Preliminary Design Studies in a Nuclear Excavation—Project Carryall

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•THE EXPANSION of population and industry in the Pacific Coast States, and particularly in California, is placing an ever increasing demand on the transportation industries operating on both rails and highways. This expansion, together with the economies found in the utilization of existing plants in the East for manufacture and the building of new plants in the West for fabrication, has made the transcontinental railway and trucking industries a network of assembly lines. Materials under load represent a huge investment unusable until delivery is made; therefore, transportation time saved may be measured in real dollars. In an attempt to keep pace with the rapid growth of both population and industry, many new Interstate Highways have been built, many are still under construction, and still more are in the planning stages. As their construction progresses, the highway transportation industry will be in a position to be a better component in the national assembly line.

In an effort to meet the ever increasing demand on the rail transportation industry, the Santa Fe embarked on a relocation study (Fig. 1) between Needles and Barstow, Calif., designed to reduce freight schedules by approximately 50 min. The most nearly acceptable route was found to the north of its present location, but the Bristol Mountains created a barrier too formidable for conventional grading equipment to remove economically. Tunneling, though technically feasible, was too expensive. At the same time, the California State Division of Highways was making a study slightly to the north of this area but still in the Bristols.

The Santa Fe, having exhausted all possibilities on the ground, turned to the Atomic Energy Commission for advice on the use of nuclear energy. A cursory investigation disclosed vast differences between conventional and nuclear method costs; conventional costs vary almost directly with the volume moved, whereas sections excavated by nuclear explosives can be enlarged considerably for very little additional cost. This gave rise to the thought of a joint venture to place the railway and highway in the same slot.

A study group was formed by members from the United States Atomic Energy Commission, the California State Division of Highways, and the Santa Fe Railway. A thorough study was made as shown in Figure 2. The Santa Fe's proposed realignment would shorten their line between Goffs and Ash Hill by 15 mi to 63 mi, and would permit higher standards of curvature and gradient. The length of highway between Ludlow and Mountain Springs would be shortened by about 10 mi. The study group determined that the railroad line could be shifted slightly to the north and the highway line could be shifted about a mile to the south, permitting the two alignments to join through the area of possible nuclear excavation. It was determined by the group that the project, insofar as the area of joint venture was concerned, was technically feasible. Costs, exclusive of the nuclear devices, were found to be much less than costs of conventional methods, and studies are presently being made to determine whether the project, Project Carryall, can now be justified economically.

An interesting note, though not applicable to this particular project, is the basic difference between the design profiles of conventional and nuclear energy constructed

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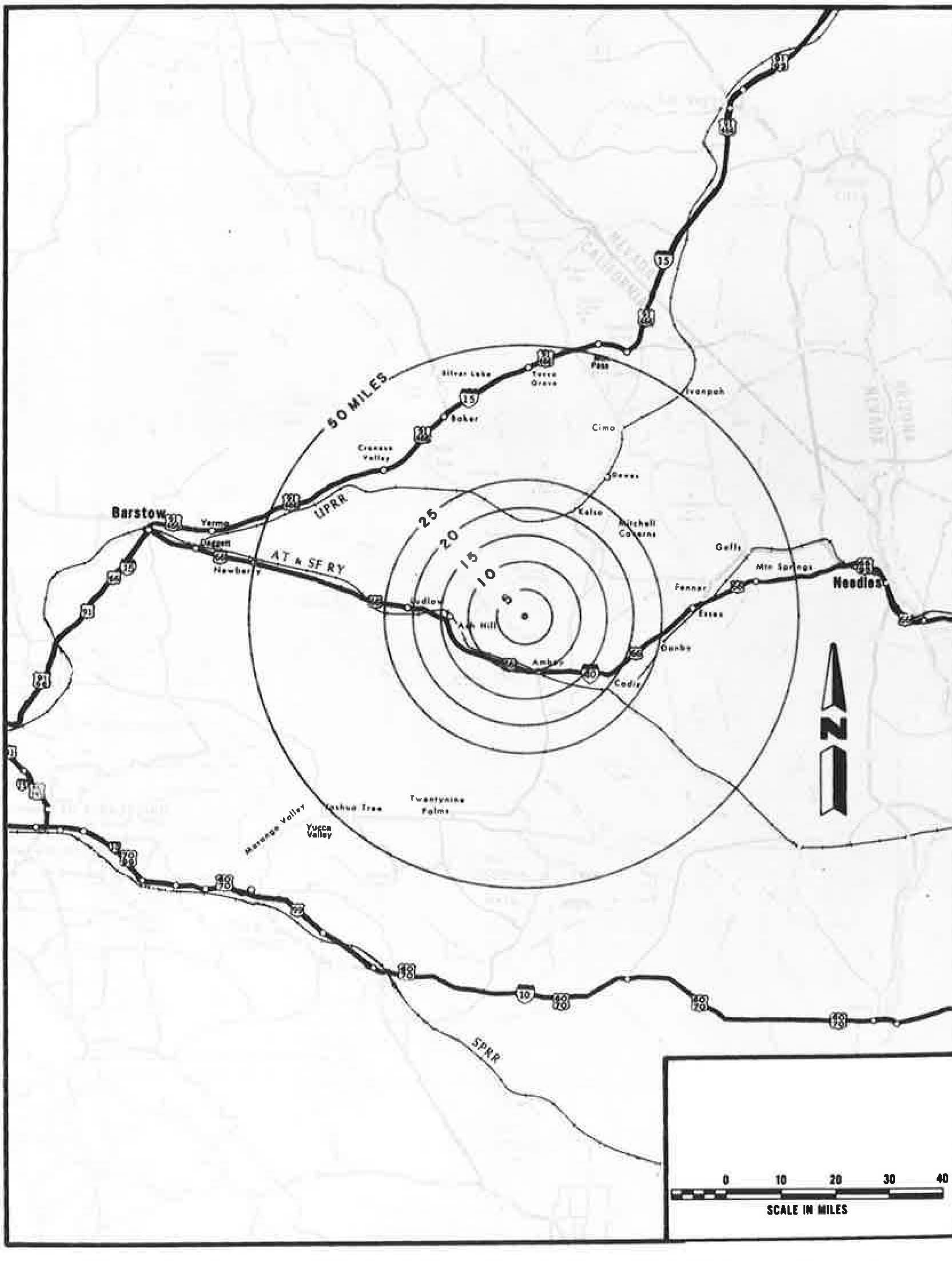

Figure 1. Area map of Project Carryall, showing radial distances from site.

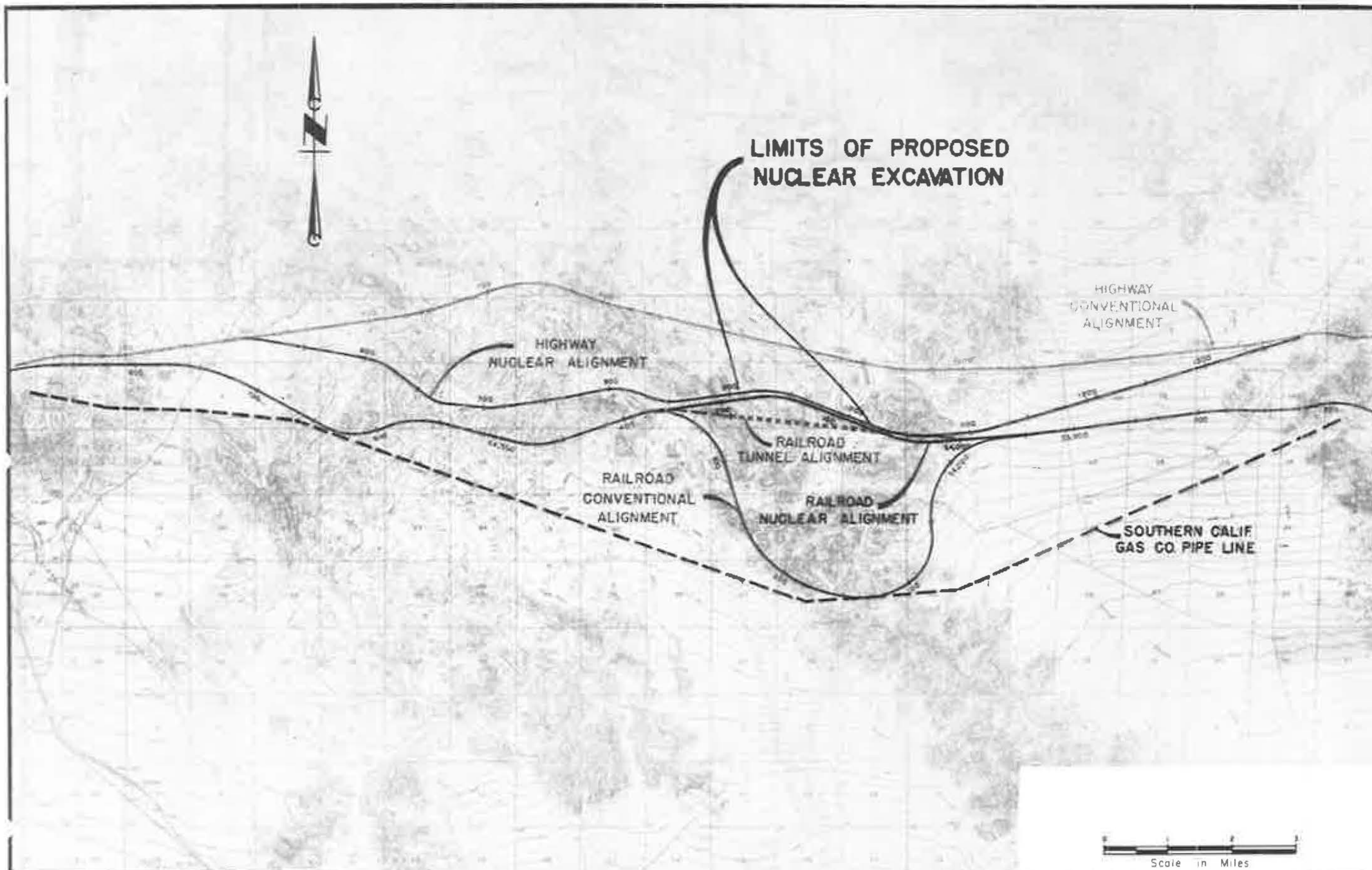

Figure 2. Study limits of Project Carryall, showing conventional and nuclear alignments.

roadbeds. Using conventional methods, balance of quantities is a principle concern and materials blasted and excavated are, more often than not, used in the construction of embankments. However, once it has been determined that an excavation is to be made with nuclear explosives, variation in depth makes little difference in cost and the cut may be deepened so as to lessen the height of adjacent embankments. This minimizes the cost of the adjacent fill and subsequently reduces the cost of drainage structures. Unlike conventional blasting, the nuclear blast not only breaks the material but also removes it, placing it on the lip of the excavation where it is available for backfill to grade in the slot or for the construction of adjacent embankments.

At this time, no subsurface exploration of the Carryall site has been made. Surface observation indicates the presence of two major rock groups. The first is comprised of Tertiary volcanics consisting essentially of hardened tuffs and harder flow rocks. The second is of hard, closely jointed and intimately fractured pre-Cambrian gneiss. No Paleozoic sedimentary rocks are known to occur in the project area. The materials to be encountered appear to have been thoroughly fractured and any handling found necessary in bringing down hazardous irregularities in slopes or in the leveling of the roadbed may be done by dozers or shovels equipped with 4-yd buckets with little or no secondary shooting.

A series of properly placed nuclear devices (Fig. 3) will produce a channel more or less parabolic in shape (Fig. 4) and reasonably free of cusps between the individual blasts. However, because some irregularities undoubtedly will occur, the bottom of the parabola is deliberately planned to be slightly below the proposed roadbed subgrade. This assures a minimum of excavation so as to avoid any possibility of removing the protective cover over radioactive debris and, at the same time, to provide additional width to receive rock falling from the slopes. Fill material required within the channel may be brought in from the ends or, where hauls would be excessive, it may be brought down over the side of the channel at intervals determined by balancing haul against the cost of moving a conveyor system or against the cleaning of the channel slope after pushing the material over the side.

One roadway of the divided freeway will be located along the bottom of the nuclear channel with the other roadway slightly higher on the northerly slope and with the railroad correspondingly higher along the southerly slope. Initial freeway construction will provide four traffic lanes (two in each direction), with room for ultimate expansion to a total of eight lanes with a standard width median.

The mathematics of magnitude of blast, spacing and depth of burial of the device, and depth and width of the resultant channel are more simple than might be expected, but a discussion is too involved for the purpose of this paper; however, the applicable equations have been graphed in Figure 5. Channel dimensions vary approximately with the $^{1}/_{3.4}$ power of yield and the following examples indicate the relative dimensions. The maximum device size proposed for this project will yield an energy release of 200 kt. If it were to be buried at optimum depth 675 ft below the surface of a basalt medium, it would produce a channel 370 ft deep and 1, 300 ft wide at the ground surface. Dimensions diminish with depth of burial either above or below optimum burial. As shown by the dashed line in Figure 5, the same device buried 825 ft below surface would produce a channel 300 ft deep and a width of 1, 100 ft. Other than to hold down radioactivity, there is no advantage in burials below optimum and drilling expenses are much higher. On the other hand, burials of less than optimum depth are objectionable because of the increase in release of radioactive materials. Until it becomes possible, however, to obtain devices having the exact yield desired, optimum burial will be rare because it will be necessary to employ the nearest but higher yield device and to bury it at whatever depth below optimum will produce the desired apparent crater depth. This problem will be resolved as use becomes more extensive.

In the event this project becomes a fact, 68 million cu yd of rock will be blasted from a channel 10, 940 ft long and having a maximum depth at center line of approximately 350 ft to the roadbed. A total of 22 nuclear devices will be used, ranging from 20- to 200-kt yield with a total yield of 1, 730 kt. Devices will be buried at depths

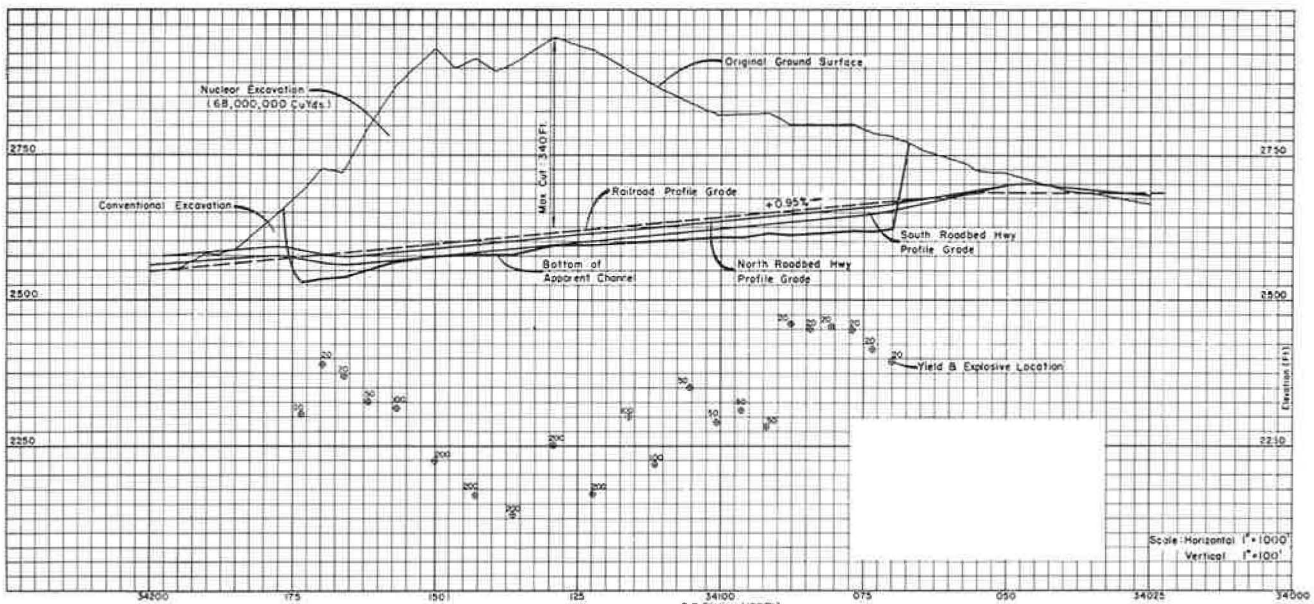

Figure 3. Excavation profile and nuclear explosive yields and locations for Project Carryall.

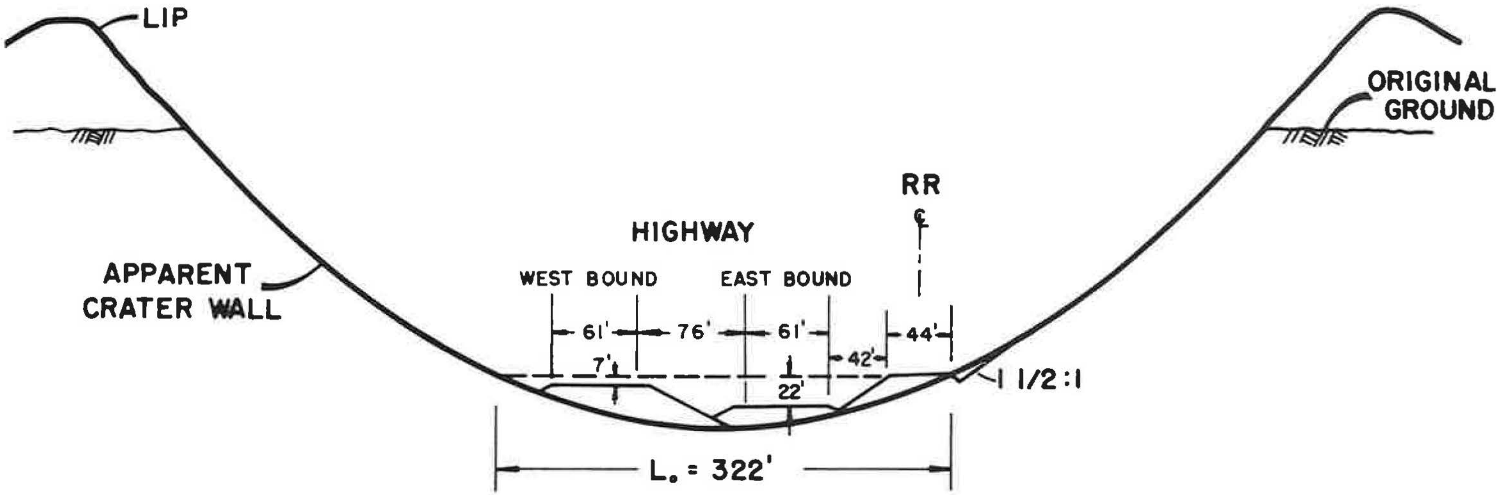

Figure 4. Typical cross section (50-kt crater) of roadway in nuclear excavation proposed for Project Carryall.

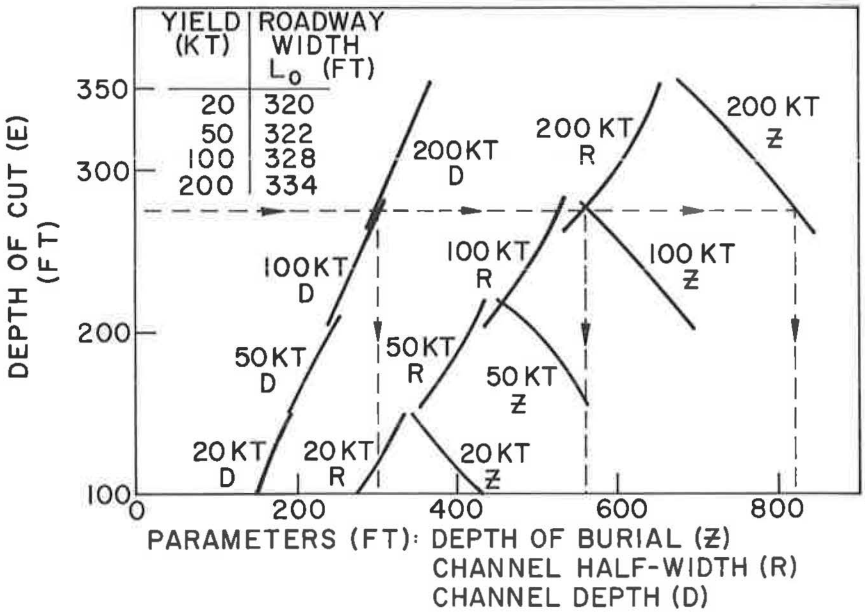

Figure 5. Cratering parameters for Project Carryall.

TABLE 1

EXPLOSIVE LOCATIONS AND CRATERING PARAMETERS OF PROJECT CARRYALL

STATION	DEPTH OF CUT E(ft)	EXPLOSIVE YIELD W(kt)	DEPTH OF BURIAL Z(ft)	CHANNEL HALF-WIDTH R(ft)	DEPTH OF CHANNEL D(ft)
34,070+00	110	20	388	290	158
073+32	120	20	372	303	168
076+83	138	20	352	325	183
080+49	142	20	348	329	185
084+16	142	20	348	329	185
087+87	150	20	343	335	192
091+90	172	50	538	383	208
096+23	184	50	517	402	220
100+61	178	50	527	394	213
105+19	202	50	485	424	236
110+32	232	100	645	481	263
115+93	262	100	588	520	292
122+25	310	200	764	608	338
129+27	340	200	705	645	361
136+23	300	200	783	596	328
143+01	316	200	753	616	342
150+01	338	200	710	641	360
156+79	280	100	555	535	309
161+78	210	50	467	430	245
166+02	140	20	350	327	183
169+72	150	20	343	335	192
173+26	114	20	382	297	162
CHANNEL TOTAL	—	1,730	11,263	—	—
ORANGE BLOSSOM CRATER	—	100	690	437	240
TOTAL	—	1,830	11,953	—	—

TOTAL LENGTH OF CHANNEL 10,940 FT
TOTAL DEPTH OF DRILL HOLES 11,953 FT

	YIELD	NO.	L_o(Ft.)
	200	5	334
	100	4	328
	50	5	322
	20	9	320
TOTAL	1,830	23	

varying from 343 to 783 ft. The total depth of holes for devices within the channel will be 11,263 ft (Table 1). In addition, a single 100-kt device will open a crater to intercept and to store water from a large shed, thus eliminating rather expensive bridge structures under the highway and the railroad.

A preliminary investigation of the nuclear construction site has yet to be made. As mentioned before, only a surface study has been made at this time and a thorough knowledge of the underlying materials is imperative, because the medium encountered will have a direct bearing on the depth of burial of the devices. The area has been severely disturbed by faulting and its materials, which may have been composed at one time of large relatively unbroken masses, have been reduced to comparatively small pieces which may be ejected without further breaking. Forces required to break large rock masses are greater than those required to dislodge interlocked rock of comparatively small sizes. In fact, as the rock sizes diminish, their resistance to ejection approaches that of a granular alluvium. It is, therefore, necessary to have a knowledge of the degree of fracture before the final yield and placement pattern can be determined. It is also necessary to know whether water will be encountered, because it will contribute to the energy release and could cause serious variations from the design channel. Aside from the effect of water on the blast, it should be determined whether the water is entrapped or is part of an underground supply serving inhabited areas.

Preliminary investigation will be followed by a more precise design of the device yields required and their spacing and depth of burial will be refined with respect to the findings of the preliminary investigation.

Unpaved access roads will be constructed, where necessary, between US 66 at Amboy to the site and along the proposed location of the holes for the devices. The access roads will eventually be used for transporting the devices to the holes, for transporting personnel, and will be constructed well enough to transport a large truck crane. Dips will be provided to handle the seldom seen flows in the dry washes typical of the area and gravel plating will be placed only where necessary.

On completion of the access roads, two mobile drill rigs with wire line coring equipment will be moved in to drill 3-in. exploratory holes and to take almost continuous 1 $\frac{7}{8}$-in. cores. Holes will be drilled in the exact location of the device holes and at least to their depth of burial. As cores are taken, comparison will be made with the information used in design and if serious differences occur, depth of burial will be changed accordingly, and possibly the distance to the next hole will be slightly changed. It is important that modifications be made as the exploratory holes are drilled in order to make certain that the device holes are centered on the exploratory holes. A 5-ft relocation of the device would necessitate the drilling of another 3-in. hole. Depths will range from 343 to 783 ft and 3-in. diameter holes may cost as much as $20 per ft so a hole lost could represent a $7,000 to $15,000 waste.

For the purpose of this study it was assumed that the placement of the nuclear devices require straight holes of a 30-in. inside diameter. The actual cost of the nuclear devices is classified information, but it is certain that it is too high to run any risk of jamming one in a hole above its designed depth of burial. To avoid this possibility, and because the rock is badly fractured in its natural state, the 3-in. exploratory holes will be used to pressure grout the entire depth of the hole. The grout should extend as much as 5 ft laterally to make a solid mass of the surrounding fractured rock and thus prevent pieces from dislodging and jamming the drilling equipment. Thirty-six-in. holes will be drilled by heavy duty, tractor mounted, rotary drills drilling a 12 $\frac{1}{2}$-in. pilot hole, making a 22-in. diameter reaming, a 30-in. reaming, and finally a 36-in. reaming. Anticipated progress per hour is 5 ft for the pilot hole, 5 ft, 4 ft, and 3 ft, respectively, for the reaming. The total cost per foot has been estimated by a responsible drilling company at $115 per ft. This figure appears to be low in view of past experience, but it has been very closely supported by an estimate made by a second and equally responsible company.

There is a remote possibility that the walls of the holes will be sufficiently stabilized to permit the lowering of the nuclear devices without having them jammed by dislodged rock, but it is felt to be good insurance to incase the holes with 30-in. 12-gage corrugated metal pipe made up in 30- or 40-ft lengths welded at the joints. This is a considerably lighter gage than has been used in the past but inasmuch as this installation will not be called on to withstand forces other than its own suspended weight, it should be adequate.

It is most fortunate that the site is in an area almost entirely owned by the Federal Government and that no active improvements are in existence in the immediate area. A few mining claims are in evidence, but apparently they are not being worked. The land was used for grazing but, due to scarcity of feed, all cattle have been removed. Neither procurement of right-of-way nor property damage should pose a serious problem.

The realization of this project will mark a tremendous step forward in construction. The knowledge gained from this experience will pave the way to greater economies in the manufacture of nuclear devices, their on-site assembly, and drilling of the holes to receive them. Smaller diameter devices requiring smaller holes might well result. Certainly, even better channel dimension control will be possible. Projects, of marginal value using conventional or even today's nuclear methods, may become possible as a result of this venture.