Operations and Safety Problems Associated With a Nuclear Excavation Project

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Operational activities normally required for the conduct of nuclear explosions include such activities as pre-shot safety studies, emplacement and firing of the nuclear charges, shot time safety and control, and post-shot safety measures. For safety, engineering, and scientific reasons, the 22 nuclear explosives required for Project Carryall will be fired in two stages. When safety permits after the detonations, the site will be returned to highway and railroad engineers for roadway construction.

Safety hazards such as radioactivity, fallout, air blast, and ground shock have been thoroughly evaluated on the basis of past experience with nuclear cratering explosions and present knowledge of the Carryall area. These evaluations have shown no hazard great enough to cause significant structural damage or endanger local inhabitants. Initial site investigations will be directed toward a better definition of these problems and a more detailed description of the geology of the area.

The present Plowshare experimental program will provide additional data for the conduct and design of nuclear excavation projects such as Carryall. The time schedule for the project is compatible with the Interstate Highway completion schedule, the interests of the Santa Fe Railway Company, and the present experimental schedule of the Plowshare program.

•**THE PURPOSE** of this paper is to describe the operations and safety problems associated with a nuclear excavation project. The responsibility for operational activities required for the conduct of nuclear explosions rests with the Atomic Energy Commission and its contractors. The Atomic Energy Commission is responsible for public safety, both on site and off site, prior to, during and after a nuclear detonation.

The Carryall study is used to illustrate these problems and to suggest methods for their solution.

PRE-SHOT SAFETY STUDIES

Hydrological

Depending on the results of preliminary groundwater studies, a limited hydrological investigation may be conducted to assess the potential hazard from the possibility of groundwater contamination from fission products and/or induced radioactivity. This will probably be accomplished by continuous observations of groundwater flow rates in one or more existing water wells or exploratory bore holes in the vicinity of the experimental area. From these observations, the flow or migration rate of activities in groundwater supplies may be evaluated.

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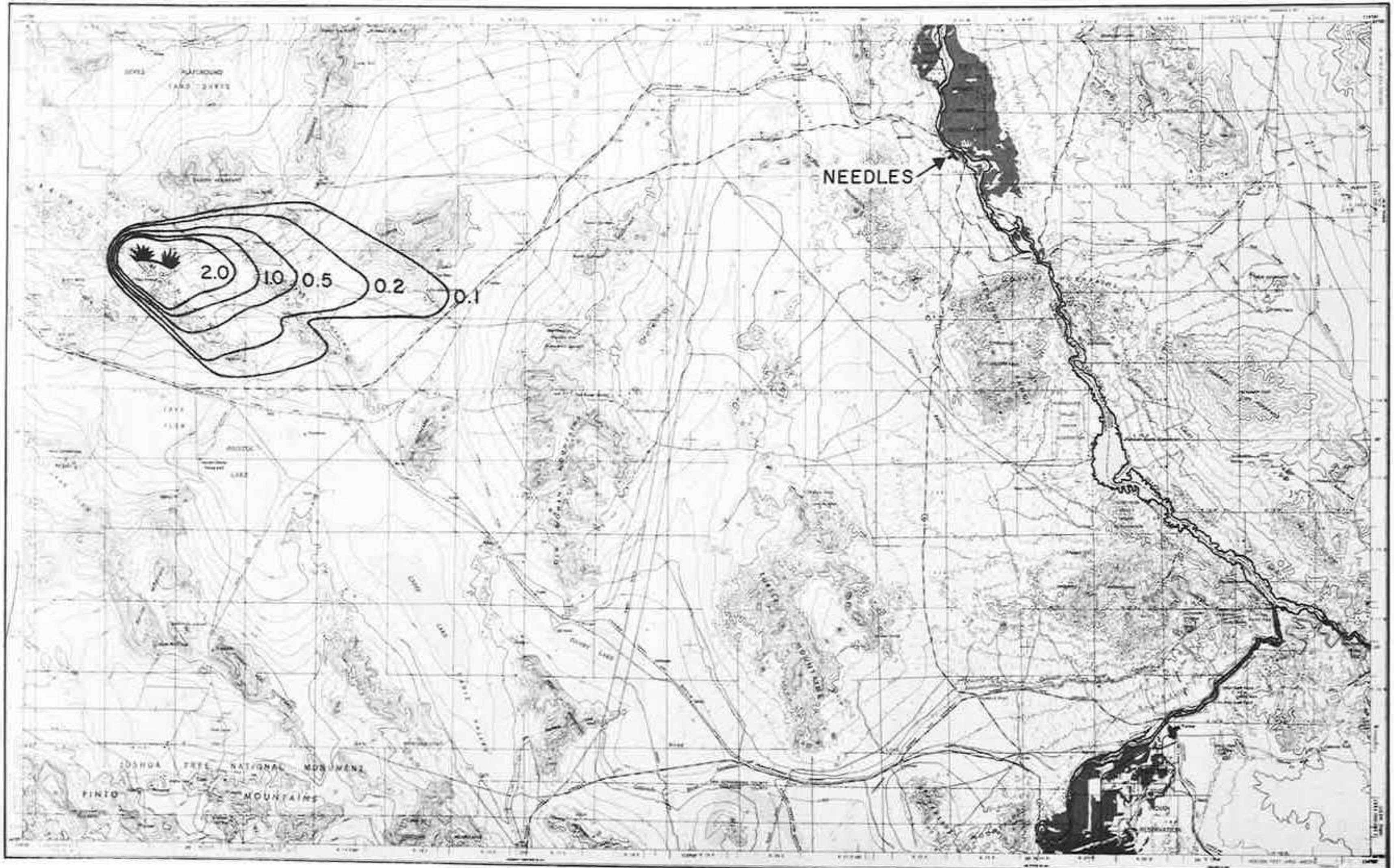

Figure 1. Fallout pattern for Project Carryall; isodose contours showing infinite dose from time of arrival in roentgens (r).

situation at shot time, a predicted fallout pattern can be calculated. In practice, to assure complete radiological safety, the shot time will be delayed until weather conditions are such that the predicted fallout pattern will not fall on an inhabited area.

Because there is a large number of "acceptable" meteorological situations, and there is no way of knowing what exact meteorological conditions will exist at shot time, two sets of winds typical for this area for the months of February and April have been used to calculate two fallout patterns, one for each detonation, using nuclear devices anticipated to be available on the Carryall time schedule. These two fallout patterns are shown superimposed on a map of the general area east of the site (Fig. 1). Shown are the infinite dose contours corresponding to the dose a person would receive if he resided at any particular place in the pattern at the time of arrival of the fallout and continuously thereafter. Experience has shown that the actual dose experienced by people averages about one half of these infinite dose numbers. Some individuals experience doses less than one half of the infinite dose, whereas a few experience doses close to the infinite dose number. If residents were evacuated for 24 hr, these infinite doses would be reduced by a factor greater than 2.

These infinite dose numbers can be compared with the Federal Radiation Council's (FRC) recommended radiation guides for individuals of 0.5 r/yr for continuous exposure. Technically, the FRC guides are in terms of rem (roentgen-equivalent-man), but for purposes of this paper this is essentially equivalent to r (roentgens). Using the 0.5 r figure, approximately 100 sq mi would require evacuation or temporary closure. The latest census data available indicate no permanent residences in the fallout area delineated inside the 0.5-r isodose line (Fig. 1).

On-Site Fallout

Based on the Sedan experience, an estimate has been made of the time when re-entry into the channel area will be permissible. This indicates that, with proper radiation protection precautions, access to the channel for limited periods of time for inspection purposes will be possible within a few days. Entry for an 8-hr workday or 40-hr workweek without unusual safeguards will be possible within a few weeks.

In all cases extensive post-shot surveys to determine the general radiation levels in the channel area, as well as to locate any "hot spots" with unusually high activity, will be made before any re-entry is permitted. Some monitoring will also be required throughout the post-shot construction phase to assure continuing safe working conditions.

AIR BLAST

Close-In Air Blast

The major problem associated with close-in air blast is related to the town of Amboy located approximately 11 mi from the detonation area in a south-southeasterly direction. Figure 2 is an aereal picture of the community of Amboy. An estimate of the air-blast hazard to Amboy has been made utilizing the data from the 0.42-kt Danny Boy event, a nuclear-cratering experiment in hard, dry basalt. An upper limit on the air-blast overpressures from a row of charges can be calculated by assuming that the air-blast waves from each explosion travel independently and are superimposed at any point of interest. Such a procedure gives a prediction for the maximum possible overpressure at Amboy of 4.3 mbars for the simultaneous detonation of the charges on the east end. The procedure is felt to be very conservative because, in reality, differing travel paths will spread the arrival times of the various waves and result in a composite pulse of longer duration but of smaller peak amplitude than direct superposition. A lower limit on the air blast can be calculated by assuming all explosions act as a single source. This will result in a peak overpressure at Amboy of 0.9 mbars. Such a range of overpressures is not expected to cause damage in a community such as Amboy, where the threshold of damage is estimated to be 10 mbars. Because Amboy is the closest community to the site and no damage is expected there, damage is not expected due to close-in air blast to any other community in the Mojave Desert area.

excavate the entire channel with one detonation. However, for the purpose of this study, excavation by two separate detonations has been used. This could be done either by excavating the central portion first, and then both ends, or one half first, and then the other half. The latter procedure has been used for evaluation of safety and nuclear operations. The final division will be made on the basis of safety requirements and the most economical engineering considerations.

Although two detonations will increase costs and time, there are several advantages in this method. Air blast and seismic shock will be significantly reduced. The maximum dose and dose rate from fallout will be cut approximately in half. Also, if two detonations are used, the channel parameters can be checked after the first detonation. This will allow any inaccuracies to be corrected in the second detonation, insuring that the channel parameters will be close to the required results. In addition, the development of nuclear excavation technology will greatly benefit by the experience of excavating a channel adjacent to an existing excavation. The ability of existing emplacement holes to hold their integrity in the vicinity of the detonation is of considerable interest. These experimental objectives can be carried out with a minimum of expenditure during this project.

Use of the three or more detonations would not significantly reduce the safety problems below their level for two detonations and would further increase time and cost. In addition, as the number of charges in a row detonation decreases below five, the row-charge effects decrease.

NUCLEAR EXPLOSIVE COSTS

The presently available schedule of charges for nuclear explosives includes such items as special materials procurement, fabrication costs, device transportation and assembly, security, emplacement, timing and firing, and safety studies. Further, these charges were predicted on the assumption of amortizing these costs over a single detonation with the statement that, "if a number of assemblies were fired in the same location, ... the ... charge per unit would be substantially reduced." In addition, in a January 1963 publication, the AEC stated:

> The single most important research advance in the Plowshare Program resulted from studies of cheaper explosives designed to produce a minimum of radioactivity....The amount charged for nuclear explosives should be considerably less in the future than the presently published estimates.

Because of these uncertainties regarding the applicability of the published charges for nuclear explosives, they have not been used in this report. Instead, the costs for device transportation and assembly, emplacement, security, timing and firing, and safety studies have been separately estimated. The cost of special material procurement and device fabrication is classified and cannot be included in this report.

SAFETY PROBLEMS

The safety problems associated with Project Carryall fall into three general categories: radioactivity release, air blast, and ground shock. Past nuclear cratering detonations have given a body of experience which can be used to evaluate generally the extent of these hazards as they relate to the specific environment to be encountered in Carryall.

Relative to off-site fallout, the cloud resulting from each of the two row detonations will be cylindrical in shape, about 12,000 ft high, and about 7 mi in diameter. The density of dust in this cloud may be such as to obscure vision during its passage within the first 100 mi. Whereas radioactivity levels in the cloud at about 100 mi do not present a hazard, it may be necessary because of reduced visibility to close highways until the cloud has passed.

Using these cloud dimensions, the total fission yield of the nuclear explosives, the fraction of the fission activity escaping to the atmosphere, and the meteorological

Air Blast

Direct and long-range air-blast studies will be conducted to predict the blast effects on existing culture in the vicinity of the experimental area and out to ranges within the possible threshold of damage. This study will include a meteorological investigation to determine under what weather conditions focusing of air-blast effects will restrict the time of the detonations.

Ground Shock

A ground shock and seismic study related to the experimental area will be made to determine the largest total detonation that can be safely fired. This study will include a detailed survey of existing structures in the area determined from the seismic studies to fall within the threshold of damage and an assessment of the damage that might be expected to these structures.

OPERATIONAL PHASE

The conduct of the operational phase of the nuclear excavation and the specifications for construction and logistics in support thereof will be under the control of the Atomic Energy Commission and the Lawrence Radiation Laboratory. Preceding this phase of the project, it is now anticipated that all initial construction and support features such as emplacement holes and roads will have been completed. It is assumed that the excavation will be accomplished by two detonations, each consisting of about 11 nuclear devices fired simultaneously.

The AEC, through its contractors, will be responsible for the emplacement of the nuclear explosives. Several device teams will be employed to achieve an emplacement time of 7 days. Before each detonation, all systems and equipment will be thoroughly checked by scheduled dry runs.

An area isolated from other activities will be provided for device storage and assembly. Earth-covered storage igloos will be constructed for device component storage. The entire assembly area will be enclosed as a security compound, with a guard station at the entrance gate.

Shot-Time Safety

Specific shot-time safety procedures will include briefings on weather information continuously collected by the U. S. Weather Bureau. This information will contain on-site and national weather forecasts. The decision to proceed with the detonations will be made by the Project Manager based on weather predictions and the recommendations of his meteorological, air blast, and radiological advisors.

Highways, railroads, and air corridors within 50 to 100 mi downwind from the excavation site will be closed for a matter of hours. All roads leading to the site will be closed. FAA will be alerted to the detonations in order to temporarily close air lanes downwind to protect aircraft from any possible air blast, dust and radioactivity.

The AEC will continue to exercise its safety responsibilities after the detonations until such time as the area is safe for re-entry and commencement of mechanical earthwork operations.

Shortly after the detonation, radiation levels in the region of the detonation will be determined by crews of ground monitors. The Project Manager will evaluate the data and determine when radioactivity has decayed sufficiently for work crews to enter the excavation. Appropriately instrumented aircraft will track the direction of the cloud and conduct aerial surveys of the fallout area. Aerial photographs of the excavation will also be taken at such time as dust conditions permit. At strategic locations around and downwind from the detonation, manned and unmanned stations will be established to record air blast, seismic intensity and fallout distribution. When the Project Manager has deemed certain areas safe for public travel, they will be immediately opened.

The number and yield of devices to be detonated simultaneously will depend on the safety requirements associated with the area. The most economical solution is to

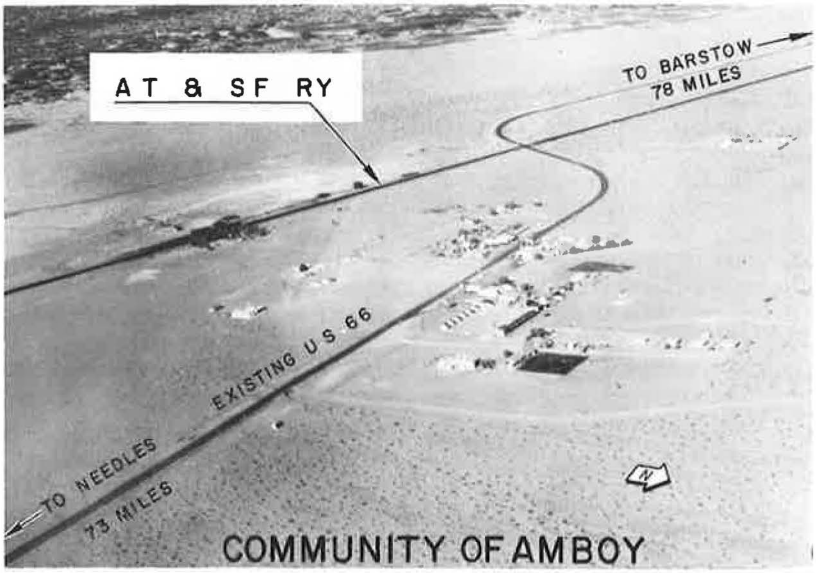

Figure 2. Amboy, showing US 66 and the Atchison, Topeka, and Santa Fe railroad line.

Present knowledge of the hydrology in the area of the proposed cut indicates that the detonation will take place in dry environment. Because of the dry nature of the medium, it is felt that the use of Danny Boy data will give the best estimate of expected blast results. However, it should be borne in mind that if the water content of the shot environment is significantly higher, as in the Sedan event, close-in and long-range air blasts will be increased. Experiments with both high explosives and nuclear explosives have indicated that the venting of a large volume of gas in the course of a cratering explosion results in the generation of an air-blast pulse considerably larger than that associated with the first motion of the ground. Thus, if an estimate of air-blast damage for Project Carryall is made based on the Sedan event results, overpressures a factor of 10 to 20 times larger than those previously used will be expected with a significant increase in the possibility of air-blast damage.

More detailed knowledge of the hydrology of the area and further study of the mechanics of air-blast generation and transmission on future nuclear cratering experiments will give data on which a final estimate of the probability of air-blast damage can be made.

Long-Range Air Blast

The Danny Boy results for long-range air blast have been used to predict that from Project Carryall. Superposition of all air-blast waves from one half of the array will result in an upper limit on the long-range air blast of 2.8 mbars. A lower limit, calculated by assuming all explosions behaved as a single source, results in an estimate of 0.65 mbars. Overpressures of 0.65 to 2.8 mbars may be expected between 100 to 150 mi. Thus, the probability of damage from long-range air blasts does not appear to be significant.

The comments relating to the importance of the water content of the medium on close-in blast apply in approximately the same proportion to long-range air blasts.

GROUND SHOCK

The maximum possible ground shock that may be experienced by the community of Amboy, calculated by assuming superposition of the seismic waves from each explosion, gives an upper limit on the predicted velocity of approximately 10 cm/sec.

Assuming all explosions acted as a single source the maximum velocity expected at Amboy will be approximately 6 cm/sec. The actual seismic shock at Amboy may be expected to lie within these two limits. The estimated threshold of damage for residences at Amboy is 8 cm/sec. Thus, it is possible that minor damage, such as cracked plaster, might occur at Amboy, but no large-scale damage is expected.

These ground-shock estimates are based on the assumption of no amplification by a deep alluvial deposit. If subsequent information discloses a much deeper alluvium, significantly higher ground shock intensities than shown here could be expected. As additional help in evaluating this aspect of the ground-shock problem, instrumentation will be included on future nuclear-cratering experiments to study amplification by deep alluvial deposits of ground shock from nuclear detonations.

A separate problem with respect to ground shock associated with this project relates to a high-pressure gas line owned by the Southern California Gas Company which passes approximately 2 ½ mi south of the proposed cut (Fig. 2, 1). This line is buried for most of its length but does include approximately 16 unsupported spans of between 30 and 70 ft. The gas line is a 30-in.-diameter ⅜-in.-sidewall steel pipe with an operating pressure of 900 psi. This pipe will, of course, experience ground shock in excess of that estimated for Amboy. Experience has shown that buried pipes are extremely invulnerable to shock and damage and none is expected in this project. The possibility of damage to the long unsupported spans of the pipeline, however, represents an area of greater concern. Preliminary analysis of the problem indicates that measures can be taken to render the probability of damage very low. Experiments with both buried and suspended pipe on future excavation experiments are planned to better evaluate the possibility of damage to this gas line.

Some pertinent information on the ability of gas lines of this nature to withstand shock loading has come from the Pacific Gas and Electric Company. They have a 34-in. high-pressure buried gas line similar to the one in question here, which crosses the White Wolf Fault between Arvin and Tehachapi, Calif. During the Tehachapi Earthquake in 1952, this fault experienced a vertical motion of approximately 2 ft in the area where the gas line crossed the fault. However, no disruption of service, damage to the line, or subsequent deterioration to the line was experienced.

DUST, ROCKS, AND EJECTA

The hazard from dust, rock, and ejecta from an excavation such as Project Carryall is limited principally to areas in the immediate vicinity of the site. The area covered by the base surge, approximately 7 mi wide extending for the length of the cut, will be covered with a coating of fine dust. Occasional rock missiles will be experienced at distances of 4,000 ft from the center line of the cut. The principal mass of the ejecta, however, will be confined to an area extending from the lip of the crater a distance approximately equal to the width of the cut. The areas involved in the mass of ejecta are shown in Figure 3. Beyond this distance, only dust coverage and isolated missiles are expected.

TIME SCHEDULE

The time schedule for Carryall must be adjusted to the construction requirements of the Santa Fe and the Division of Highways. Because the railway has no set construction schedule, the Interstate Highway schedule becomes the critical factor in determining the time schedule for the project.

A proposed time schedule for Project Carryall and Project Gally is shown in Figure 4. Project Galley is a nuclear-excavation experiment using row charges through varying terrain and will insure the proper parameters for Carryall. Other nuclear experiments are also planned. If Carryall is initiated, the study group foresees a schedule of approximately 5 ½ yr for its completion. Investigations and engineering design could begin in 1964, major pre-shot construction in 1965, and the nuclear operations in 1966. The remaining time would be required for post-shot surveys, design, grading and construction of the railroad and highway, with the pass open

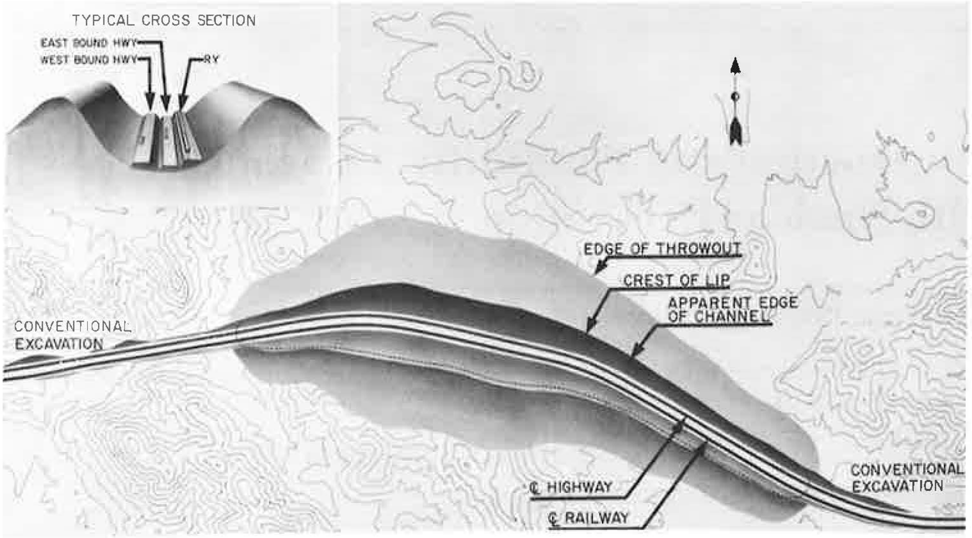

Figure 3. Plan view of the proposed Carryall excavation, showing throwout distribution.

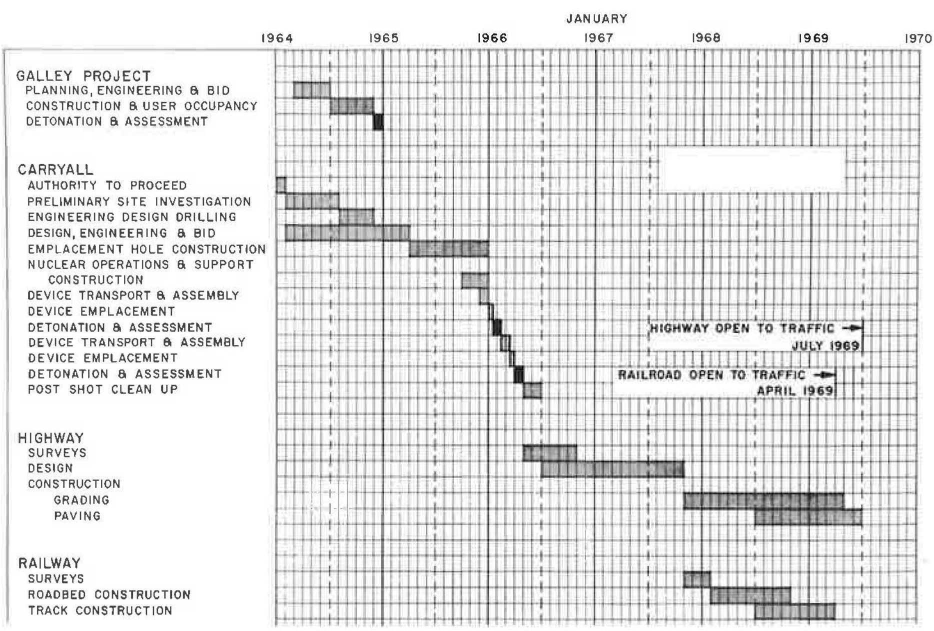

Figure 4. Proposed Carryall time schedule.

to traffic possibly in 1969. This study is only one of feasibility. There is no proposal at this time for undertaking such a project. The time schedule given, therefore, is illustrative.

REFERENCE

1. Fry, J. G., Stane, R. A., and Crutchfield, W. H., Jr., "Preliminary Design Studies in a Nuclear Excavation—Project Carryall." HRB Highway Res. Record 50, pp. 32-39 (1964).