)	1,616 (733)	121 (54.9)	11.14	8.3 lb B_4C (3.8 kg)
	Lower ore	-	8,362 (3,793)	2,661 (1,207)	1,883 (854)	143 (64.9)	11.14	8,661 lb Al_2O_3 (3,929 kg)
A_6	Upper ore	10,427 (4,730)	-	3,065 (1,390)	2,199 (997)	97 (44.0)	11.09	-
	Lower ore	2,096 (951)	10,963 (4,973)	3,490 (1,583)	1,972 (894)	155 (70.3)	11.09	4,826 lb 3/8-inch rock (2,189 kg)

CONCRETE MIXING TECHNIQUES

All of the concrete mixing and pouring was performed by the Whitewater Building Materials Corporation of Grand Junction, Colorado. In the case of barren zones, the specifications were supplied to Whitewater, and the batching and mixing were accomplished at the Whitewater plant, with Whitewater-supplied aggregates. The fine aggregates (uranium ores, sand, corundum, and boron carbide) for the ore zones were purchased separately by Bendix Field Engineering Corporation. These materials were mixed in the proper proportions and blended in a twin shell blender at the Bendix Sample Handling Plant. Whitewater supplied the 3/4-inch rock, 3/8-inch rock, cement, and water for the ore zones. The mixing procedures will now be described in greater detail.

Barren Zone Mixing

Since neutron transport properties of rock are strongly affected by the water content, the batching and mixing procedures were formulated to allow maximum control over the water content of each concrete mix.

Water control could probably have been most easily maintained if it had been possible to thoroughly dry all of the aggregates prior to weighing and batching. This approach was abandoned for two reasons:

(1) No local plant had the capability to dry aggregates in the quantities required, and

(2) even if the aggregates could be dried, they would begin to collect water from the atmosphere as soon as the drying process was terminated.

A reasonable alternative to the use of dried aggregates is the use of wet aggregates for which the moisture contents have been determined and correction factors applied. This approach was implemented as follows.

In the late afternoon before the pour, the 3/4-inch rock and sand were placed in the concrete truck drum. The truck was then left undisturbed at the concrete plant overnight. During the aggregate batching, three to six samples were collected of each type of aggregate. These samples were sealed in plastic bags and delivered to the Bendix Geochemistry Laboratory, where the moisture content was determined by noting the change in sample mass that resulted from drying overnight at 110° C. The next morning, the moisture results were used to correct, if necessary, the amounts of aggregates in the concrete truck drum. The cement and water were then added, and the truck proceeded to the DOE/Grand Junction facility to pour the concrete.

During the first barren zone pours (lower zones of A_1 and A_4), several observations were made. The first concerns the method whereby the aggregate moistures were measured and the mixture specifications were adjusted accordingly. This method worked reasonably well for producing a concrete of given slump at the concrete plant. However, the slump always decreased by the time the trucks reached the pour site, and additional water had to be added to the mix. The required amount of additional water depended on (1) the time between batching and pouring, (2) the ambient temperature and humidity, and (3) the amount of water "soaked up" by the concrete truck drum (up to about 10 gallons for the first concrete batch of the day).

The second observation concerns the method of determining the water content of sand. A number of experiments were conducted in which sand of known moisture was tested at Whitewater with an instrument known as the "Speedy Moisture Tester."* It was found (see Figure 12) that the true** sand moisture (M) was related to the Whitewater instrument readout (M_S) by

$$M = 0.92\ M_S + 1.11\%.$$

The two observations just discussed led to several slight adjustments in the barren zone concrete mixing procedures. Masonry sand was no longer collected for moisture analysis. Instead, the sand moisture was determined by the "Speedy" at the time of batching, and corrections were calculated and implemented immediately. Also, due to the concrete drum "soaking" factor and the temperature and humidity effects on the concrete slump, the attempt to tightly control the water during batching was abandoned. Instead, the Whitewater personnel were simply instructed to mix the concrete to a slump of 2.5 to 3.5 inches at the pour site. Aggregate samples were collected and sealed in plastic bags during batching and records were kept of all amounts of water added. Later, the samples were moisture analyzed. These data, plus the records of water addition, allowed the calculation of the total water content of each batch of model concrete mix.

Ore Zone Mixing

The procedures for mixing the ore zone concretes generally followed the steps outlined in the last paragraph of the Barren Zone Mixing section. The exception is found in the treatment of ore zone fine aggregates. The corundum and boron carbide were received from the suppliers in a dry condition. The Schwartzwalder uranium ore had been previously dried and crushed. It was known from previous experience at the Bendix Sample Handling Plant that these fine dry materials could not be blended properly with moist sand. Since all of the Whitewater sand supply was moist (from being stored outside in February) 80-pound bags of kiln-dried masonry sand were purchased for the ore zones from Dri-Mix Concrete Company of Grand Junction, Colorado.

Dry sand, uranium ore, and boron carbide or corundum (if used) were combined in the proper proportions (see Table 6) and blended together for at least 30 minutes in a twin-shell blender. These dry ore zone blends were then stored in sealed 55-gallon drums.

On the pour date, the concrete truck was loaded with 3/4-inch rock. Samples were collected for moisture determination. The truck then proceeded to the Bendix Field Engineering Sample Handling Plant to load the ore zone fine

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*Manufactured by Thomas Ashworth Burnley of Lancaster, England, serial number 51354.

**Determined by measuring the mass of water driven off upon heating to 110° C.

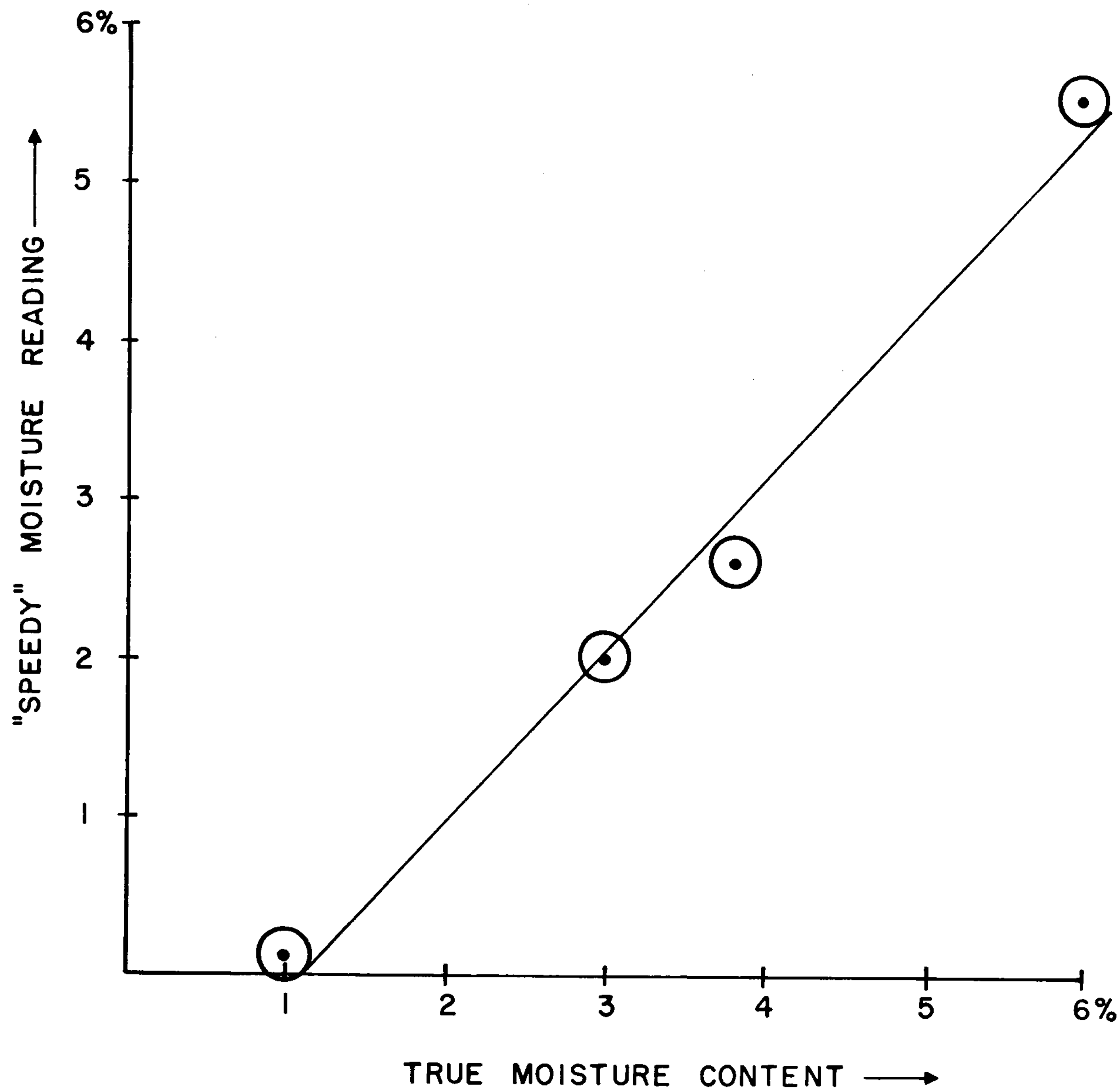


Figure 12. "Speedy" Moisture Measurement Versus True Moisture Content.

aggregate mixture. After this was accomplished, the truck returned to the Whitewater plant to load cement and water. At the pour site, the truck drum was turned for at least 30 minutes, and the concrete slump was adjusted to between 2.5 and 3.5 inches (6.4 to 9.0 cm). The concrete pour then began.

Although it may consume extra time, it is important to place the 3/4-inch rock in the truck before the fine aggregate is added. The rock keeps the truck drum "scoured" and does not allow the fine aggregate to "cake" on the drum sides. During routine concrete mixing operations, it is not uncommon for some of the fine aggregate to cake in the mixing drum. This is usually of little consequence to a construction contractor, because the strength of the finished product is not drastically affected. However, the occurrence of caking during model building is more serious. During batching of the A_4 ore zone, the fine aggregate was loaded first. Caking apparently took place during the mixing of the ore zone (the second of the model ore zones to be poured), and the gradual removal of caked ore zone material from the truck drum during the pour caused the uranium grade of the zone to increase from bottom to top.

DESCRIPTIONS OF MODEL MATERIALS

This section is devoted to descriptions of the aggregate materials used in the Fission Neutron Calibration Models. All of the petrographic studies were performed by the Bendix Field Engineering Petrology Laboratory. The petrographic reports appear in Appendix II.

Cement

In all cases, the cement was type II cement, supplied by the Whitewater Building Materials Corporation.

3/4-inch Rock

The 3/4-inch rock was also supplied by Whitewater Building Materials. The report on a petrographic study of one sample is found in Appendix II, Report 5.

Sand

The barren zone masonry sand was supplied by Whitewater Building Materials Corporation. Grain sizes were approximately -10 mesh. Two samples of this sand were petrographically investigated. Volcanic rock fragments, quartz and sedimentary or plutonic rock fragments constituted the bulk of the samples studied. Complete petrographic reports appear in Appendix II, Reports 1 and 2.

The ore zone masonry sand was kiln dried and packed in 80-pound bags by the Dri-Mix Concrete Company of Grand Junction, Colorado. The supplier for Dri-Mix was United Redi-Mix Company, Incorporated, of Grand Junction. Grain sizes were approximately -10 mesh. One sample of this sand was examined petrographically. The bulk of this sample consisted of quartz, metamorphic rock fragments, plutonic rock fragments, volcanic rock fragments, and sedimentary rock fragments. The complete petrographic report is given in Appendix II, Report 3.

3/8-inch Rock

The 3/8-inch rock (pea gravel) for the low porosity ore zone was supplied by Whitewater Building Materials. One sample was petrographically examined. The report appears in Appendix II, Report 4.

Boron Carbide

The boron carbide for the high thermal neutron cross section ore zone was purchased from Boride Products, Incorporated, of Traverse City, Michigan. The average particle size was 5.2 microns. Boron carbide was selected for the high thermal neutron cross section material because the ^{10}B isotope (18.83 percent of natural boron) has a high thermal neutron absorption cross section (3,840 barns), the compound is not prohibitively expensive, and it has a high melting point (2,450°C) and is insoluble in water and acid.

Corundum

Corundum (Al_2O_3) for the high density ore zone was purchased from Bendix Abrasives, of Westfield, Massachusetts. Two tons (1,814 kg) of material with grain sizes of −180 mesh and 5 tons (4,536 kg) of material with grain sizes of −36 mesh were ordered. Bendix Abrasives furnished the composition information in Table 7.

Table 7

Composition of Commercial Corundum

Compound	Mass Fraction (%)
Al_2O_3	89.0
SiO_2	6.6
TiO_2	3.0
Cr_2O_3	0.6
Fe_2O_3	0.6
CaO	0.1
MgO	0.1

Corundum was selected as the high density material because it is dense and inexpensive and bears a close chemical resemblance to the silicon dioxide that it presumably replaces. Tables 8 and 9 give comparisons of chemical properties of aluminum and silicon, and corundum and quartz.

Table 8

Chemical Properties of Aluminum and Silicon

	Aluminum	Silicon
Z	13	14
Atomic wt	27.0	28.1
Valence	3	4
σ_{th}, barns	0.23 for ^{27}Al	0.16 for ^{28}Si

Table 9

Comparison Between Corundum and Quartz

	Corundum (Al_2O_3)	Quartz (SiO_2)
Z/A	0.49	0.50
Melting point	2,015°C	1,470°C
Solubility, water	Insoluble	Insoluble
Solubility, acid	Very slight	Slight
Solubility, base	Very slight	Very slight
Specific gravity	3.97	2.6

Uranium Ore

The uranium ore was purchased from the Schwartzwalder Mine, Jefferson County, Colorado. This ore was taken from a vein-type primary deposit (mainly pitchblende) in Precambrian rock. The uranium is known to be near secular equilibrium with its daughter elements. For model use, the ore was ground to −28 mesh by the Bendix Field Engineering Sample Handling Laboratory. Chemical uranium grades of various ore batches were established by the Bendix Field Engineering Geochemistry Department. Results are shown in Appendix III. The Bendix Field Engineering Corporation Petrology Laboratory also conducted a petrographic examination of an ore sample. The report appeared in a previous publication (Ward, 1978); it is reproduced in Appendix II, Report 6.

MODEL PARAMETER CHARACTERIZATIONS

Three types of concrete samples were collected during various phases of the Fission Neutron Calibration Model construction. The sample types and the assays performed are described further in the following paragraphs. Documentation for all assays appears in Appendix IV.

Concrete Can Samples

Bulk concrete samples, of approximately 1 kilogram each, were collected directly from the concrete truck chute at the time of the concrete pour. The mix was packed into gamma-ray spectroscopy cans, then allowed to cure in contact with the atmosphere for 1 month. No attempt was made to drive away the remaining free water. The cans were then hermetically sealed (to allow the establishment of radium/radon equilibrium) and assayed through gamma-ray spectroscopy. One assay set was done a few hours after the cans were sealed; the other was performed 20 days later. The assays at 20 days were used to determine the bulk sample radiometric grades (potassium, uranium, and thorium), and the two sets of assays were used to calculate an emanation coefficient ξ for each sample:

$$\xi = \frac{\begin{pmatrix}\text{apparent uranium}\\ \text{content at 20 days}\end{pmatrix} - \begin{pmatrix}\text{apparent uranium}\\ \text{content at sealing}\end{pmatrix}}{\begin{pmatrix}\text{apparent uranium}\\ \text{content at 20 days}\end{pmatrix}} .$$

The significance of the emanation coefficient is described below.

The sixth daughter of ^{238}U is ^{222}Rn, an inert gas with a 3.8-day half life. ^{222}Rn decays via ^{218}Po (3.1-minute half life) to ^{214}Pb (26.8-minute half life) then to ^{214}Bi (19.8-minute half life). ^{214}Bi is an emitter of energetic gamma rays, certain of which are utilized in laboratory uranium assays. The uranium window of gamma-ray spectroscopy, described in the "General Assay Discussion" below, encloses the 1764-keV, 1847-keV, 2118-keV, and 2204-keV lines of ^{214}Bi.

In an unsealed uranium sample there exists a state of equilibrium among three processes: the rate of production of ^{222}Rn in the sample, the rate of escape of ^{222}Rn from the sample, and the rate of decay of ^{222}Rn within the sample. The rate of decay of ^{222}Rn within the sample controls the rate of decay of ^{214}Bi in the sample. Since the radiometric laboratory uranium assay is based on the rate of decay of ^{214}Bi, it follows that the apparent uranium concentration of the sample is proportional to the rate of ^{222}Rn decay within the sample. When the sample is sealed, the rate of production of ^{222}Rn is unaffected, but the ^{222}Rn which would otherwise have escaped is constrained to remain in the sample. After 20 days (about 5.2 half lives of ^{222}Rn) the new rate of ^{222}Rn decay in the sample is considered to be in equilibrium with the rate of ^{222}Rn production. The radiometric uranium assay which is run at that time yields a higher value for the apparent uranium concentration. The emanation coefficient is proportional to the difference between the apparent uranium concentration of a sample that has been sealed for 20 days, and the apparent uranium concentration of the same sample at the time of sealing.

Concrete Carton Samples

These samples, of approximately 2 to 4 kilograms each, were collected directly from the concrete truck chute during the pour. The mix was packed into half-gallon cardboard ice cream cartons, then allowed to cure, in contact with the atmosphere, for 1 month. The cardboard cartons were then discarded, and each concrete cylinder was cut in half lengthwise with a diamond saw. One half of each cylinder was placed in archive. The other halves were used for analyses, as follows.

The bulk density of each sample was determined by the Bendix Field Engineering Geochemistry Laboratory. The samples were then crushed to -10 mesh by the Bendix Sample Handling Laboratory, then returned to the Geochemistry Laboratory to be dried overnight at 110°C. For each sample, the mass change associated with water loss was measured, and a percent "loss-on-drying" (LOD) was calculated:

$$\text{LOD} = \left(\frac{\text{mass change}}{\text{mass before drying}}\right) \times 100.$$

The dry sample pulp was then reduced to -28 mesh. Part of this powder was packed into gamma-ray spectroscopy cans. These cans were sealed and taken through the steps for the determination of emanation coefficients and radiometric grades. The remainder of the dry -28 mesh powder was used for magnetic susceptibility measurements and chemical (colorimetric or fluorometric) uranium assays.

Concrete Core Samples

As described in the "Construction" section, the boreholes in models A_5 and A_6 were cored, not cast. The core samples were cut into a number of cylindrical plugs with a diamond saw. Each plug was cut in half lengthwise. As with the carton samples, one half of each plug was placed in archive and the other half was used for determination of emanation coefficient, radiometric potassium, uranium, and thorium grades, chemical uranium grade, and magnetic susceptibility. In addition, chemical potassium and x-ray thorium assays were done. Other core test results are described in the section "Special Problems Addressed through Core Studies."

General Assay Discussion

As outlined in the preceding paragraphs, the can concrete samples and the carton concrete samples were assayed through gamma-ray spectroscopy for potassium, uranium, and thorium. Each KUT (potassium, uranium, and thorium) sample assay was performed by measuring gamma-ray count rates in three energy windows (ranges). On the sodium iodide system, the nominal window settings were approximately 1320 keV to 1575 keV for the potassium window, 1650 keV to 2390 keV for the uranium window, and 2475 keV to 2765 keV for the thorium window. Further comments on assay methods appear in Appendix IV.

Radiometric grades of bulk can concrete samples are routinely calculated on a total mass basis. Part of the total mass includes free water in the matrix, which can vary, for example, with the atmospheric humidity at the time the cans are sealed. In establishing radiometric grades, therefore, more credence is generally placed in the assays of powdered carton concrete samples, because the free water is removed from these samples prior to assay, and the radiometric grades are calculated on a dry-mass basis.

Preliminary Determination of Model Grades

For a given type of assay, a number, N, of samples from the same ore zone were analyzed. The reported grade G of an ore zone is the arithmetic mean of the N sample assays:

$$G = \frac{\Sigma\, G_i}{N} ,$$

where each G is an individual assay result. The standard deviation σ is defined in the usual way:

$$\sigma^2 = \frac{\Sigma\, (G_i - G)^2}{N - 1} .$$

The bounds on the 95 percent confidence interval are defined as follows:

$$\text{lower bound} = G - \frac{t\sigma}{N,}$$

$$\text{upper bound} = G + \frac{t\sigma}{N,}$$

where t, Student's t, is taken from Student's t distribution table for 95 percent confidence and for N-1 degrees of freedom.

The results of the KUT gamma-ray spectroscopic assays and emanation coefficient determinations are listed in Table 10 for bulk can samples and in Table 11 for powdered carton samples. Table 12 contains the results of chemical uranium assays, LOD measurements, bulk density determinations, and magnetic susceptibility measurements for carton samples. Chemical uranium grades, chemical potassium grades, x-ray thorium grades, grain densities, and bulk densities for core samples are reported in Table 13.

The equivalent radiometric uranium grades (denoted "eU_3O_8" in Tables 10 and 11) are proportional to the concentrations of certain gamma-ray emitting isotopes, notably ^{214}Bi, in the uranium decay series. These grades should therefore be used only in conjunction with sondes that collect equivalent uranium data, such as gross gamma-ray or KUT logs. The entries of Table 11 should receive more credence than those of Table 10 because of the difference in sample preparation. The sample materials for Table 10 were assayed as solid concrete, whereas the sample materials for Table 11 were crushed and oven dried prior to radiometric assay. Since the radiometric assay standards consist of crushed material, density or matrix differences between samples and standards are minimal in the case of the Table 11 samples. Also, the concentrations in Table 11 are based on dry mass, as is conventional in reporting ore grade.

The chemical uranium grades of Table 12 should be used in connection with any of the direct uranium logging methods, such as fission neutron logging or high resolution gamma-ray logging. The grades of Table 12 are based on dry mass.

Users of the fission neutron calibration facilities may be assured that fission neutron logging does not appreciably reduce the uranium grades cited in the tables. In the following paragraph an estimate is derived for the rate of uranium depletion during logging with a representative fission neutron sonde in model A_2.

Woolson and Gritzner (1977) have developed calculational models that simulate neutron transport during fission neutron logging. One set of neutron transport calculations was performed for a 14-MeV neutron source in a water-filled, 4.5-inch diameter borehole. The simulated rock medium was a sandstone of 2.645 grams per cubic centimeter grain density, 15 percent porosity, 100 percent saturation, and 2.40 grams per cubic centimeter bulk density. For a grade of 0.08 percent U_3O_8 and a source strength of 10^9 neutrons per second, the calculations indicate that the maximum rate of prompt fission neutron production from ^{235}U is about 7.0 fission neutrons per cubic centimeter per second. If an average of 2.5 fission neutrons are released per fission event, then the maximum ^{235}U fission rate is about 2.8 fissions per cubic centimeter per second. Additional ^{235}U depletion occurs via the (n, γ) reaction. The total ^{235}U depletion rate can be estimated by multiplying the fission rate by the ratio of total absorption cross section to fission cross section. This ratio is about 1.17. Therefore, the total ^{235}U depletion rate is about 3.3 atoms per cubic centimeter per second. For a grade of 0.08 percent U_3O_8 and a bulk density of 2.40 grams per cubic centimeter, the atomic density of ^{235}U is about 3×10^{16} atoms per cubic

Table 10

Concrete Can Samples--Radiometric Assays (Ge(Li))

T, C, B represent top, center, and bottom zones. Samples were collected in gamma-ray spectroscopy cans at the time of the concrete pour, then air-dried for 1 month, sealed, then assayed 20 days after sealing.

Model Zone	Number of Samples N	Uranium Grade Average ($\%eU_3O_8$)	Uranium Grade σ ($\%eU_3O_8$)	Uranium Grade 95% Confidence Interval ($\%eU_3O_8$)	Potassium Concentration Avg. (%K)	Potassium Concentration σ (%K)	Thorium Concentration Average (ppm eTh)	Thorium Concentration σ (ppm eTh)	Emanation Coefficient Avg. (%)	Emanation Coefficient σ (%)
Ore Zones										
A-1-C	23	0.0243	0.0027	0.0232-0.0255	1.82	0.21	7.9	1.2	8.0	2.7
A-2-C	23	0.0606	0.0026	0.0595-0.0617	1.72	0.19	7.6	1.7	7.6	2.4
A-3-C	23	0.1173	0.0053	0.1151-0.1196	1.77	0.24	7.9	1.9	6.6	2.0
A-4-C	19	0.1744	0.0284	0.1607-0.1881	1.72	0.26	7.4	2.2	13.0	1.7
A-5-T	20	0.0602	0.0033	0.0587-0.0618	1.66	0.15	7.6	1.2	1.6	1.2
A-5-B	20	0.0602	0.0032	0.0587-0.0617	1.28	0.19	5.0	1.1	7.5	3.0
A-6-T	20	0.0639	0.0037	0.0621-0.0656	1.25	0.19	6.6	1.3	10.5	3.7
A-6-B	20	0.0611	0.0077	0.0575-0.0647	1.91	0.23	9.2	1.3	4.4	2.4
Barren Zones										
A-1-T	5	0.00064	0.00013		1.64	0.09	7.1	0.8		
A-1-B	5	0.00037	0.00004		1.89	0.10	8.3	1.5		
A-2-T	5	0.00029	0.00006		1.70	0.08	7.8	1.0		
A-2-B	5	0.00026	0.00003		1.72	0.05	7.4	0.5		
A-3-T	5	0.00033	0.00004		1.68	0.05	8.0	0.7	Not Measured	
A-3-B	5	0.00027	0.00004	Not Calculated	1.77	0.07	7.3	1.6		
A-4-T	5	0.00029	0.00007		1.74	0.09	6.8	0.9		
A-4-B	5	0.00036	0.00012		1.71	0.08	7.2	0.9		
A-5-C	5	0.00036	0.00006		1.76	0.05	7.4	0.6		
A-6-C	5	0.00046	0.00008		1.70	0.11	6.5	1.4		

Table 11

Crushed Concrete Carton Samples--Radiometric Assays (NaI)

T, C, B represent top, center, and bottom zones. Samples were collected in cardboard cartons, air dried for 1 month, crushed, dried at 110°C, canned, sealed and assayed 20 days after sealing.

		Uranium Grade			Potassium Concentration		Thorium Concentration	
Model Zone	Number of Samples N	Average (%eU_3O_8)	σ (%eU_3O_8)	95% Confidence Interval (%eU_3O_8)	Avg. (%K)	σ (%K)	Average (ppm eTh)	σ (ppm eTh)
Ore Zones								
A-1-C	6	0.0292	0.0021	0.0270 - 0.0314	1.79	0.17	6.7	0.7
A-2-C	6	0.0731	0.0024	0.0706 - 0.0755	2.18	0.24	9.5	1.5
A-3-C	6	0.1383	0.0075	0.1304 - 0.1462	1.85	0.12	6.7	1.4
A-4-C	5	0.2122	0.0769	0.1168 - 0.3077	2.13	0.40	8.4	1.4
A-5-T	5	0.0723	0.0059	0.0650 - 0.0797	2.40	0.36	10.6	1.1
A-5-B	5	0.0737	0.0019	0.0714 - 0.0760	2.34	0.20	7.9	0.8
A-6-T	5	0.0730	0.0021	0.0704 - 0.0757	1.66	0.17	7.1	0.5
A-6-B	5	0.0713	0.0171	0.0501 - 0.0925	2.25	0.18	9.0	0.6

Table 12

Crushed Concrete Carton Samples--Chemical Assays

T, C, B represent top, center, and bottom zones. Samples were collected in cardboard cartons, air-dried for 1 month, crushed, dried at 110°C, canned, sealed, and assayed.

Model Zone	Number of Samples N	Uranium Grade: Average (%eU_3O_8)	Uranium Grade: σ (%eU_3O_8)	Uranium Grade: 95% Confidence Interval (%eU_3O_8)	Loss on Drying: Avg. (%)	Loss on Drying: σ (%)	Bulk Density: Avg. (g/cm^3)	Bulk Density: (g/cm^3)	Emanation Coefficient: Avg. (%)	Emanation Coefficient: σ (%)
Ore Zones										
A-1-C	6	0.0278	0.0032	0.0245 - 0.0312	4.1	1.1	2.22	0.02	9.0	0.6
A-2-C	6	0.0757	0.0040	0.0715 - 0.0798	3.9	0.7	2.17	0.01	4.8	0.8
A-3-C	6	0.1550	0.0077	0.1469 - 0.1631	4.0	0.8	2.18	0.01	3.7	2.5
A-4-C	5	0.2280	0.0759	0.1338 - 0.3222	3.3	0.2	2.22	0.06	1.2	0.5
A-5-T	5	0.0780	0.0032	0.0741 - 0.0819	3.2	0.3	2.15	0.01	4.4	2.0
A-5-B	5	0.0824	0.0091	0.0711 - 0.0937	2.7	0.1	2.41	0.02	3.6	1.1
A-6-T	5	0.0688	0.0073	0.0598 - 0.0778	5.1	0.1	1.86	0.01	4.6	0.6
A-6-B	5	0.0700	0.0149	0.0515 - 0.0885	2.9	0.5	2.19	0.04	4.4	1.1
Barren Zones										
A-1-T	1	0.00083	Not Applicable for 1 sample		3.0	N/A	2.20	N/A	Below detection limits	
A-1-B	1	0.00035			3.4		2.18			
A-2-T	1	0.00012			2.9		2.17			
A-2-B	1	0.00024			2.7		2.20			
A-3-T	1	0.00012			2.9		2.17			
A-3-B	1	0.00012			3.0		2.19			
A-4-T	1	0.00012			3.2		2.18			
A-4-B	1	0.00024			2.9		2.19			
A-5-C	1	0.00055			2.9		2.18			
A-6-C	1	0.00024			3.0		2.19			

Table 12 - Continued
Crushed Concrete Carton Samples--Chemical Assays

Magnetic Susceptibility for Fission Neutron Models

Zone	Number of Samples	Average Magnetic Susceptibility (10^{-6} c.g.s.)	Standard Deviation (10^{-6} c.g.s.)	95% Confidence Interval (10^{-6} c.g.s.)
A-1-C	6	841.3	39.8	799.5 - 883.1
A-2-C	4	804.3	24.5	765.3 - 843.3
A-3-C	6	822.2	48.5	771.3 - 873.1
A-4-C	4	884.3	7.2	872.8 - 895.8
A-5-T	5	740.8	43.8	686.4 - 795.2
A-5-B	4	596.5	30.5	548.0 - 645.0
A-6-T	5	348.4	9.5	336.6 - 360.2
A-6-B	4	1055.3	51.0	974.2 - 1136.4
All Barren Zones	10	993.0	40.5	964.0 - 1022.0

Table 13

Core Sample Chemical Assays for Models A_5 and A_6

Core samples were crushed, dried at 110°C, and assayed.

Model Zone	Number of Samples, N	Average U_3O_8 Concentration	σ	Average K Concentration	σ	Average Th Concentration	Mean Bulk Density	Mean Grain Density
A_5 Upper Ore	5	0.0804%	0.0034%	1.710%	0.076%	<5 ppm	2.170 g/cm^3	2.640 g/cm^3
A_5 Lower Ore	5	0.0826%	0.0192%	1.346%	0.146%	<5 ppm	2.404 g/cm^3	2.922 g/cm^3
A_6 Upper Ore	5	0.0726%	0.0062%	1.320%	0.027%	<5 ppm	1.854 g/cm^3	2.598 g/cm^3
A_6 Lower Ore	5	0.0730%	0.0105%	1.944%	0.085%	<5 ppm	2.208 g/cm^3	2.638 g/cm^3
A_5 Barren	3	51 ppm	79 ppm	1.870%	0.052%	<5 ppm	2.197 g/cm^3	2.653 g/cm^3
A_6 Barren	3	5 ppm	3 ppm	1.903%	0.023%	<5 ppm	2.203 g/cm^3	2.640 g/cm^3

centimeter. At a constant depletion rate of 3.3 atoms per cubic centimeter per second, a one percent reduction of the ^{235}U concentration would require continuous logging for a period of 9.1×10^{13} seconds (2.9×10^{6} years).

Similar calculations for ^{238}U indicate one percent depletion times of order 3.2×10^{7} years for reactions with neutrons of energy 14 MeV, and 5.2×10^{6} years for thermal neutron reactions.

PROBLEMS ADDRESSED THROUGH CORE STUDIES

The method of concrete emplacement for models A_5 and A_6 was described in the "Construction" section. This experimental pouring method was motivated by concern over the possibility of undesirable neutron transport perturbations arising from water-filled cracks between zones. Since the experimental pouring technique had not been employed in previous DOE/Grand Junction model construction projects, it was appropriate to undertake special studies on the core samples. Some results of these studies are described in the following paragraphs.

Quality of the Bonds at the Ore Zone/Barren Zone Interfaces

Scale drawings of the cores from models A_5 and A_6 appear in Figure 13. As indicated in the figure, the A_5 core broke at both ore zone/barren zone interfaces during the coring operation. The A_6 core broke at the upper ore zone/barren zone interface but did not break at the lower interface. These observations suggest that the interfaces are zones of structural weakness but do not establish whether or not a water-filled crack exists there. An investigation of gross gamma-ray logs for the entire Fission Neutron Calibration Model suite (Figures 14 to 18) does not shed further light on the question. This is not surprising, because a thin water-filled crack would have little effect on gamma-ray transport. The question remains unanswered at this time.

Possibility of Uranium Migration Across Barren Zone/Ore Zone Boundaries

In the A_5 and A_6 construction technique, the model zones were poured in rapid succession, with minimum cure time between pours. Core studies were done to investigate whether this construction technique encouraged the migration of uranium-bearing fluid from ore zones to barren zones.

The A_5 and A_6 core columns are depicted in Figure 13. The locations of analyzed samples are also shown. Table 14 lists individual chemical assay results for selected samples.

It was mentioned previously that the cores broke at three of the four ore zone/barren zone interfaces during the coring operation. The A_5 core broke at both ore zone/barren zone interfaces, and the A_6 core broke at the upper ore zone/barren zone interface. In these cases, core samples were taken from material adjacent to, and on both sides of, each interface (see Figure 13).

The entries of Table 14 show that sharp changes in the uranium concentration occur across the zone interfaces. These results indicate that (with a possible exception at the A_5 lower barren zone/ore zone interface) uranium-bearing fluids did not migrate across zone interfaces during model construction. That is, with the possible exception at the lower A_5 interface, the barren zones were not contaminated by uranium migration from adjacent ore zones.

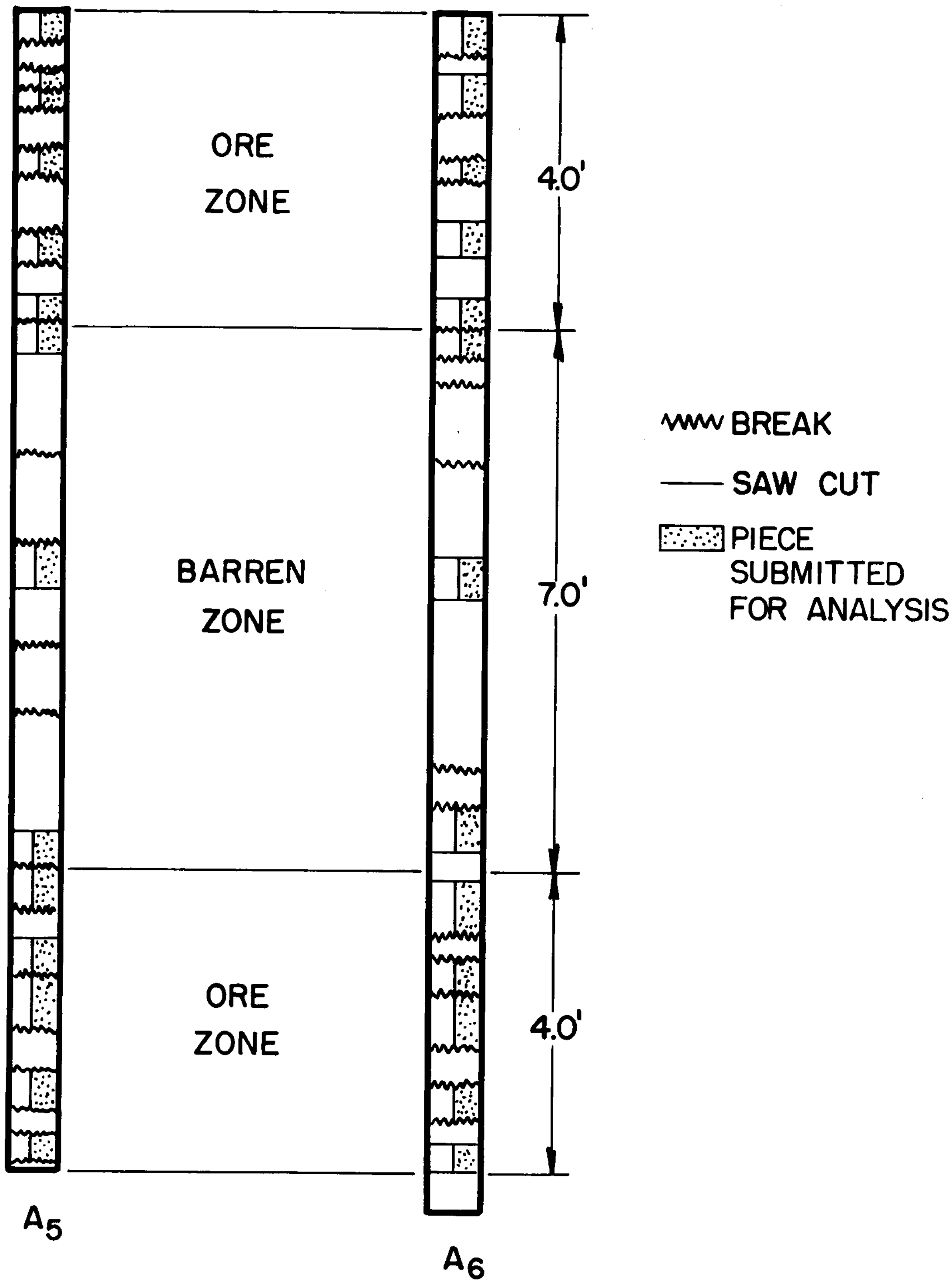


Figure 13. Borehole Core Samples from Models A_5 and A_6.

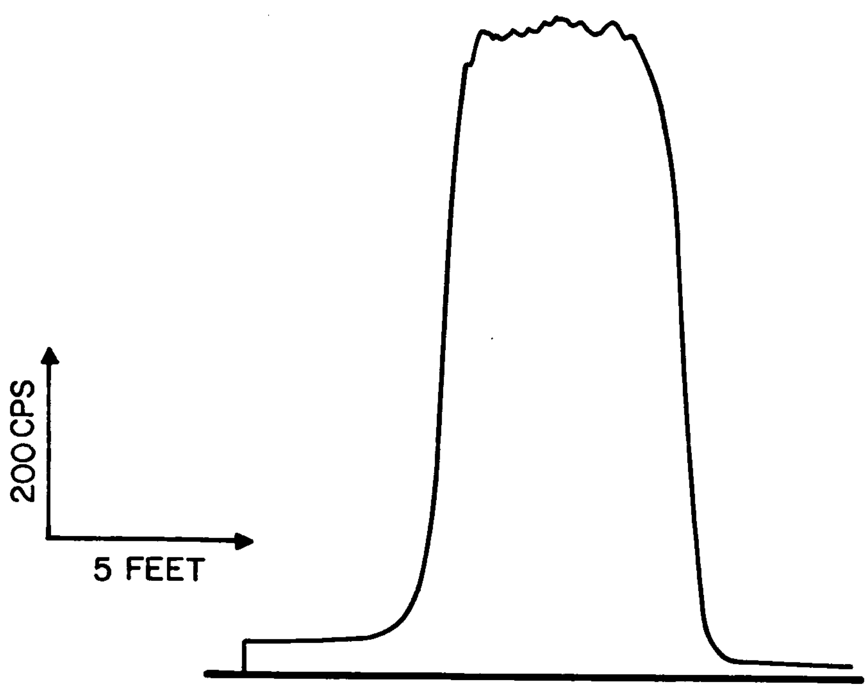


Figure 14. Gross Gamma-ray Log of Model A_1.

Log was run by Bendix, with truck 1709, probe 302, 0.75-inch by 1.25-inch NaI (Tl) crystal.

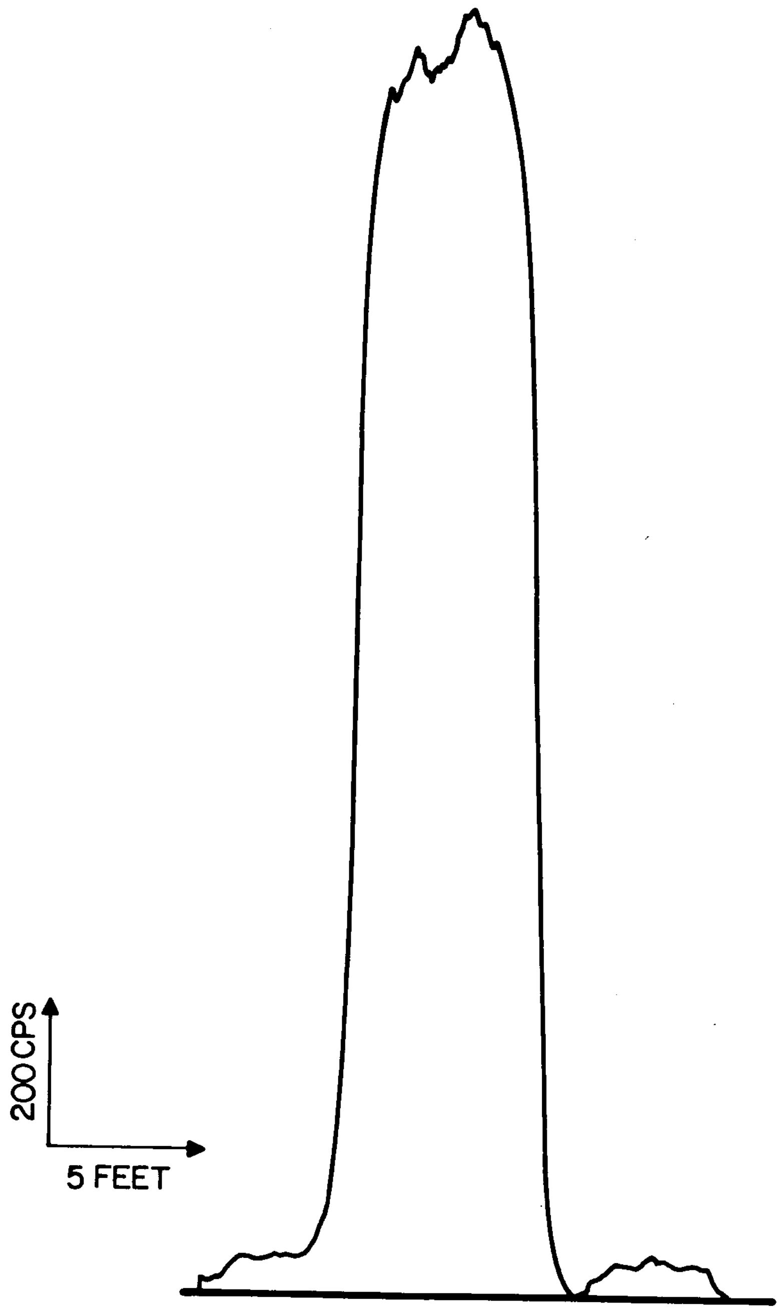


Figure 15. Gross Gamma-ray Log of Model A_2.

Log was run by Bendix, with truck 1709, probe 302, 0.75-inch by 1.25-inch NaI (Tl) crystal.

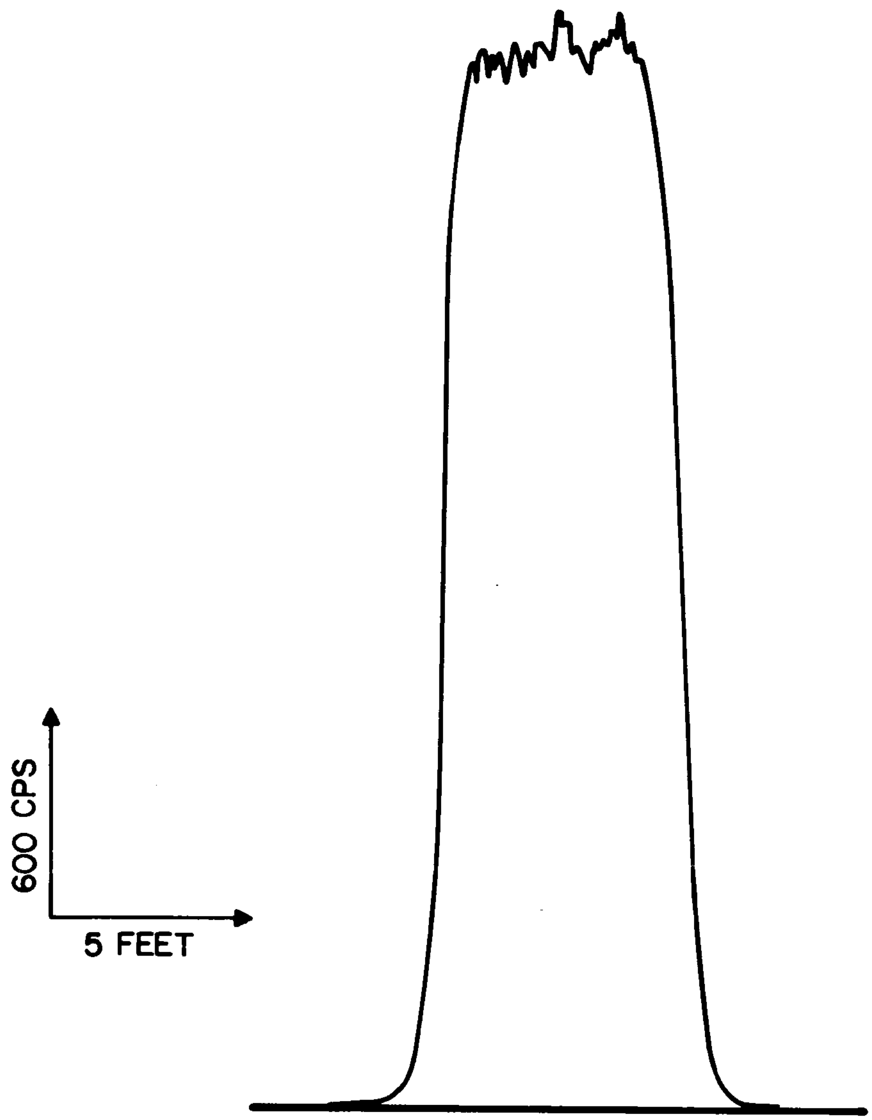


Figure 16. Gross Gamma-ray Log of Model A_3.

Log was run by Bendix, with truck 1709, probe 302, 0.75-inch by 1.25-inch NaI (Tl) crystal.

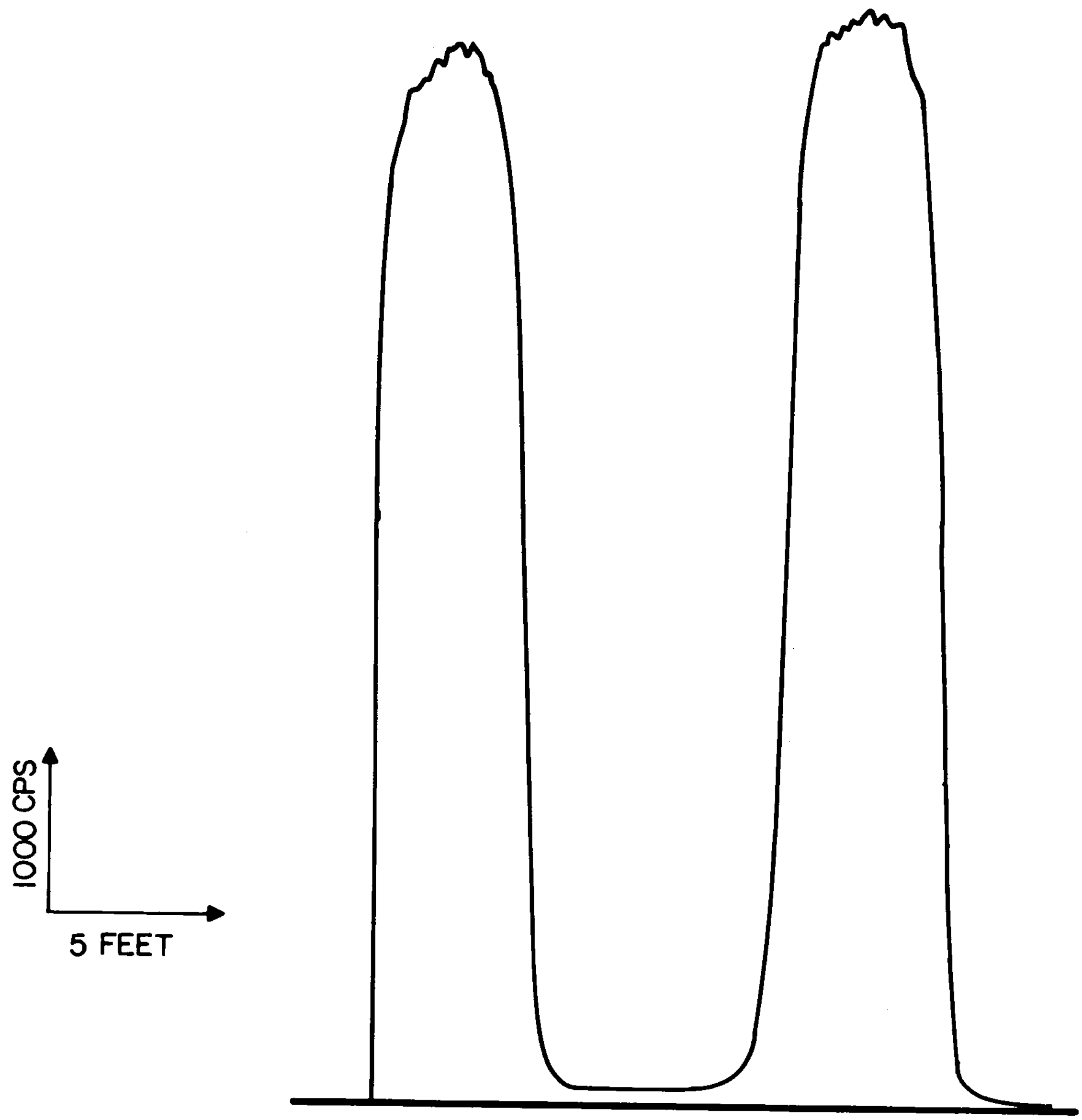


Figure 17. Gross Gamma-ray Log of Model A_5.

The lower ore zone is on the right. Log was run by Bendix, with truck 1709, probe 302, 0.75-inch by 1.25-inch NaI (Tl) crystal.

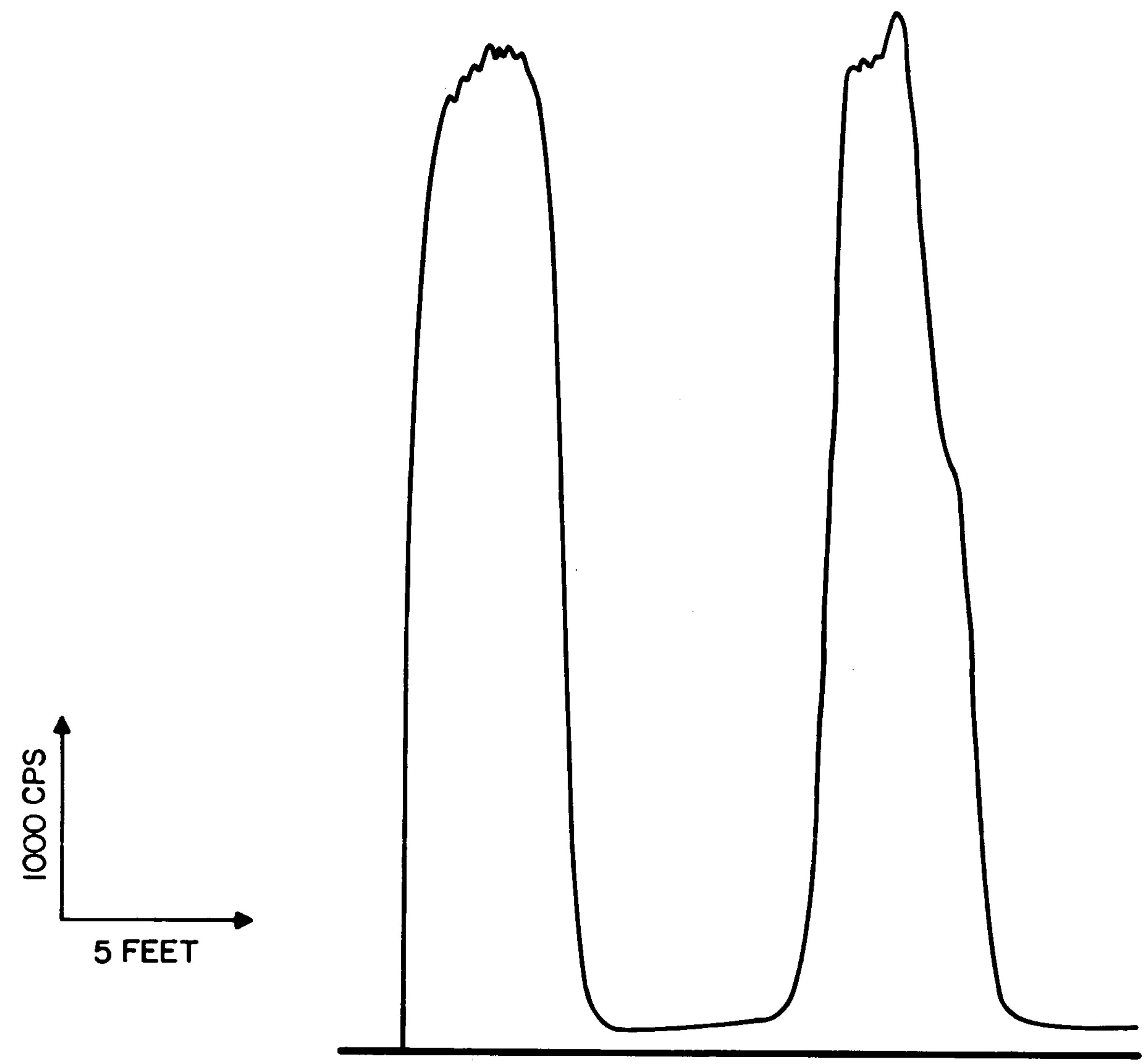


Figure 18. Gross Gamma-ray Log of Model A_6.

The lower zone is on the right. Log was run by Bendix, with truck 1709, probe 302, 0.75-inch by 1.25-inch NaI (Tl) crystal.

Table 14

Individual Chemical Assay Results for A_5 and A_6 Core Samples

Model	Zone	Sample Location	K(%)	U_3O_8(ppm)	Th(ppm)	Bulk Density(g/cm^3)	Grain Density(g/cm^3)
A_5	Upper Ore	Bottom of Zone	1.74	850	<5	2.19	2.64
A_5	Barren	Top of Zone	1.93	5	<5	2.19	2.66
A_5	Barren	Middle of Zone	1.84	5	<5	2.20	2.65
A_5	Barren	Bottom of Zone	1.84	142	<5	2.20	2.65
A_5	Lower Ore	Top of Zone	1.21	770	<5	2.44	2.96
A_6	Upper Ore	Bottom of Zone	1.35	750	<5	1.89	2.62
A_6	Barren	Top of Zone	1.93	8	<5	2.21	2.62
A_6	Barren	Middle of Zone	1.89	2	<5	2.19	2.65
A_6	Barren	Bottom of Zone	1.89	4	<5	2.21	2.65
A_6	Lower Ore	Top of Zone	2.03	630	<5	2.25	2.64

Comparison of Core Sample Grades with Carton Sample Grades

With respect to chemical assays, core samples and carton samples received identical treatment (i.e., both types of samples were crushed, dried, and assayed). It is of interest, therefore, to compare core sample assays with carton sample assays. This comparison appears in Table 15.

Table 15

Core Sample Assays Compared to Carton Sample Assays for A_5 and A_6

Model, zone	Type of Sample	Average U_3O_8	Average Bulk Density (g/cm^3)
A_5 Upper Ore	Carton	0.078%	2.15
	Core	0.080%	2.17
A_5 Barren	Carton	5.5 ppm	2.18
	Core	51 ppm*	2.20
A_5 Lower Ore	Carton	0.0824%	2.41
	Core	0.0826%	2.40
A_6 Upper Ore	Carton	0.0688%	1.86
	Core	0.0726%	1.85
A_6 Barren	Carton	2.4 ppm	2.19
	Core	5 ppm	2.20
A_6 Lower Ore	Carton	0.0700%	2.19
	Core	0.0730%	2.21

* This average was adversely affected by the high assay for the core sample from the bottom of the A_5 barren zone. See Table 14, column 5.

The excellent agreement between each corresponding set of core and carton assays (agreement within 6 percent for U_3O_8, within 1 percent for bulk density) implies that carton sample analyses yield accurate values for the actual in-situ model parameters.

SUMMARY

An examination of the preliminary model parameters reported in this paper indicates that (with the exception of A_4) the grade and bulk density design specifications were met, within reasonable limits. The chemical uranium grades are in agreement with the design grades, and the bulk density of the A_5 bottom ore zone is higher than the other bulk densities, as desired. Evaluation of the porosities of the A_6 ore zones and the average thermal neutron cross section of the A_5 upper ore zone requires the services of laboratories that specialize in these analyses. This work has not been completed.

Visual inspection of the boreholes and core samples from A_5 and A_6 indicates that the driller was able to stay on a vertical track and avoid excessive curvature and rugosity in the boreholes. The uranium migration studies done with core material imply that no appreciable migration of uranium across the ore zone/barren zone boundaries took place. The experimental construction techniques used in A_5 and A_6 may be regarded as successful; the methods could be viewed as desirable, in consideration of the fact that cores are obtained, and core samples are probably the best samples attainable from any model.

In time, the model grades reported in this paper will require updating. For example, some type of formation moisture correction, such as developed by Eschliman and Key (1972) for gross gamma-ray logging models, will probably be conceived for the fission neutron logging models. The assignment of final model grades thus awaits the completion of additional laboratory studies (especially moisture studies) and the collection and interpretation of numerous logs of various kinds.

REFERENCES

Eschliman, D. H., and Key, B. N., 1972, A change of assigned radiometric grades for the USAEC gamma-ray logging calibration models: Geophysics/Electronics Report Number 5, prepared for U. S. Atomic Energy Commission by Lucius Pitkin, Inc., Grand Junction, Colorado.

Ward, D. L., 1978, Construction of calibration pads facility, Walker Field, Grand Junction, Colorado: Bendix Field Engineering Corporation Open File Report number GJBX-37(78), U. S. Department of Energy, Grand Junction, Colorado.

Woolson, W. A., and Gritzner, M. L., 1977, Borehole model calculations for direct uranium measurement with neutrons: Bendix Field Engineering Corporation Open File Report number GJBX-44(77), prepared for U. S. Energy Research and Development Administration by Science Applications, Incorporated, La Jolla, California.

BIBLIOGRAPHY

Czubeck, J. A., 1972, Pulsed Neutron Method for Uranium Well Logging: Geophysics, v. 37. p. 160-173.

Givens, W. W., Mills, W. R., Dennis, C. L., and Caldwell, R. L., 1976, Uranium Assay Logging using a Pulsed 14-MeV Neutron Source and Detection of Delayed Fission Neutrons: Geophysics, v. 41, p. 468-490.

Mills, W. R., Hoyer, W. A., Tittman, J., and Wilson, B. F., 1977, A Proposed Calibration Facility for Pulsed Neutron Logging Tools: The Log Analyst, January-February, p. 3-5.

Steinman, D. K., Costello, D. G., Pepper, C. S., Galloway, R. N., John, J., and Dodd, P. H., 1976, Californium -252- Based Borehole Logging System for in-situ Assaying of Uranium Ore: Proceedings: IAEA Symposium, Vienna, IAEA-SM-208/43.

Wormald, M. R., and Clayton, C. G., 1976, Some Factors Affecting Accuracy in the Direct Determination of Uranium by Delayed Neutron Borehole Logging: Proceedings: IAEA Symposium, Vienna, IAEA-SM-208/35.

APPENDIX I

Determination of Model Diameters

The model diameters were set at 6 feet (1.83 m) with the aid of neutron transport and attenuation calculations done by Science Applications, Incorporated, La Jolla, under subcontract to Bendix Field Engineering Corporation. These calculations determined the fraction of source neutrons attenuated (absorbed) within distance r of a 14-MeV neutron source centered in a 4.5-inch unlined borehole in sandstone. The results of the calculations are tabulated in Table A-1.

Table A-1

Neutron Attenuation Calculations

Sandstone Specific Gravity, ρ_B	Sandstone Moisture Content, M (%)	Distance from Neutron Source, r (cm)	Fraction of Source Neutrons Attenuated Within r	Empirical Attenuated Fraction (see below)
2.372	7	35.85	0.67	0.682
		65.31	0.95	0.957
		88.46	0.99	0.991
2.179	13	31.64	0.67	0.651
		61.10	0.95	0.953
		82.14	0.99	0.989
1.942	22	29.53	0.67	0.643
		58.99	0.95	0.952
		80.04	0.99	0.989

The relationship

$$\text{fraction attenuated} = \frac{N}{N_o} = 1 - \frac{20.8}{\rho_B M^{0.45}} \exp\left(- \frac{0.0681}{\text{cm}} r\right) \qquad (1)$$

gives an excellent fit to the Science Applications calculations. Attenuated fractions calculated from Equation (1) are shown in the fifth column of Table A-1.

If Equation (1) is applied to a concrete of ρ_B = 2.2 grams per cubic centimeter and M = 12 percent, then the 99 percent attenuation fraction corresponds to a radius of r = 84.2 cm = 2.8 feet. Therefore, if a 14-MeV source is placed in a 4.5-inch borehole in a concrete model, then about 99 percent of the source neutrons will be absorbed within approximately 3 feet of the borehole. This result led to the choice of 6 feet for the model diameters.

APPENDIX II

Aggregate Materials Studies

Samples were collected from batches of aggregates that were used in the Fission Neutron Calibration Model concretes. Petrological studies of selected samples of sand, gravel, and uranium ore were performed by the Bendix Field Engineering Petrology Laboratory. Summaries appear in Reports 1 through 6 of this Appendix.

Radiometric and chemical analyses were done by the Bendix Field Engineering Geochemistry Laboratory, or an appropriate independent laboratory. Results are listed in Tables A-2 and A-3 of this Appendix. Details about the analytical procedures of the Bendix Field Engineering Geochemistry Laboratory appear in Appendix IV.

APPENDIX II

Report 1

REQUEST # 400122

PROJECT # 50-51-5003

CALIBRATION AND TEST FACILITIES

A grain mount of the sample submitted was examined petrographically. The rock types are described on a petrographic description sheet due to the number of grains and their fine-grained nature. Polished sections of the samples were tested for uranium $^{+6}$ by chemical contact printing and no uranium $^{+6}$ could be detected.

PETROGRAPHIC DESCRIPTION

PROJECT: Cal. and Test Facil. 50-51-5003 REQUEST: 400122 FIELD NO.: MAN-795 AASSN: 32550

ROCK NAME:

GENERAL TEXTURE AND FEATURES: Whitewater masonry sand grain mount.

Mineral/Component	%	Texture	Characteristics	Alteration/Replacement
Volcanic Rock Fragments	85	Angular, subangular, and subrounded; 0.15 to 2.8 mm long.	Andesites, diorite porphyries, altered dacites, altered dark colored aphanitic rock fragments. Aphanitic and microcrystalline groundmasses are common.	Pervasive alteration of mafic minerals is common. Plagioclase is sometimes replaced by epidote.
Sedimentary Rock Fragments	9	Angular and subangular; 0.2 to 0.7 mm long.	Quartz wackes.	
Feldspar	2	Subangular and subrounded; 0.02 to 0.08 mm long.	Predominantly microcline grains, some plagioclase.	
Quartz	4	Subangular and subrounded; 0.02 to 0.07 mm long.	Usually exhibit overgrowths.	
Muscovite	tr	Angular laths; 0.2 to 0.6 mm long.		
Hornblende	tr	Subangular; 0.3 mm long.		

OTHER COMMENTS:

(Continued on next page)

PETROGRAPHIC DESCRIPTION

PROJECT: Cal. and Test Facil. 50-51-5003 REQUEST: 400122 FIELD NO.: MAN-795 AASSN: 32550-Continued

ROCK NAME:

GENERAL TEXTURE AND FEATURES:

Mineral/Component	%	Texture	Characteristics	Alteration/Replacement
Opaque	tr	Subangular; 1.5 mm long.		
Metamorphic Rock Fragments	tr	Subrounded; approximately 0.7 mm long.	Quartzite fragment.	
Plutonic Rock Fragments	tr	Subrounded; 0.4 to 0.8 mm long.	Granitic fragments.	

OTHER COMMENTS:

APPENDIX II

Report 2

REQUEST #400097

PROJECT #50-51-5003

MARCH 9, 1978

CALIBRATION AND TEST FACILITES

A grain mount thin section of the sample of Whitewater masonry sand was examined by petrographic microscope. Mineral descriptions, semiquantitative modal analyses, and photomicrographs are included in this report.

PETROGRAPHIC DESCRIPTION

PROJECT: Calibration and Test Facilities REQUEST: 400097 FIELD NO.: MAS-121 AASSN: 30209

ROCK NAME: Whitewater Masonry Sand

GENERAL TEXTURE AND FEATURES: Poorly sorted, unconsolidated.

Mineral/Component	%	Texture	Characteristics	Alteration/Replacement
Volcanic Rock Fragments	64	Medium sand- to pebble-sized, rounded to subangular.	Porphyritic. Predominately intermediate in composition (latite, andesite). Subordinate basic compositions (basalt). One diabase grain observed. Zeolites present.	Feldspar phenocrysts exhibit moderate to strong argillization. Mafics are chloritized and replaced by iron oxides. Silicified groundmasses.
Quartz	18	Fine- to coarse sand-sized, rounded to subangular.	Variable extinction. Some rounded, embayed (volcanic) grains observed.	
Plutonic Rock Fragments	9	Very coarse sand- to granule-sized, subangular.	Zoned plagioclase, K-feldspar, quartz, muscovite, biotite opaques, and sphene.	
Metamorphic Rock Fragments	2	Coarse sand- to granule-sized, subangular.	Quartzite and muscovite schist.	
Sedimentary Rock Fragments	tr	Medium- to coarse sand-sized, subrounded to subangular.	Argillaceous siltstone, calcareous siltstone, and shale.	

OTHER COMMENTS:

(Continued on next page)

PETROGRAPHIC DESCRIPTION

PROJECT: Calibration and Test Facilities REQUEST: 400097 FIELD NO.: MAS-121 AASSN: 30209-Continued

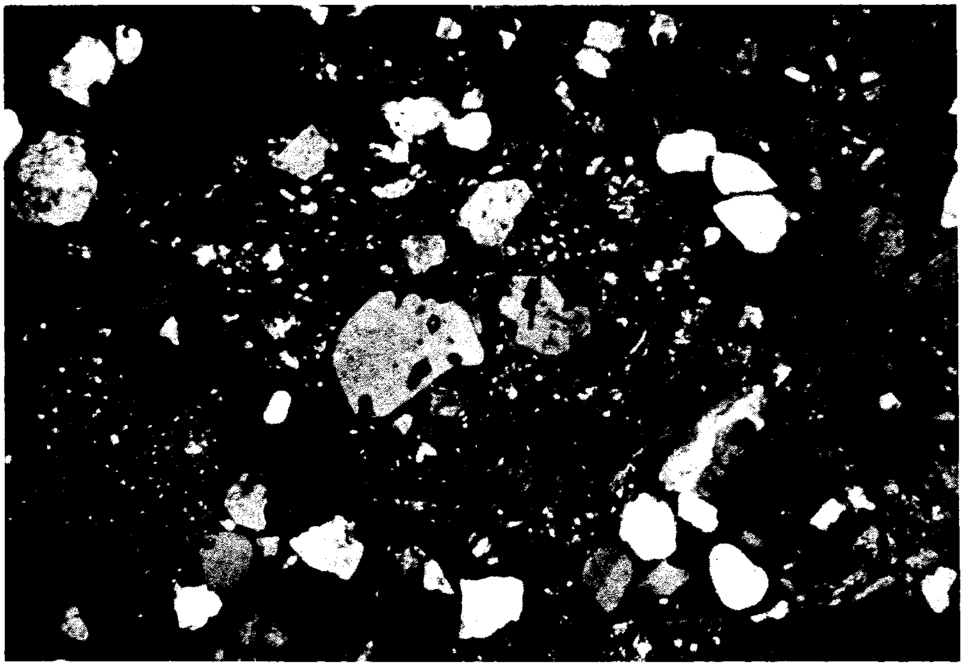
ROCK NAME: Whitewater Masonry Sand

GENERAL TEXTURE AND FEATURES:

Mineral/Component	%	Texture	Characteristics	Alteration/Replacement
Plagioclase	3	Fine- to coarse sand-sized, subangular to subrounded.		Some sericitization. Minor to moderate argillization.
K-feldspar	3	Coarse- sand-sized, subangular to subrounded.	Microcline and orthoclase	Minor argillization.
Muscovite	tr	Coarse sand-sized, subangular.	Books	
Hornblende	tr	Medium sand-sized, angular.		
Chlorite	tr	Medium sand-sized, sub-angular.		

OTHER COMMENTS:

Figure II-I. Photomicrographs of Sample 30209



General texture of sample showing several volcanic rock fragments. The large central rock fragment contains sanidine (large grain, embayed) and quartz (adjacent to right) phenocrysts. 16x, plane polarized light.

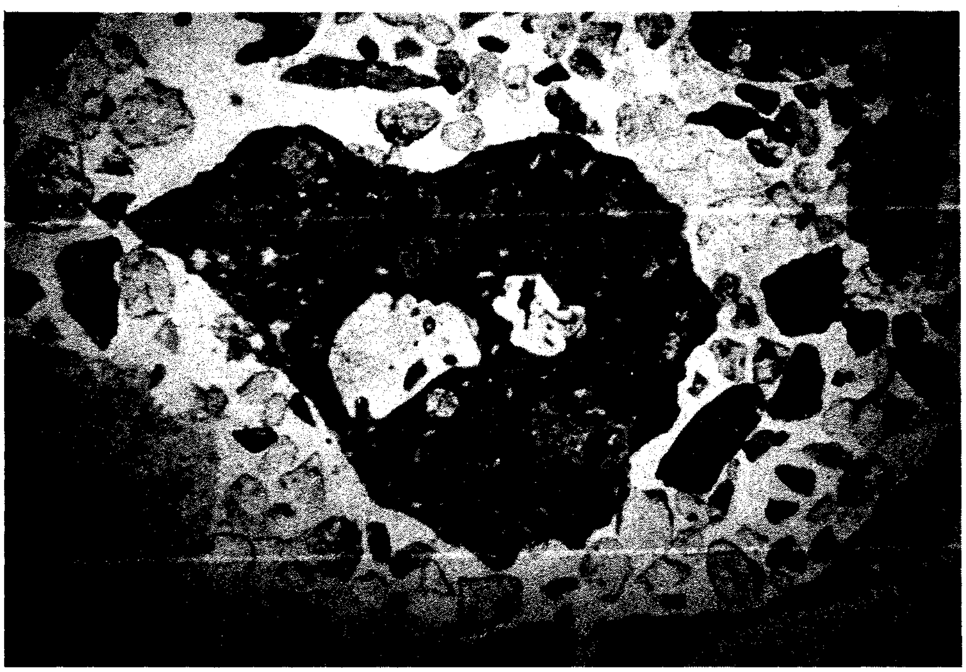
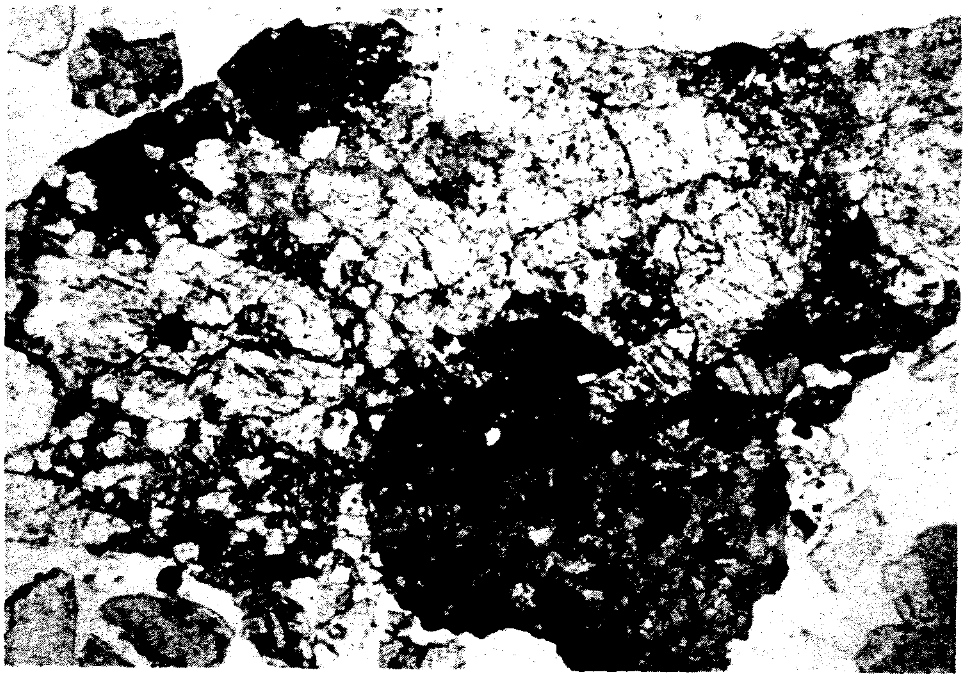


Figure II-2. Same, crossed polarizers.

Figure II-3. Photomicrographs of Sample 30209-Continued



A rather large plutonic rock fragment which contains quartz, feldspars, biotite, muscovite, opaques, and sphene. 40x, plane polarized light.

Figure II-4.

Diabase rock fragment. Phases include: plagioclase, pigeonite, and opaques. 64x, plane polarized light

APPENDIX II

Report 3

REQUEST # 400097

PROJECT # 50-51-5003

MARCH 9, 1978

CALIBRATION AND TEST FACILITIES

A grain mount thin section of the sample of Dri-mix masonry sand was examined by petrographic microscope. Mineral descriptions, semiquantitative model analyses, and photomicrographs are included in this report.

PETROGRAPHIC DESCRIPTION

PROJECT: Calibration and Test Facilities   REQUEST: 400097   FIELD NO.: MAS-122   AASSN: 30210

ROCK NAME: Dri-Mix Masonry Sand

GENERAL TEXTURE AND FEATURES:

Mineral/Component	%	Texture	Characteristics	Alteration/Replacement
Quartz	23	Very fine- to very coarse sand-sized, angular to subangular.	Variable extinction.	
Metamorphic Rock Fragments	18	Very coarse sand-sized, subangular to subrounded.	Quartzite, gneiss, schist.	
Plutonic Rock Fragments	18	Coarse sand- to granule-sized, subrounded to subangular.	Plagioclase, K-feldspar, quartz, muscovite, biotite, opaques, and epidote.	Variable alteration.
Volcanic Rock Fragments	18	Coarse sand- to granule-sized, rounded to subangular.	Porphyritic. Intermediate to basic in composition.	Some silicified groundmasses. Phenocryst alteration variable.
Sedimentary Rock Fragments	14	Coarse sand- to granule-sized, rounded to subrounded.	Calcareous and argillaceous sandstone, shale.	
K-feldspar	4	Medium- to coarse sand-sized, angular to subrounded.	Microcline and microcline perthite.	Minor argillization.
Plagioclase	3	Medium- to coarse sand-sized, angular to subrounded.		Minor to moderate argillization.

OTHER COMMENTS:

(Continued on next page)

PETROGRAPHIC DESCRIPTION

PROJECT: Calibration and Test Facilities REQUEST: 400097 FIELD NO.: MAS-122 AASSN: 30210-Continued

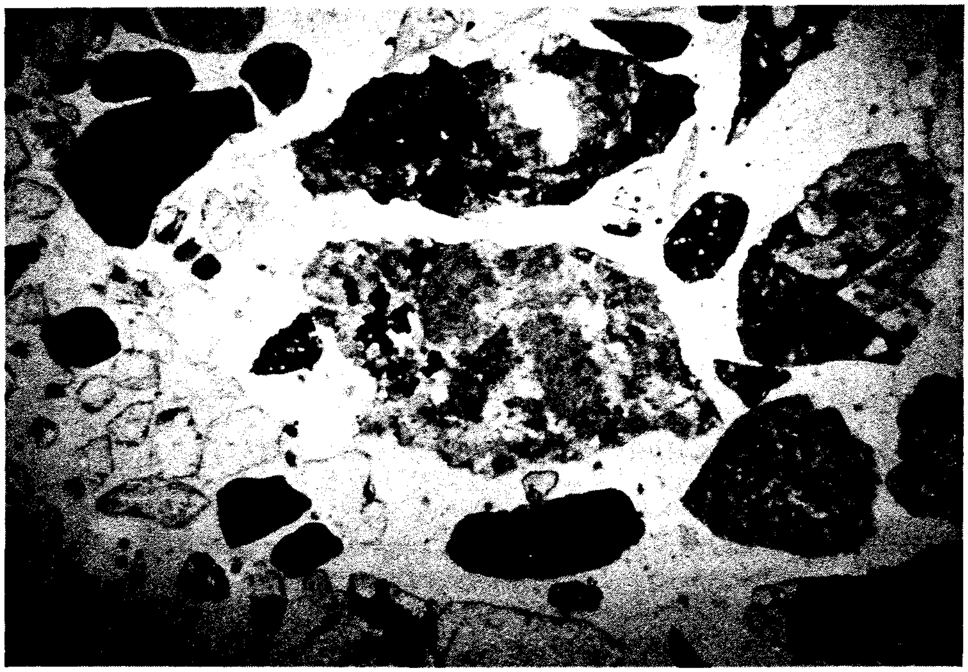
ROCK NAME: Dri-Mix Masonry Sand

GENERAL TEXTURE AND FEATURES:

Mineral/Component	%	Texture	Characteristics	Alteration/Replacement
Biotite	tr	Medium sand-sized, subrounded.		Moderate to strong argillization.
Muscovite	tr	Coarse sand-sized, subangular.		
Zeolite (?)	1	Granule-sized, subrounded.	Fibrous, radial. Low birefringence.	Some replacement by calcite .
Calcite	tr	Medium- to coarse sand-sized, angular to subangular.	Sparite and micrite.	

OTHER COMMENTS:

Figure II-5. Photomicrographs of Sample 30210



General texture of sample showing quartz, feldspar, and muscovite grains and plutonic, volcanic, and sedimentary rock fragments. 16x, plane polarized light.

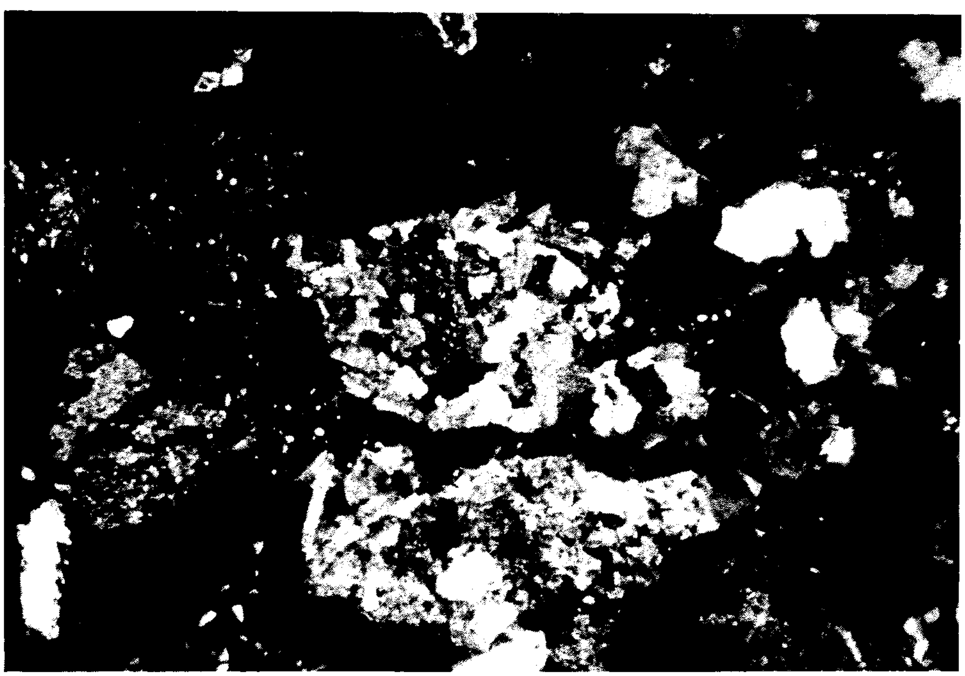


Figure II-6. Same, crossed polarizers.

APPENDIX II

Report 4

REQUEST # 400122

PROJECT # 50-51-5003

CALIBRATION AND TEST FACILITIES

A grain mount of the sample of 3/8-inch gravel submitted was examined petrographically. The rock types are described in the text. Polished sections of the samples were tested for uranium $^{+6}$ by chemical contact printing and no uranium $^{+6}$ could be detected.

FIELD NO. - MAN-791

SAMPLE # - 32549

SAMPLE TYPE - Whitewater 3/8-inch gravel

CAL. AND TEST FACIL.

PROJECT # 50-51-5003

REQUEST # 400122

Rock Types

Dacite Porphyry: Plagioclase and goethite phenocrysts in a partly aphanitic groundmass with some plagioclase and quartz grains distinguishable.

Andesite Porphyry: Plagioclase phenocrysts, opaques and altered mafics in an aphanitic groundmass with some distinguishable opaque and plagioclase grains.

Altered Volcanic: Very fine-grained and altered pyroxene phenocrysts in a dark aphanitic groundmass.

Quartz Wacke (mudstone): Subangular and subrounded quartz grains with opaques and about 75 percent clay matrix. Some small veinlets and pods of polycrystalline quartz.

Sericitic Plagioclase Gneiss: Mostly consists of sericitic plagioclase porphyroblastics with quartz, chlorite, biotite, and disseminated opaques. Very fine-grained (possibly granulated) quartz grains and chlorite. A ferruginous staining, restricted to the plagioclase grains interstitial areas, imparts an orange color to the pebble.

Plagioclase Biotite Schist: Consists of plagioclase, biotite, quartz, and opaques. Very fine-grained quartz, muscovite, and sericite occur interstitially.

Quartz Arenite: Consists mostly of subangular quartz grains with some subrounded and rounded grains plus a minor amount of feldspar and clay.

Feldspathic Arenite: Consists of poorly sorted subangular and subrounded single grain quartz, chert, plagioclase and microcline grains.

Other Comments: Grain size ranges from 4.9 to 10.0 mm in length.

APPENDIX II

Report 5

REQUEST # 400122

PROJECT # 50-51-5003

CALIBRATION AND TEST FACILITIES

A grain mount of the sample of 3/4-inch gravel submitted was examined petrographically. The rock types of each sample are described in the text. Polished sections of the samples were tested for uranium $^{+6}$ by chemical contact printing and no uranium $^{+6}$ could be detected.

FIELD NO. - MAN-787 | CAL. AND TEST FACIL.

SAMPLE # - 32548 | PROJECT # 50-51-5003

SAMPLE TYPE - Whitewater 3/4-inch gravel | REQUEST # 400122

Rock Types

Epidote Schist: Consists of quartz, epidote, calcite, and sericite.

Andesite: Phenocrysts of plagioclase, biotite, hornblende, and opaques in a very fine-grained matrix with some distinguishable plagioclase laths and chloritized hornblende fragments.

Thoroughly Altered Dacite Porphyry: Consists of altered plagioclase phenocrysts (replaced by calcite and clay), chlorite phenocrysts (probably replaced hornblende), and opaque phenocrysts set in a matrix of quartz and clay.

Other Comments: The epidote schist is 17.1 mm long, the andesite is 22.5 mm long, and the dacite porphyry is larger than the width of the thin section and has been cut to fit on the slide.

APPENDIX II

Report 6

Sample 18290 - Schwartzwalder Ore

This sample consists of angular to subangular fragments containing calcite, quartz, K-feldspar, muscovite, uraninite, pyrite, and hematite (Table A-2). Some fragments are monomineralic but most contain several minerals. The sample is coarser than the other samples but the actual percentage of fines is probably greater than indicated in the sieve analysis (Table A-3) because the fine fraction is very cohesive and tends to stick to the coarser particles.

Calcite is generally fine grained with some sparite present. It forms the matrix surrounding most of the other minerals. Quartz occurs as subangular, monocrystalline grains and as fine intergrowths with calcite. K-feldspar, both orthoclase and microcline, occurs as fresh subhedral grains in some of the fragments. Scattered flakes of muscovite are present. Uraninite (Tables A-2 and A-4), pyrite, and hematite occur as scattered grains and bands. Many fragments contain these opaque minerals as a matrix making up to 90 percent of the fragments.

The texture of individual fragments ranges from granular to schistose. Calcite and the opaque minerals are generally replacements of earlier formed minerals but it is difficult to see the whole picture because of the fragmental nature of the sample.

A heavy mineral separation using bromoform (sp. gr. 2.85) was performed. The heavy fraction (29.8 percent of the sample) consists of those fragments rich in uraninite, pyrite, and hematite.

Table A-2

Semiquantitative Modal Analysis

Sample 18290 - Schwartzwalder Ore

Mineral/Component	Percent
Calcite	38
Quartz	36
K-feldspar	9
Muscovite	6
Uraninite	5
Pyrite	4
Hematite	2

Table A-3

Sieve Analysis

Sample 18290 - Schwartzwalder Ore

Screen Mesh U.S. Series	Size Opening (millimeters)	phi units	Weight Retained (g)	Cumulative Weight (g)	Percent Retained	Cumulative Percent
5	2.0	-2	0	0	0	0
10	4.0	-1	12.1	12.1	9.98	9.93
18	1.0	0	40.4	52.5	33.33	43.32
35	0.5	1	31.5	84.0	25.99	69.31
60	0.25	2	15.2	99.2	12.54	81.85
120	0.125	3	19.6	118.8	16.7	98.42
230	0.0625	4	1.7	120.5	1.40	99.42
325	0.0440	4.5	0.3	120.8	0.24	99.67
Pan	<0.0440	<4.5	0.4	121.2	0.33	100.00

Table A-4

X-ray Powder Diffraction Comparison

Uranium Mineral Sample 18290		Uraninite[1] 5-0549[2]	
d Spacing (Å)	I/I	d Spacing (Å)	I/I
3.15	100	3.16	100
2.74	50	2.73	50
1.92	70	1.93	80
1.64	70	1.65	80
1.55	20	1.57	20
1.38	60	1.37	10

[1]Uraninite - $(U, TH)O_2$

[2]file number of standard from Joint Committee on Powder Diffraction Standards

APPENDIX III

Schwartzwalder Ores Available for Neutron Fission (A) Models

Below is a full inventory of Schwartzwalder ores available for the Neutron Fission (A) Calibration Pits. This analysis was received from the Geochemistry Laboratory on December 9, 1977.

Drum No.	Net Weight, lbs	Percent U_3O_8 Grade
1	645.5	11.1422
2	712.5	11.087
3	779.0	10.788
4	751.0	10.435
5	689.0	2.598
6	770.5	2.904
7	827.5	2.882
8	727.0	2.620

With the above weights and grades, any drum or combination of drums of ore can be used to obtain the desired model grade.

APPENDIX IV

Assay methods and standards used for samples from "A" Models and Thin Dipping Beds

The procedures and standards used for the Fission Neutron Calibration Models ("A" Models) and Thin Dipping Bed Models samples are described below. Following these descriptions is a list of the respective requisitions, sample numbers, dates, and procedures used.

1. Ge(Li) System

Data are collected in 4,000 channels of an Ino-Tech Ultima II computer-based analyzer from a 16 percent Ge(Li) detector and stored on 7-track magnetic tape. Each spectrum is further analyzed by the computer using Ino-Tech software which determines the peak area of the potassium, uranium, and thorium energy peaks. The concentrations of K, U, and Th are then calculated by comparison to previously run references.

The standards used are:

Potassium	Ultra Pure K_2CO_3	56.58% K		575.63g
Uranium	NBL-75	510 ppm U		683.60g
Thorium	NBL-81	510 ppm Th	23.5 ppm U	689.27g

The "A" Model samples were run for 3,500 seconds each.

2. NaI System

Data are collected by a 512 channel TMC analyzer from a 5-inch diameter by 4-inch thick NaI detector and stored on 7-track magnetic tape. Each spectrum is further analyzed by the CDC computer which sums regions of interest to obtain K, U, and Th data. The concentrations are calculated using the KOSNAI program which used a matrix method to account for interferences between peaks. The calculations are based on previously run references which are:

Potassium	Ultra Pure K_2CO_3	56.58% K		575.63g
Uranium	NBL-75	510 ppm U		683.60g
Thorium	NBL-81A	510 ppm Th	23.5 ppm U	689.27g

The "A" Model samples were run for 2,400 seconds each.

3. Chemical Potassium

The analyses are performed on either a Perkin-Elmer 603 or 303 Atomic Absorption Spectrometer. The instrument is calibrated with each batch of samples (20-30). The standard is prepared from a commercially available aqueous standard (1,000 ppm KCl) purchased from ALFA Products (Lot #051376).

4. Chemical Uranium Analyses

Depending on the uranium concentration, uranium is determined by either a fluorometric or colorimetric technique. Either a Jarrel-Ash fluorometer or a Beckman Double Beam Spectrophotometer is used in the analysis. In either case the instrument is calibrated with each batch of samples (about 30) with an aqueous uranium standard. The uranium standards are diluted from a stock solution prepared from NBS-9500 (99.44 percent U_3O_8 as certified by NBS).

5. Chemical Thorium Analyses

The thorium analyses on these samples were analyzed on a wavelength dispersive X-ray fluorescence spectrometer. The spectrometer is standardized daily with four to six of the following thorium standards:

USGS Standards	NBL Standards	Canadian Certified Reference Materials
G-2	NBL 110	BL-1
W-1	NBL 109	DL-1
GSP-1	NBL 82-A	
DTS-1		
PCC-1		
BCR-1		
AGV-1		

6. Magnetic Susceptibility

Samples are analyzed on a Bison magnetic susceptibility bridge which has been calibrated at the factory to read directly in units of magnetic susceptibility. The instrument is checked at least twice daily with three standards supplied by the manufacturer (Bison).

Assay reports for samples from the Fission Neutron Calibration Models are reproduced on the following pages.

REQUISITION NO. 400110

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30792	3/16/78	4/10/78
30793	3/16	4/10
30794	3/15	4/10
30795	3/16	4/10
30796	3/17	4/10
30797	3/16	4/10
30798	3/16	4/10
30799	3/17	4/10
30800	3/16	4/10
30801	3/16	4/11
30802	3/15	4/11
30803	3/16	4/11
30804	3/15	4/11
30805	3/15	4/11
30806	3/15	4/11
30807	3/15	4/11
30808	3/15	4/11
30809	3/15	4/11
30810	3/15	4/11
30811	3/16	4/11
30812	3/15	4/11
30813	3/15	4/11
30814	3/15	4/11

Form No. L-8 Rev.
8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400110 DATE April 12, 1978

Lab Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
030792	MAI 376	1.79	187	8	4	A-1-C
030793	" 377	1.55	185	6	5	
030794	" 378	1.76	192	7	9	
030795	" 379	1.82	170	9	4	
030796	" 380	1.71	225	8	12	
030797	" 381	2.24	228	9	12	
030798	" 382	1.92	183	8	12	
030799	" 383	1.82	169	7	10	
030800	" 384	2.10	193	8	6	
030801	" 385	1.68	216	7	8	
030802	" 386	1.61	211	8	5	
030803	" 387	1.73	216	7	11	
030804	" 388	1.84	204	10	9	
030805	" 389	1.83	253	9	11	
030806	" 390	2.31	230	8	7	
030807	" 391	1.92	236	9	9	
030808	" 392	1.62	207	6	8	
030809	" 393	2.09	202	6	9	
030810	" 394	1.78	203	10	6	
030811	" 395	1.41	192	7	10	
030812	MAS 903	1.68	215	8	6	
030813	" 904	1.81	187	9	8	
030814	" 905	1.92	244	8	4	

REQUISITION NO. 400111

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30815	3/14/78	4/6/78
30816	3/14	4/5
30817	3/14	4/6
30818	3/14	4/5
30819	3/14	4/5
30820	3/14	4/5
30821	3/14	4/5
30822	3/14	4/5
30823	3/14	4/5
30824	3/14	4/6
30825	3/14	4/5
30826	3/14	4/5
30827	3/14	4/5
30828	3/14	4/5
30829	3/14	4/6
30830	3/14	4/5
30831	3/14	4/5
30832	3/14	4/6
30833	3/14	4/6
30834	3/14	4/6

Form No. L-8 Rev.
8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400111 DATE April 12, 1978

Lab Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
030815	MAS 876	1.76	1211	6	13	A-4-C
030816	" 877	1.68	1214	11	12	
030817	" 878	2.00	1199	4	16	
030818	" 879	1.95	1173	6	14	
030819	" 880	1.50	1340	7	12	
030820	" 881	1.56	1318	9	10	
030821	" 882	1.81	1429	8	14	
030822	" 883	1.61	1283	6	14	
030823	" 884	1.82	1598	5	15	
030824	" 885	1.58	1327	8	13	
030825	" 886	2.44	1378	8	13	
030826	" 887	1.38	1486	4	11	
030827	" 888	1.61	1550	12	14	
030828	" 889	1.74	1588	10	15	
030829	" 890	1.96	1624	6	11	
030830	" 891	1.42	1740	7	11	
030831	" 892	1.50	1900	7	11	
030832	" 893	1.43	1834	10	15	
030833	" 894	1.88	1910	6	12	

REQUISITION NO. 400112

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30835	3/21/78	4/12/78
30836	3/20	4/12
30837	3/21	4/12
30838	3/21	4/12
30839	3/20	4/12
30840	3/20	4/12
30841	3/20	4/12
30842	3/20	4/12
30843	3/21	4/12
30844	3/21	4/13
30845	3/21	4/13
30846	3/20	4/13
30847	3/20	4/13
30848	3/20	4/13
30849	3/20	4/13
30850	3/20	4/13
30851	3/20	4/13
30852	3/20	4/13
30853	3/20	4/13
30854	3/20	4/13

Form No. L-8 Rev.
8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400112 DATE April 17, 1978

Sample Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
30835	MAI 426	1.10	496	6	6	A-5-B
30836	MAI 427	1.38	559	5	11	
30837	MAI 428	1.21	527	6	5	
30838	MAI 429	1.08	484	5	2	
30839	MAI 430	1.24	496	3	9	
30840	MAI 431	1.34	486	5	8	
30841	MAI 432	1.55	509	4	6	
30842	MAI 433	1.40	481	6	8	
30843	MAI 434	0.99	490	4	6	
30844	MAI 435	1.41	485	5	12	
30845	MAI 436	1.15	514	6	7	
30846	MAI 437	0.93	492	7	10	
30847	MAI 438	1.19	565	5	13	
30848	MAI 439	1.27	500	4	9	
30849	MAI 440	1.33	497	5	5	
30850	MAI 441	1.03	564	3	8	
30851	MAI 442	1.46	522	5	10	
30852	MAI 443	1.40	528	4	2	
30853	MAI 444	1.41	525	6	5	
30854	MAI 445	1.66	495	5	8	

REQUISITION NO. 400113

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30855	3/28/78	4/18/78
30856	3/27	4/18
30857	3/27	4/18
30858	3/27	4/18
30859	3/27	4/18
30860	3/27	4/18
30861	3/27	4/18
30862	3/28	4/18
30863	3/27	4/19
30864	3/27	4/19
30865	3/28	4/19
30866	3/28	4/19
30867	3/27	4/19
30868	3/27	4/19
30869	3/27	4/19
30870	3/27	4/19
30871	3/27	4/19
30872	3/27	4/19
30873	3/27	4/19
30874	3/27	4/19

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8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400113 DATE April 17, 1978

Sample Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
30855	MAU 001	1.53	486	9	<1	A-5-T
30856	" 002	1.70	530	9	3	
30857	" 003	1.58	494	7	<1	
30858	" 004	1.58	503	6	<1	
30859	" 005	1.54	482	8	<1	
30860	" 006	1.63	556	10	5	
30861	" 007	1.92	496	8	<1	
30862	" 008	1.71	487	8	3	
30863	" 009	1.58	469	7	2	
30864	" 010	1.57	556	7	1	
30865	" 011	1.76	479	7	<1	
30866	" 012	1.67	503	10	<1	
30867	" 013	1.48	488	6	<1	
30868	" 014	1.85	541	7	<1	
30869	" 015	1.38	520	6	1	
30870	" 016	1.68	546	7	2	
30871	" 017	1.79	492	8	<1	
30872	" 018	1.57	547	7	<1	
30873	" 019	1.96	525	7	4	
30874	" 020	1.74	515	7	<1	

REQUISITION NO. 400114

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30875	3/28/78	4/19/78
30876	3/28	4/20
30877	3/28	4/20
30878	3/28	4/20
30879	3/28	4/20
30880	3/28	4/20
30881	3/28	4/20
30882	3/28	4/20
30883	3/28	4/20
30884	3/28	4/20
30885	3/28	4/20
30886	3/28	4/20
30887	3/28	4/20
30888	3/28	4/20
30889	3/28	4/20
30890	3/28	4/20
30891	3/28	4/20
30892	3/28	4/20
30893	3/28	4/20
30894	3/28	4/20

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8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400114 DATE April 21, 1978

Sample Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
30875	MAU 026	2.16	408	12	1	A-6-B
30876	" 027	2.21	441	9	7	
30877	" 028	1.95	404	9	6	
30878	" 029	1.99	460	8	4	
30879	" 030	2.16	463	9	<1	
30880	" 031	2.35	500	11	7	
30881	" 032	1.74	483	10	5	
30882	" 033	1.80	502	7	7	
30883	" 034	2.20	508	7	2	
30884	" 035	1.46	536	11	2	
30885	" 036	1.78	470	10	4	
30886	" 037	1.86	560	9	4	
30887	" 038	1.74	526	9	6	
30888	" 039	2.07	612	9	6	
30889	" 040	1.68	605	10	<1	
30890	" 041	1.52	545	8	<1	
30891	" 042	1.91	571	8	7	
30892	" 043	1.92	598	9	7	
30893	" 044	1.89	604	9	3	
30894	" 045	1.85	569	9	6	

REQUISITION NO. 400115

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30895	3/29/78	4/21/78
30896	3/30	4/21
30897	3/29	4/21
30898	3/30	4/21
30899	3/30	4/21
30900	3/30	4/21
30901	3/30	4/21
30902	3/30	4/21
30903	3/30	4/21
30904	3/30	4/21
30905	3/30	4/21
30906	3/29	4/21
30907	3/29	4/21
30908	3/29	4/22
30909	3/29	4/22
30910	3/29	4/22
30911	3/29	4/22
30912	3/29	4/22
30913	3/29	4/22
30914	3/29	4/22

Form No. L-8 Rev.
8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400115 DATE April 27, 1978

Sample Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
30895	MAU 076	1.39	578	6	12	A-6-T
30896	MAU 077	0.98	550	5	5	
30897	MAU 078	1.08	524	7	7	
30898	MAU 079	1.21	521	8	8	
30899	MAU 080	1.50	610	8	8	
30900	MAU 081	1.25	552	7	16	
30901	MAU 082	1.27	541	8	14	
30902	MAU 083	1.64	553	6	14	
30903	MAU 084	1.39	544	7	9	
30904	MAU 085	1.19	521	7	11	
30905	MAU 086	1.67	556	7	9	
30906	MAU 087	1.10	536	5	16	
30907	MAU 088	0.95	528	6	8	
30908	MAU 089	1.29	492	8	7	
30909	MAU 090	1.26	509	8	14	
30910	MAU 091	1.28	566	7	13	
30911	MAU 092	1.13	568	8	3	
30912	MAU 093	1.09	587	4	14	
30913	MAU 094	1.11	485	5	13	
30914	MAU 095	1.21	510	5	9	

REQUISITION NO. 400116

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30915	3/24/78	4/16/78
30916	3/24	4/16
30917	3/24	4/16
30918	3/24	4/16
30919	3/23	4/16
30920	3/23	4/16
30921	3/24	4/16
30922	3/24	4/16
30923	3/24	4/16
30924	3/23	4/16
30925	3/23	4/16
30926	3/23	4/16
30927	3/23	4/16
30928	3/23	4/16
30929	3/23	4/17
30930	3/23	4/17
30931	3/23	4/17
30932	3/23	4/17
30933	3/23	4/17
30934	3/23	4/17
30935	3/23	4/17
30936	3/24	4/17
30937	3/24	4/17

Form No. L-8 Rev.
8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400116 DATE April 18, 1978

Sample Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
30915	MAU 176	1.72	515	9	8	A-2-C
30916	MAU 177	1.77	522	8	7	
30917	MAU 178	1.82	507	9	9	
30918	MAU 179	1.41	561	7	7	
30919	MAU 180	1.91	505	10	9	
30920	MAU 181	1.73	541	7	9	
30921	MAU 182	1.55	517	10	12	
30922	MAU 183	1.60	527	10	8	
30923	MAU 184	2.08	483	8	7	
30924	MAU 185	1.70	481	10	8	
30925	MAU 186	2.03	543	6	8	
30926	MAU 187	1.91	484	6	10	
30927	MAU 188	1.80	512	7	8	
30928	MAU 189	1.67	493	7	6	
30929	MAU 190	1.80	547	7	9	
30930	MAU 191	1.69	505	5	5	
30931	MAU 192	1.87	526	4	1	
30932	MAU 193	1.90	523	9	5	
30933	MAU 194	1.49	482	7	5	
30934	MAU 195	1.47	531	9	7	
30935	MAU 120	1.43	502	6	10	
30936	MAU 121	1.57	503	6	11	
30937	MAU 122	1.58	506	7	6	

REQUISITION NO. 400117

Sample Number	Ge(Li) Date First Run	Ge(Li) Date Second Run
30938	3/22/78	4/13/78
30939	3/22	4/14
30940	3/22	4/14
30941	3/22	4/14
30942	3/22	4/14
30943	3/21	4/14
30944	3/21	4/14
30945	3/22	4/14
30946	3/22	4/14
30947	3/22	4/14
30948	3/22	4/14
30949	3/21	4/14
30950	3/22	4/14
30951	3/22	4/14
30952	3/22	4/14
30953	3/21	4/14
30954	3/22	4/14
30955	3/21	4/14
30956	3/21	4/14
30957	3/21	4/14
30958	3/21	4/14
30959	3/21	4/14
30960	3/22	4/14

Form No. L-8 Rev.
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BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400117 DATE April 17, 1978

Sample Number	Ticket Number	K (%)	eU (ppm)	eTh (ppm)	Emanation (%)	Zone
30938	MAU 201	1.82	954	7	8	A-3-C
30939	MAU 202	2.04	1031	5	5	
30940	MAU 203	1.26	1041	8	7	
30941	MAU 204	1.87	1006	7	6	
30942	MAU 205	1.65	962	6	8	
30943	MAU 206	2.19	983	7	11	
30944	MAU 207	2.11	1104	6	7	
30945	MAU 208	1.87	1056	7	9	
30946	MAU 209	1.62	938	11	6	
30947	MAU 210	1.69	975	12	5	
30948	MAU 211	1.60	1037	8	9	
30949	MAU 212	2.03	1015	11	7	
30950	MAU 213	1.69	999	6	5	
30951	MAU 214	2.30	1025	8	3	
30952	MAU 215	1.57	963	9	4	
30953	MAU 216	1.64	951	5	6	
30954	MAU 217	1.67	925	7	8	
30955	MAU 218	1.52	954	10	6	
30956	MAU 219	1.64	989	10	7	
30957	MAU 220	1.78	967	9	6	
30958	MAU 124	1.55	1037	8	3	
30959	MAU 125	1.72	1028	7	8	
30960	MAU 276	1.80	948	8	8	

REQUISITION NO. 400119

Sample Number	FLU* Date Run	SPH** U_3O_8 Run	Ge(Li) Date First Run	Ge(Li) Date Second Run	NaI Date First Run	NaI Date Second Run
31161		4/18/78			4/17/78	5/10/78
31162		4/18			4/17	5/10
31163		4/18			4/17	5/10
31166		4/18			4/17	5/10
31167		4/18			4/17	5/10
31168		4/18			4/17	5/10
31170		4/18	4/17/78	5/10/78		
31171		4/18	4/17	5/10		
31172		4/18	4/17	5/10		
31173		4/18	4/17	5/10		
31174		4/18	4/17	5/10		
31177		4/18			4/18	5/10
31178		4/18			4/18	5/10
31179		4/18			4/18	5/10
31180		4/18			4/18	5/10
31181		4/18			4/18	5/10
31184		4/18	4/17	5/10		
31185		4/18			4/17	5/10
31186		4/18			4/17	5/10
31187		4/18			4/18	5/10
31188		4/18			4/18	5/10
31191		4/18			4/18	5/10
31192		4/18			4/18	5/10
31193		4/18			4/19	5/10
31194		4/18			4/19	5/10
32205		4/18			4/17	5/10
32206		4/18			4/17	5/10
32207		4/18			4/17	5/10
32209		4/18			4/17	5/10
32210		4/18			4/17	5/10
32211		4/18			4/17	5/10
32214		4/18	4/17	5/10		
32215		4/18	4/17	5/10		
32216		4/18	4/17	5/10		
32218		4/18	4/17	5/10		
32219		4/18	4/17	5/10		
32220		4/18	4/17	5/10		
31198		4/18			4/18	5/10
31199		4/18			4/18	5/10
31200		4/18			4/18	5/10
31201		4/18			4/18	5/10

*fluorometric

**spectrophotometric (colorimetric)

REQUISITION NO. 400119-Continued

Sample Number	FLU Date Run	SPH U_3O_8 Run	Ge(Li) Date First Run	Ge(Li) Date Second Run	NaI Date First Run	NaI Date Second Run
31202		4/18			4/18	5/10
31195		4/18			4/19	5/10
32237	4/27/78				4/19	5/10
32224	4/27				4/19	5/10
32279	4/27				4/19	5/10
32265	4/27				4/19	5/10
32286	4/27				4/19	5/10
32272	4/27				4/19	5/10
32244	4/27				4/29	5/10

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BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400119 DATE July 20, 1978

Zone	Lab No.	U_3O_8 (%)	LOD (%)	Density (g/cc)	EMN (%)
A-1-C	031161	0.028	3.40	2.24	9
A-1-C	031162	0.027	3.03	2.18	9
A-1-C	031163	0.026	4.54	2.24	10
A-1-C	031166	0.025	3.14	2.20	8
A-1-C	031167	0.027	5.31	2.23	9
A-1-C	031168	0.034	5.35	2.23	9
A-2-C	032210	0.071	4.78	2.17	4
A-2-C	032211	0.071	3.41	2.17	5
A-2-C	032205	0.079	3.51	2.16	5
A-2-C	032206	0.075	4.84	2.18	6
A-2-C	032207	0.078	3.43	2.16	4
A-2-C	032209	0.080	3.49	2.17	5
A-3-C	032214	0.152	3.47	2.17	<1
A-3-C	032215	0.164	4.51	2.18	7
A-3-C	032216	0.164	3.51	2.18	6
A-3-C	032218	0.150	3.44	2.18	4
A-3-C	032219	0.155	5.42	2.17	3
A-3-C	032220	0.145	3.50	2.18	1
A-4-C	031170	0.179	3.42	2.25	1
A-4-C	031171	0.186	3.47	2.27	2
A-4-C	031172	0.208	3.52	2.24	1
A-4-C	031173	0.205	3.33	2.24	1
A-4-C	031174	0.362	2.92	2.12	<1
A-5-T	031184	0.077	2.77	2.15	1
A-5-T	031185	0.080	3.14	2.14	5
A-5-T	031186	0.073	3.35	2.14	6
A-5-T	031187	0.079	3.41	2.16	5
A-5-T	031188	0.081	3.20	2.16	5
A-5-B	031177	0.078	2.71	2.43	5

Zone	Lab No.	U_3O_8 (%)	LOD (%)	Density (g/cc)	EMN (%)
A-5-B	031178	0.089	2.52	2.39	3
A-5-B	031179	0.071	2.79	2.40	4
A-5-B	031180	0.094	2.81	2.40	2
A-5-B	031181	0.080	2.58	2.42	4
A-6-T	031198	0.063	5.04	1.86	5
A-6-T	031199	0.062	5.00	1.85	4
A-6-T	031200	0.066	5.17	1.86	5
A-6-T	031201	0.075	4.95	1.85	4
A-6-T	031202	0.078	5.14	2.53	5
A-6-B	031191	0.050	2.13	2.16	6
A-6-B	031192	0.066	2.93	2.13	5
A-6-B	031193	0.075	2.64	2.21	3
A-6-B	031194	0.068	3.08	2.24	4
A-6-B	031195	0.091	3.56	2.19	4
A-1-T	03223T	7 ppm	3.03	2.20	Below det.
A-1-B	032224	3 ppm	3.40	2.18	for EMN
A-2-T	032279	1 ppm	2.88	2.17	"
A-2-B	032265	2 ppm	2.67	2.20	"
A-3-T	032286	1 ppm	2.92	2.17	"
A-3-B	032272	1 ppm	3.03	2.19	"
A-4-T	032244	1 ppm	3.22	2.18	"
A-4-B	032230	2 ppm	2.94	2.19	"
A-5-C	032251	3 ppm	2.89	2.18	"
A-6-C	032259	2 ppm	2.95	2.19	"

REQUISITION NO. 400120

Sample Number	Ge(Li) Date Run
30961	4/22/78
30962	4/22
30963	4/22
30964	4/22
30965	4/22
30981	4/22
30982	4/22
30983	4/22
30984	4/22
30985	4/22
31001	4/22
31002	4/22
31003	4/22
31004	4/22
31005	4/22
31021	4/22
31022	4/22
31023	4/23
31024	4/23
31025	4/23
31041	4/23
31042	4/23
31043	4/23
31044	4/23
31045	4/23
31061	4/23
31062	4/23
31063	4/23
31064	4/23
31065	4/23
31081	4/23
31082	4/23
31083	4/23
31084	4/23
31085	4/23
31101	4/23
31102	4/23
31103	4/23
31104	4/23
31105	4/23
31121	4/23
31122	4/24
31123	4/24
31124	4/24
31125	4/24
31141	4/24
31142	4/24
31143	4/24
31144	4/24
31145	4/24

Requested by C. Koizumi   Requisition Number 400120   Date April 22, 1978

Sample Number	Ticket Number	Zone	K (%)	eU (ppm)	eTh (ppm)
31001	MAS 926	A-1-T	1.56	5.9	7.0
31002	MAS 927	A-1-T	1.67	7.1	7.2
31003	MAS 928	A-1-T	1.67	5.2	8.2
31004	MAS 929	A-1-T	1.53	4.6	6.0
31005	MAS 930	A-1-T	1.76	4.5	7.3
30961	MAI 276	A-1-B	1.72	2.7	6.3
30962	MAI 277	A-1-B	1.92	3.5	7.9
30963	MAI 278	A-1-B	1.95	3.0	9.5
30964	MAI 279	A-1-B	1.93	3.3	7.9
30965	MAI 280	A-1-B	1.94	3.2	10.0
31121	MAU 226	A-2-T	1.77	1.7	9.1
31122	MAU 227	A-2-T	1.78	2.7	7.9
31123	MAU 228	A-2-T	1.59	2.6	8.2
31124	MAU 229	A-2-T	1.64	2.3	6.4
31125	MAU 230	A-2-T	1.72	2.9	7.5
31081	MAU 126	A-2-B	1.78	2.3	7.4
31082	MAU 127	A-2-B	1.70	2.5	8.3
31083	MAU 128	A-2-B	1.66	2.5	7.1
31084	MAU 129	A-2-B	1.76	2.1	7.3
31085	MAU 130	A-2-B	1.68	2.0	6.9
31141	MAU 251	A-3-T	1.74	3.3	7.4
31142	MAU 252	A-3-T	1.66	2.7	8.5
31143	MAU 253	A-3-T	1.67	2.6	7.6
31144	MAU 254	A-3-T	1.62	2.5	9.0
31145	MAU 255	A-3-T	1.70	2.7	7.5
31101	MAU 151	A-3-B	1.83	2.2	5.9
31102	MAU 152	A-3-B	1.85	2.3	7.0
31103	MAU 153	A-3-B	1.73	1.8	8.6
31104	MAU 154	A-3-B	1.68	2.4	5.7
31105	MAU 155	A-3-B	1.75	2.7	9.4
31021	MAS 976	A-4-T	1.65	3.1	6.2
31022	MAS 977	A-4-T	1.81	2.0	7.4
31023	MAS 978	A-4-T	1.86	2.9	6.6
31024	MAS 979	A-4-T	1.70	2.2	7.9
31025	MAS 980	A-4-T	1.69	2.0	5.8
30981	MAI 326	A-4-B	1.60	1.4	6.3
30982	MAI 327	A-4-B	1.80	2.8	6.6
30983	MAI 328	A-4-B	1.69	4.0	7.1
30984	MAI 329	A-4-B	1.70	3.3	7.3
30985	MAI 330	A-4-B	1.77	3.6	8.5
31041	MAS 951	A-5-C	1.73	2.8	7.2
31042	MAS 952	A-5-C	1.79	3.7	7.5
31043	MAS 953	A-5-C	1.70	2.6	6.5
31044	MAS 954	A-5-C	1.82	3.6	8.2
31045	MAS 955	A-5-C	1.74	2.7	7.8
31061	MAU 051	A-6-C	1.69	4.6	5.6
31062	MAU 052	A-6-C	1.58	4.7	5.1
31063	MAU 053	A-6-C	1.72	3.0	8.6
31064	MAU 054	A-6-C	1.65	3.6	6.0
31065	MAU 055	A-6-C	1.87	3.7	7.2

REQUISITION NO. 400121

Sample Number	Ge(Li) Date Run	NaI Date Run
32537		5/22
32538		5/22
32539		5/22
32540		5/25
32541		5/25
32542		5/25
32543		5/25
32544		5/25
32545		5/25

REQUESTED BY C. Koizumi REQUISITION NUMBER 400121 DATE May 25, 1978

Ticket Number	Lab Number	Aggregate Material	K (%)	eU (ppm)	eTh (ppm)
MAN 788	32537	3/4-inch rock--Whitewater	2.75	5.6	9.7
MAN 789	32538	3/4-inch rock--Whitewater	2.54	3.6	10.6
MAN 790	32539	3/4-inch rock--Whitewater	2.55	3.9	10.7
MAN 792	32540	3/8-inch rock--Whitewater	2.30	4.2	10.8
MAN 793	32541	3/8-inch rock--Whitewater	2.26	4.4	9.6
MAN 794	32542	3/8-inch rock--Whitewater	2.64	4.2	12.2
MAN 796	32543	Masonry sand---Whitewater	3.01	3.6	12.6
MAN 797	32544	Masonry sand---Whitewater	2.77	2.2	11.3
MAN 798	32545	Masonry sand---Whitewater	2.61	3.0	10.0

REQUISITION NUMBER 400229 DATE December 29, 1978

MIB 269	43248	Type II cement--Whitewater	0.47	3.1	6.0

All measurements were made on the NaI system of the Bendix Field Engineering Geochemistry Department.

REQUISITION NO. 400140

Sample Number	SPH U_3O_8 Date Run	AA* K Date Run	XRF** Th Date Run
33739	8/1/78	7/31/78	8/8/78
33740	8/1	7/31	8/8
33741	8/1	7/31	8/8
33742	8/1	7/31	8/8
33743	8/1	7/31	8/8
33744	8/1	7/31	8/8
33745	8/1	7/31	8/8
33746	8/1	7/31	8/8
33747	8/1	7/31	8/8
33748	8/1	7/31	8/8
33749	8/1	7/31	8/8
33750	8/1	7/31	8/8
33751	8/1	7/31	8/8
33752	8/1	7/31	8/8
33753	8/1	7/31	8/8
33754	8/1	7/31	8/9
33755	8/1	7/31	8/9
33756	8/1	7/31	8/9
33757	8/1	7/31	8/9
33758	8/1	7/31	8/9
33759	8/1	7/31	8/9
33760	8/1	7/31	8/9
33761	8/1	7/31	8/9
33762	8/1	7/31	8/9
33763	7/1	7/31	8/9
33764	8/1	7/31	8/9

* atomic absorption

** x-ray fluorescence

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400140 DATE September 6, 1978

Zone	Lab Number	U_3O_8 (%)	Pulp LOD (%)	Wt. as Rec'd (g)	Dry Wt. (g)	Wet Wt. (g)	Bulk Density (g/cc)	K (%)	Grain Density (g/cc)	LOI (%)	Th (ppm)
A-5-T	033739	0.077	0.38	1006	982	1034	2.21	1.79	2.65	6.57	<5
A-5-T	033740	0.083	0.49	783	769	818	2.18	1.59	2.64	6.54	<5
A-5-T	033741	0.078	0.34	592	578	617	2.13	1.74	2.64	6.83	<5
A-5-T	033742	0.079	0.43	473	464	495	2.14	1.69	2.63	6.99	<5
A-5-T	033743	0.085	0.44	657	643	679	2.19	1.74	2.64	6.49	<5
A-5-C	033744	5 ppm	0.26	699	683	723	2.19	1.93	2.66	6.42	<5
A-5-C	033745	5 ppm	0.50	583	571	605	2.20	1.84	2.65	5.92	<5
A-5-C	033746	142 ppm	0.31	700	685	724	2.20	1.84	2.65	6.23	<5
A-5-B	033747	0.077	0.23	978	962.5	1014	2.44	1.21	2.96	6.27	<5
A-5-B	033748	0.088	0.33	1837	1804	1902.5	2.44	1.45	2.89	6.15	<5
A-5-B	033749	0.096	0.25	1656	1624	1719	2.43	1.26	2.98	6.14	<5
A-5-B	033750	0.100	0.23	1005	986.5	1047.5	2.42	1.26	3.00	6.51	<5
A-5-B	033751	0.052	0.26	508	497	530	2.29	1.55	2.78	6.90	<5
A-6-T	033752	0.069	0.41	696	678	754	1.85	1.30	2.58	9.49	<5
A-6-T	033753	0.075	0.37	823	801	894	1.84	1.30	2.59	9.69	<5
A-6-T	033754	0.064	0.43	377.5	368	411.5	1.84	1.35	2.59	10.15	<5
A-6-T	033755	0.080	0.38	830	810	903	1.85	1.30	2.61	9.74	<5
A-6-T	033756	0.075	0.43	539	527	585	1.89	1.35	2.62	9.28	<5
A-6-C	033757	8 ppm	0.38	693	680	720.5	2.21	1.93	2.62	5.84	<5
A-6-C	033758	2 ppm	0.43	730	717	763	2.19	1.89	2.65	6.20	<5
A-6-C	033759	4 ppm	0.37	819.5	804	854	2.21	1.89	2.65	6.14	<5
A-6-B	033760	0.063	0.44	716.5	705.5	743	2.25	2.03	2.64	5.79	<5
A-6-B	033761	0.072	0.46	481	473	500	2.25	1.93	2.64	6.12	<5
A-6-B	033762	0.084	0.45	1168	1142	1214	2.20	1.84	2.63	6.59	<8
A-6-B	033763	0.003	0.34	691	678	724	2.19	1.89	2.64	5.81	<5
A-6-B	033764	0.002	0.34	690	674.5	724	2.15	2.03	2.64	7.03	<5

Form No. L-8 Rev.
8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY C. Koizumi REQUISITION NO. 400140 DATE 3/7/79

GAMMA-RAY SPECTROSCOPY ANALYSIS (Ge(Li))

	Sample No.	K (%)	eU (ppm)	Total gamma eU (ppm)	eTh (ppm)
MAN 804	033739	1.98	701	669	6.5
MAN 805	033740	2.13	687	661	11.9
MAN 806	033741	1.69	687	680	17.4
MAN 807	033742	2.05	663	699	14.9
MAN 808	033743	Insufficient sample			
MAN 809	033744	2.49	9.5	34.2	16.1
MAN 810	033745	2.23	7.3	32.1	10.3
MAN 811	033746	2.10	132	149	23.7
MAN 812	033747	2.22	699	663	11.6
MAN 813	033748	1.65	706	701	8.4
MAN 814	033749	0.98	653	676	6.4
MAN 815	033750	1.97	746	757	15.0
MAN 816	033751	1.52	407	394	5.3
MHP 126	033752	1.75	638	617	22.8
MHP 127	033753	.34	747	766	13.3
MHP 128	033754	2.07	641	603	15.9
MHP 129	033755	1.78	684	639	10.8
MHP 130	033756	2.19	630	625	3.4
MHP 131	033757	2.36	12.6	33.9	19.0
MHP 132	033758	1.86	6.8	30.2	20.6
MHP 133	033759	2.13	8.2	31.1	7.2
MHP 134	033760	1.77	538	509	3.8
MHP 135	033761	3.13	642	599	14.6
MHP 136	033762	2.08	623	658	8
MHP 137	033763	2.30	7.2	35	11
MHP 138	033764	1.98	5.4	32	13

Procedures for Core Studies

Requisition 400140

1. Split each core sample. Place one portion in archive and use the other for the following tests.

2. Record the weight (weight as received) of each sample.

3. Dry the samples at 110°C. Record the dry weights.

4. Submerge the samples in water. Weigh the samples periodically and record the weight (wet weight) of each sample after the samples stop absorbing water.

5. Dry the samples at 110°C. Record the dry weights.

6. Determine the bulk density of each sample.

7. Crush each sample, taking care to minimize loss of sample material. Record the weights of the sample pulps.

8. Dry the pulp samples at 110°C. Record the dry sample weights.

9. Determine the grain density for each sample.

10. Place each pulp sample in a crucible and ignite (heat to 1,000°C) in the presence of air. Allow each sample to cool, then record the weight.

11. Run chemical potassium, uranium, and thorium analyses on the pulp samples.

REQUISITION NO. 400143

Sample Number	Mag S Date Run	Sample Number	Mag S Date Run
31161	7/26/78	31177	7/26/78
31162	7/26	31178	7/26
31163	7/26	31179	7/26
31166	7/26	31180	7/26
31167	7/26	31181	7/26
31168	7/26	31198	7/26
32210	7/27	31199	7/26
32211	7/27	31200	7/26
32205	7/27	31201	7/26
32206	7/27	31202	7/26
32207	7/27	31191	7/26
32209	7/27	31192	7/26
32214	7/27	31193	7/26
32215	7/27	31194	7/26
32216	7/27	31195	7/26
32218	7/27	32237	7/27
32219	7/27	32224	7/27
32220	7/27	32279	7/27
31170	7/26	32265	7/27
31171	7/26	32286	7/27
31172	7/26	32272	7/27
31173	7/26	32244	7/27
31174	7/26	32230	7/27
31184	7/26	32251	7/27
31185	7/26	32259	7/27
31186	7/26	32222	7/27
31187	7/26		
31188	7/26		

Form No. L-8 Rev.
8/2/77-500

BENDIX FIELD ENGINEERING CORP.

P. O. Box 1569

Grand Junction, Colorado 81502

CERTIFICATE OF ASSAY

REQUESTED BY D. C. George REQUISITION NO. 400143 DATE 8/1/78

Lab No.	Zone	Mag. Sus. (cgs x 10^{-6})	Lab No.	Zone	Mag. Sus. (cgs x 10^{-6})
31161	A-1-C	841	31188	A-5-T	772
31162	A-1-C	850	31177	A-5-B	616
31163	A-1-C	814	31178	A-5-B	559
31166	A-1-C	801	31179	A-5-B	512
31167	A-1-C	828	31180	A-5-B	585
31168	A-1-C	914	31181	A-5-B	626
32210	A-2-C	807	31198	A-6-T	340
32211	A-2-C	701	31199	A-6-T	347
32205	A-2-C	824	31200	A-6-T	355
32206	A-2-C	817	31201	A-6-T	361
32209	A-2-C	769	31202	A-6-T	339
32214	A-3-C	784	31191	A-6-B	1043
32215	A-3-C	767	31192	A-6-B	1111
32216	A-3-C	790	31193	A-6-B	1076
32218	A-3-C	840	31194	A-6-B	991
32219	A-3-C	868	31195	A-6-B	899
32220	A-3-C	884	32237	A-1-T	1015
31170	A-4-C	880	32224	A-1-B	973
31171	A-4-C	881	32279	A-2-T	1005
31172	A-4-C	895	32265	A-2-B	1007
31173	A-4-C	881	32286	A-3-T	1076
31174	A-4-C	684	32272	A-3-B	981
31184	A-5-T	680	32244	A-4-T	1016
31185	A-5-T	757	32230	A-4-B	977
31186	A-5-T	784	32251	A-5-C	947
31187	A-5-T	711	32259	A-6-C	933

REQUESTED BY C. Koizumi REQUISITION NUMBER 400157 DATE 1/15/79

Ticket Number	Lab Number	Aggregate Material	Th[2] (ppm)	K[1] (%)	Magnetic Susceptiblity (10^{-6} c.g.s.)	Gd[3] (ppm)	Cl[4] (%)
MIB 253	036155	Masonry Sand-Whitewater	<5	2.16	932	4	0.04
MIB 254	036156	Masonry Sand-Whitewater	<5	2.22	894	4	0.02
MIB 255	036157	Masonry Sand-Dri-Mix	<5	1.71	429	4	0.03
MIB 256	036158	Masonry Sand-Dri-Mix	<5	1.71	385	4	<0.01
MIB 257	036159	3/4-inch rock-Whitewater	<5	2.33	1333	5	<0.01
MIB 258	036160	3/4-inch rock-Whitewater	8	2.39	1316	4	0.05
MIB 259	036161	3/8-inch rock-Whitewater	<5	2.45	1266	5	0.03
MIB 260	036162	3/8-inch rock-Whitewater	8	2.51	1316	4	0.03
MIB 261	036163	Boron carbide-Boride Products	<5	0.09	<1	<1	0.04
MIB 262	036164	Boron carbide-Boride Products	<5	0.06	<1	<1	0.04
MIB 263	036165	Corundum-Bendix	<5	0.44	64	2	0.04
MIB 264	036166	Corundum-Bendix	<5	0.47	182	3	0.04
MIB 265	036167	Uranium Ore-Schwartzwalder	<5	4.60	104	7	0.03
MIB 266	036168	Uranium Ore-Schwartzwalder	<5	4.74	85	7	0.02

[1]Atomic absorption measurement by Geochemistry Department, Bendix Field Engineering.

[2]X-ray fluorescence measurement by Geochemistry Department, Bendix Field Engineering.

[3]Analysis by Analytical Consulting Services, Houston, Texas.

[4]Analysis by Hazen Research, Incorporated, Golden, Colorado.

APPENDIX V

Construction Records

This Appendix contains copies of
(1) the Project Authorization,
(2) the Construction Work Order,
(3) a modification to the Project Authorization,
(4) the concrete pour schedules, and
(5) the project Cost Closing Statement.

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
GRAND JUNCTION OFFICE
GRAND JUNCTION, COLORADO 81501

August 18, 1977

PROJECT AUTHORIZATION
NO. GJO-PA-77-5

John G. Themelis, Director
Engineering & Safety Division

PROJECT AUTHORIZATION - NEUTRON CALIBRATION AND TEST FACILITY

A. Source of Request: Director, Advanced Technology Division, BFEC.

B. Project Description: This project consists of the construction of six (6) test models to be used for the calibration of fission neutron logging tools. The models will be located northwest of Building 22 and placed almost completely underground. Each model will consist of a uranium ore bearing concrete cylinder six feet in diameter and 15 feet in length in a steel container. The model will be vertically placed in a cylindrical test pit with an 8 feet diameter and 15 feet length. The annulus formed between the pit wall and steel cylinders will be rock filled. The top 7 feet and the bottom 4 feet of the concrete casting will be barren of uranium ore.

A 4-1/2 inch diameter unlined hole will be cast or drilled laterally completely through the axis of the concrete cylinder to accept the logging tool probes. The hole will be extended an additional 15 feet below the bottom of the model by means of a 12 inch diameter steel tube. This extension or "run-tube" is designed to accommodate the much greater length of new and future probes.

Construction of these six models will provide part of the uranium calibration facilities needed for logging tools which locate uranium by determining its fission neutrons. The six models differ by ore composition and borehole size.

C. Justification: Calibration and test facilities are required to support techology development projects and for calibration of industry equipment which provides a major input to the ore reserves and resource data for the NURE program.

C. Justification: (continued)

These six (6) test models will be used to test prototype systems, develop quantitative analysis methods, and ultimately to calibrate and standardize commercial units which will obtain assay data for ore reserves estimation, in-situ leach mining and resource evaluation.

Existing calibration facilities cannot be used because of borehole sizing and model chemical composition requirements. Contracts for development of neutron logging probes require that calibration models be completed and available as soon as they can be constructed.

D. Health, Safety, and Evnironmental Analysis: Surface radiation levels, when logging, are estimated to be less than 4.0 mR/hr. Suitable barricades will be constructed to control access to the calibration area during logging activities. Specific safety, operating, and monitoring procedures will be developed prior to use of the facility. No environmental problems are expected in connection with this facility.

E. Work Authorized: EDI and Construction.

F. Preliminary Proposal: None Required.

G. Special Approval of Higher Authority: None Required.

H. Responsible ERDA Official: Director, Engineering and Safety Division.

I. Excess Material Available: None.

J. Method of Accomplishment:

	Type of Contract	Contractor	Contract No.
EDI and Construction	CPAF	BFEC	E(05-1)-1664

Design and construction may be partly accomplished under BFEC subcontracts.

K. Schedule:

	Start	Complete
EDI and Construction	8/22/77	
Pit Construction		10/31/77
Model Construction		11/18/77

L. Current Cost Estimate:

	Item Cost
EDI	$ 70,000
Contingency	10,000
Total	$ 80,000

M. Cost Limitation: Cost not to exceed $80,000 for EDI and Construction.

N. Source of Funds: FY 77 GPP.

Eugene W. Grutt, Jr.
Manager

cc: BFEC (3)
FBO (1)

BENDIX FIELD ENGINEERING CORPORATION
GRAND JUNCTION OFFICE
U.S. ERDA Contract No. E-(05-1)-1664
Grand Junction, Colorado 81501

CONSTRUCTION WORK ORDER

Original X Modification No. ______

Work Order No. Authorization GJO-PA-77-5 Authorized by Eugene W. Grutt, Jr.

Estimated Beginning Date 8/22/77 Date 8/22/77

Estimated Completion Date 11/18/77 Funds Authorized $80,000

DESCRIPTION AND SCOPE OF WORK:

Construction of six (6) test models to be used for the calibration of neutron logging tools.

Cost Account 30101 Plant Project No. 77-014

Based on latest estimate (Project Authorization GJO-PA-77-5)

dated August 18, 1977, and changes in the work since that date,

revised estimate as of ______ 19__ is as follows:

Funds Authorized	$ 80,000.00
Approved Change Orders	$
Requested Change Order	$
TOTAL FUNDS AS AT (Date: August 22, 1977)	$ 80,000.00

Revised estimated job completion date ______

Issued by [signature] 8/22/77
Plant Engineer Date

Approved [signature] 8/22/77
Director of Operations Date

Dist: Director of Operations
Plant Engineer
B&G Department
Accounting (Cost)
Accounting (Job)
Accounting (Payroll)
ERDA-Engineering

Bendix

Field Engineering Corporation

Grand Junction Operations

P.O. Box 1569
Grand Junction, CO. 81501
Tel (303) 242-8621

A Subsidiary of
The Bendix Corporation

Mr. John G. Themelis, Director
Engineering and Safety Division
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

January 24, 1978

Dear Mr. Themelis:

Plant Authorization GJO-PA-77-5 authorized construction of six (6) Neutron Calibration and Test Pits. The pits were to contain an ore zone placed between a top and bottom barren zone.

Advanced Technology Division, by internal memorandum dated January 20, 1978, from C. Koizumi to T. D. Price, has requested that the Authorization be modified to permit use of two (2) ore zones separated by a barren zone in two (2) of the test pits. This memo also contains an analysis of the increased radiation exposure to be expected. A copy of the memo is attached.

The requested design change will be included in the Neutron Calibration and Test Pit construction unless DOE, Engineering and Safety Division has objections.

Very truly yours,

C. A. Lemons
Director of Operations

fj

cc CKoizumi

Attachment

Internal
Memorandum

Bendix Field Engineering Corporation
Grand Junction Operations

P.O. Box 1569
Grand Junction, CO. 81501
Tel (303) 242-8621

A Subsidiary of
The Bendix Corporation

Date January 20, 1978 Letter No.

To D. Price

VIA H. B. Evans

From C. Koizumi, SS Dept.

Subject Modification of Project Authorization, Number GJO-PA-77-5, Neutron Calibration and Test Facility

Please arrange for the following amendments to the above Project Authorization (copy attached).

B. Project Description

Last sentence to be changed to:

"In 4 of the models, the top 5 feet and bottom 4 feet of the concrete casing will be barren of uranium ore."

Sentence to be added:

"In 2 of the models, the top 4 feet and bottom 4 feet will contain a low concentration (0.08%eU_3O_8) of uranium ore. The middle 7 feet will be barren of uranium ore."

D. Health, Safety, and Environmental Analysis

First sentence to be changed to:

"Surface radiation levels, when logging, are estimated to be less than 4.0 mR/hr on the models with barren zones at the surface."

Sentences to insert immediately after the above sentence:

"At the surfaces of models with exposed ore zones there will be additional radiation levels due to the ore. The ore itself will contribute an estimated additional dose rate of 0.5 mR/hr. The additional dose rate due to gamma radiation from uranium fission during logging is estimated to be 0.1 mR/hr."

CK/skk
Attachment

Internal
Memorandum

Bendix Field Engineering Corporation
Grand Junction Operations

P.O. Box 1569
Grand Junction, CO. 81501
Tel (303) 242 8621

A Subsidiary of
The Bendix Corporation

Date 2/6/78 Letter No.

To C. Koizumi

From C. L. Bruner

Subject A Test Pit Pouring Schedule

The following revised pouring schedule has been established for the subject test pits:

		A1	A4	Date
Bottom Barren Zone	(1 truck)	8:00 a.m.	10:00 a.m.	Feb. 7, 1978
Ore Zone	(2 trucks)	9:30 a.m.	10:30 a.m.	Feb. 8, 1978
Top Barren Zone	(1 truck)	9:30 a.m.	10:30 a.m.	Feb. 9, 1978
		A5	A6	
Bottom Ore Zone	(2 trucks)	8:30 a.m.	9:30 a.m.	Feb. 10, 1978
Barren Zone	(2 trucks)	11:00 a.m.	12:00 noon	Feb. 10, 1978
Top Ore Zone	(2 trucks)	1:30 p.m.	2:30 p.m.	Feb. 10, 1978
		A2	A3	
Bottom Barren Zone	(1 truck)	8:00 a.m.	10:00 a.m.	Feb. 14, 1978
Ore Zone	(2 trucks)	9:30 a.m.	10:30 a.m.	Feb. 15, 1978
Top Barren Zone	(1 truck)	9:30 a.m.	10:30 a.m.	Feb. 16, 1978

Please schedule your support personnel accordingly.

Chuck
C. L. Bruner
Assistant Director of Operations

CC: C. Edwards
R. Lionberger
J. Hightower
D. Price
K. Knapp
E. Gardner, Whitewater Building Materials

Bendix

Field Engineering
Corporation

Grand Junction Operations

P.O. Box 1569
Grand Junction, CO. 81501
Tel (303) 242-8621

A Subsidiary of
The Bendix Corporation

Mr. John G. Themelis, Director
Engineering and Safety Division
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado 81501

June 8, 1978

Dear Mr. Themelis:

Attached herewith is the cost closing statement on the Neutron Calibration Pits (A pits).

Sincerely,

C. A. Lemons
Director of Operations

fj

Attachment

cc CLBruner
JAPapania
CLGreenslit
EKlooz
TDPrice

COST CLOSING STATEMENT

June 8, 1978

1. The project was authorized by Directive GJO-PA-77-5 dated August 18, 1977. No modifications were issued.

2. Summary of estimates and costs:

	Original* Directive	Actual Costs
EDI and Construction	$ 70,000	$78,948.73
Contingency	10,000	0
Total	$ 80,000	$78,948.73

*The original directive authorized all funds