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DEFENSE ATOMIC SUPPORT AGENCY  
Office of the Deputy Chief of Staff, Research and Development  
SANDIA BASE, ALBUQUERQUE, NEW MEXICO

25705

PEACEFUL USES OF NUCLEAR EXPLOSIVES (U)

PROJECT FLOWSHARE

1. September 1959

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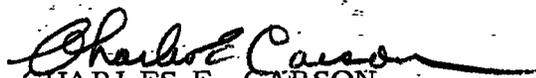
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## PUBLICATION REVIEW

Commander, Field Command, DASA, has reviewed this report and approves its publication. The information contained herein has been obtained from liaison with the laboratories and from their publications; however, the verbatim report has not been reviewed nor concurred in by them. The report is current as of the date of publication but should be used with caution as the program is changing continually.

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CHARLES E. CARSON  
Colonel USAF  
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## I. INTRODUCTION

### A. PLOWSHARE DEFINED

1. The possibility of non-military use of NE has been discussed ever since the detonation of the first nuclear device. The PLOWSHARE program is the study of the industrial and other peaceful uses of nuclear explosives (NE).

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2. In February 1957, the first symposium on the Industrial Uses of Nuclear Explosives was held at the University of California Lawrence Radiation Laboratory (LRL). This symposium resulted in the establishment of Project PLOWSHARE. Theoretical studies soon showed that several projects involving the use of NE appear feasible with marked reductions in cost--by factors up to several hundred. With these encouraging preliminary findings, LRL began more detailed analyses of specific projects. In outline form these projects are:

#### Excavation

- Cratering Experiment - OXCART
- Harbors - CHARIOT
- Canals - Isthmian Canal

#### Power and Isotope Production - GNOME

#### Oil Production

- Oil Sands - CAULDRON
- Oil Shale - VINTAGE

#### Improving Underground Storage of Water - AQUIFER

#### Miscellaneous Industrial Projects

#### Scientific Experiments

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### B. UNDERGROUND DETONATIONS

1. The weapon tests of primary interest to the PLOWSHARE program are those detonations that took place underground. There have been nine underground nuclear explosions detonated by the U. S.

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These shots are shown in Table I. In addition to these nuclear detonations, several series of tests with HE have been conducted at Dugway Proving Grounds and the Nevada Test Site. As a result of the NE and HE tests, data were obtained concerning cratering and containment.

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2. The data relating depth of burst to apparent crater depth and radius are shown in Figure 1. Comparing the results of the nuclear explosions that produced craters with the mean of the HE results in the Nevada alluvium, leads to the approximation that the radius of a crater produced by NE is 80%, and the depth 90%, of that for an HE explosion of the same TNT equivalent energy release.\* The results from the test in the Nevada alluvium can be related to other media. Table II shows the expected crater dimensions in various media for a 1 KT nuclear explosion at two depths of burial, 63 feet ( $\lambda^{**} = 0.5$ ) and 200 feet ( $\lambda = 1.6$ ). For scaling to larger

\* Relative cratering efficiency of NE and HE may be compared in many ways. For this definition of cratering efficiency - same energy release - the efficiency has been observed to vary from 35% - 74% for radii of crater and from 51% to 97% for depth. Cratering efficiency varies with depth of burst and these numbers quoted are probably close to the maximum efficiencies - those observed at  $\lambda = .12$  for the Jangle-U shot.

\*\* 
$$\lambda (\text{lambda}) = \frac{\text{actual depth of burial (ft)}}{\text{Yield}^{1/3} (\text{lbs.})} ; \quad \text{Scaled Depth} = \frac{\text{actual depth of burial (ft)}}{\text{Yield}^{1/3} (\text{KT})}$$

A Scaled Depth of 126 feet (dimensions  $\frac{\text{ft}}{\text{KT}^{1/3}}$ ) corresponds to

$$\lambda = 1 \text{ (dimensions } \frac{\text{ft}}{\text{lbs.}^{1/3}})$$

Note the difference of units between  $\lambda$  and the Scaled Depth. These definitions will be used throughout this report, even though some papers refer to  $\lambda$  as the Scaled Depth.

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yields, it is believed that the radius of the crater is proportional to the third root of the yield ( $W^{1/3}$ ) and the depth of the crater is proportional to the fourth root of the yield ( $W^{1/4}$ ). These scaling laws are subject to some uncertainty and must be confirmed by further tests.

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3. On the subject of containment, it is believed that in the kiloton region and above, complete containment of all radioactive debris can be expected for scaled depths of  $450 W^{1/3}$  feet ( $\lambda = 3.57$ ). At a scaled depth of  $290 W^{1/3}$  feet ( $\lambda = 2.3$ ) only 0.1% of the debris escapes. These depths of burst are considerably greater than those for maximum crater volume.

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4. As shown in Table I it is possible, by varying the depth of burst, to exercise some control over the amount of radioactivity that is introduced into the biosphere. In addition, by designing devices which derive the majority of their energy from the fusion reaction, one can reduce the amount of radioactive fission debris produced. However, the fusion reaction produces large numbers of neutrons which can make most substances radioactive. These neutrons can be absorbed by certain elements--such as boron--without producing radioactivity. Thus, by surrounding the fusion explosives with a neutron absorbing blanket, the radiological effects can be reduced to acceptable levels.

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5. It has been publicly announced that at the present time a fusion reaction can be produced only by using the fission process. For explosives in the megaton range, about 5 per cent of the energy release must come from fission. Consequently, to assure public safety one must control the fusion neutrons and the fission products. Studies are continuing at the Atomic Energy Commission (AEC) laboratories to develop nuclear explosives which will be "cleaner," i. e., explosives with lower percentages of their energy derived from the fission process. (See Section III)

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DATA ON UNDERGROUND NUCLEAR EXPLOSIVES

TABLE I.

Event	Yield (W) KT	Depth (D) Ft.	Scaled Depth $\frac{D}{W^{1/3}}$ Ft./KT <sup>1/3</sup>	Radioactivity Escape %	Crater Volume Yd <sup>3</sup>	Crater Volume Yd <sup>3</sup> /KT
JANGLE-ESS	1.2 <sub>-0.05</sub>	-3.5*	-3.3*	>50	165	140
JANGLE-U	1.2 <sub>-0.05</sub>	17	16	>50	37,000	31,000
TEAPOT-ESS	1.2 <sub>-0.05</sub>	67	63	50	96,000	80,000
**NEPTUNE	.09 <sub>+0.015</sub>	99	220	1-2	33,000	370,000
BLANCA	19 <sub>+1.5</sub>	835	290	0.1-0.2	-CONTAINED-	
LOGAN	5.0 <sub>+0.2</sub> <sub>-0.4</sub>	830	500	0	"	
RAINIER	1.7 <sub>+0.05</sub>	790	670	0	"	
TAMALPAIS	.072 <sub>+0.01</sub>	330	840	0***	"	
EVANS	.055 <sub>+0.03</sub>	840	2260	0***	"	
MARS	.013 <sub>+0.003</sub>	90	380	0	"	

\* 3.5 Feet above surface (included for comparison).

\*\* Shots NEPTUNE thru MARS were in tunnels in a volcanic tuff medium as opposed to the alluvial medium of the first three listed. Depth stipulated for these shots is nearest distance from detonation point to ground zero.

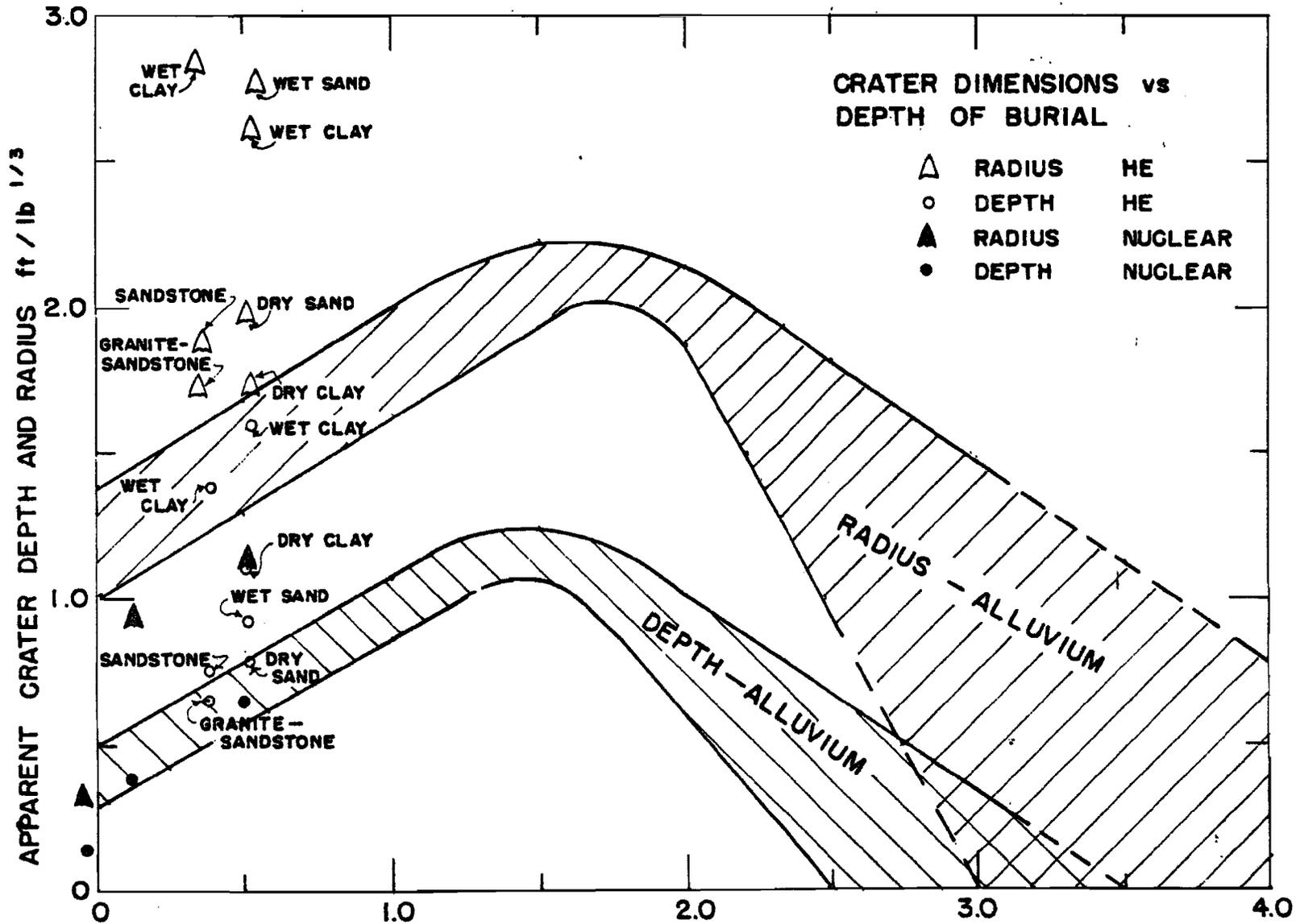
\*\*\* No breakthrough to surface but radioactive Xe and Kr in large quantities leaked into the tunnel.

\*\*\*\* No breakthrough to surface but stemming failed, releasing gross fission activity into the tunnel.

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FIG 1

APPARENT CRATER DEPTH AND RADIUS VS  $\lambda$



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TABLE II

Expected Crater Dimensions for 1 KT  
Nuclear Explosions in Various Media

	<u>RADIUS (feet)</u>		
	<u>Depth = 63'</u>	<u>Ratio to Nevada</u>	<u>Depth = 200'</u>
Nevada Alluvium	135	1.0	210
Sandstone	205	1.5	320
Dry Sand	198	1.5	310
Granite-Limestone	187	1.4	290
Dry Clay	175	1.3	275
Wet Clay	290	2.1	450
	<u>DEPTH (feet)</u>		
Nevada Alluvium	82	1.0	126
Sandstone	97	1.18	150
Dry Sand	97	1.18	150
Granite-Limestone	83	1.0	128
Dry Clay	122	1.5	188
Wet Clay	165	2.0	255
	<u>VOLUME (Yd<sup>3</sup>/KT)</u>		
	Volume = $1/2 \pi R^2 D$ *		
Nevada Alluvium	88,000	1.0	320,000
Sandstone	240,000	2.7	920,000
Dry Sand	220,000	2.5	830,000
Granite-Limestone	168,000	1.9	625,000
Dry Clay	220,000	2.5	830,000
Wet Clay	800,000	9.0	3,000,000

(UICL)

\* Volume of paraboloid of revolution used as an approximation due to lack of detailed knowledge.

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## II. PROJECTS

### A. OXCART

1. The cratering capabilities of nuclear explosives are known for some conditions. However, the largest yield used in a cratering shot was 1.2 KT. For harbor and canal excavation, detonations up to the megaton range are required. To provide the additional data required, LRL has proposed two experiments in the excavation field--OXCART and CHARIOT. (UNCL)

2. Project OXCART is an experiment designed to study the phenomenology of nuclear cratering detonations. The present plan is to detonate two 2.5 KT devices in the alluvium of Area 10 at the Nevada Test Site (NTS). The first detonation will be at a depth of 400 feet (scaled depth of 300 feet) and the second shot at 275 feet (scaled depth of 200 feet). Both devices will be placed in 36-inch cased holes which will be plugged with a lead shot shield weighing approximately 2,500 pounds and with 50 feet of high density drilling fluid. The location was selected because the geological conditions will be identical with those of the TEAPOT-ESS and BUSTER-JANGLE underground detonations. Both detonations will produce craters, but it is anticipated that most of the radioactive debris will be trapped. Design and specifications are being prepared for the device shaft and related experiments. Invitations for bids on the major portion of the construction can be released immediately upon receipt of authorization to proceed with site preparation. (~~CONF~~)

3. On 10 March 1959, the Atomic Energy Commission gave approval for the Director of Military Application (DMA) to proceed with the planning and preparation to fire two low yield cratering shots at NTS. By teletype dated 13 March 1959, DMA gave the San Francisco Operations Office of the AEC (SAN) approval to proceed with OXCART planning with the provision that after the completion

of the general plan further approval must be obtained from DMA to commit funds for major expenditures or solicit bids for excavation or construction. The general plan is being prepared by SAN, and it is expected that the completed plan will be forwarded to DMA by September 1959.

~~(CONF)~~

4. The major elements of data that are planned to be obtained from OXCART are:

- a. Crater dimensions.
- b. Surface motion and permanent displacement due to underground nuclear explosions.
- c. Containment and distribution of radioactive debris.
- d. Long range and close in blast measurements.
- e. Close in shock time of arrival measurements.

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5. The predicted depths and diameters of craters from deeply buried (greater than 100 feet scaled depth) detonations as given in TM 23-200, "Capabilities of Atomic Weapons," are based entirely on data from high-explosive tests and theory. They are likely to be conservative; that is, they lean to the low side of the range of uncertainty. There is a strong probability, supported by the NEPTUNE shot, that dimensions for the OXCART events will be appreciably larger than indicated by TM 23-200. The following dimensions are modifications of TM 23-200 predictions based in part on NEPTUNE and in part on theoretical considerations:

	2.5 KT at 400 Feet	2.5 KT at 275 Feet
Crater depth	13 ft $\pm$ 13 ft	65 ft $\pm$ 20 ft
Crater diameter	236 ft $\pm$ 80 ft	420 ft $\pm$ 80 ft
Crater volume	0 - 38,000 cu. yds.	76,000 - 310,000 cu. yds.
Fallout fraction		
Max.	2%	6%
Min.	0%	1%
Expected	0.05%	2%

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[REDACTED]

6. Major factors influencing the initiation and completion of Project OXCART are:

a. DMA Policy Considerations:

(1) DMA stipulates that detonation may not occur until after 1 November 1959.

(2) Prior to making any major expenditures for site or device preparation, DMA will be informed of all applicable factors, permitting DMA to decide whether preparations should go forward.

(3) Existing operational criteria, as established by the AEC, limit the yield of surface or cratering shots to 1 KT. Approval for increased yields would require further Commission review and approval of the higher yields anticipated for OXCART.

b. Construction Considerations:

(1) Utilization of a cost plus fixed fee (CPFF) contractor on an accelerated schedule will require 56 days to complete construction; while utilization of a lump sum contractor involving a normal bid period, award action, etc. will require an estimated 81 working days from date of authorization.

(2) The use of a lump sum contractor plus a provision of 30 days user occupancy, requires a minimum four months from authorization to proceed to detonation day.

c. Weather Considerations:

(1) Weather during the late fall and early winter provides an average of two or three days each month with acceptable winds.

(2) With normal wind and stability conditions, the extent of the 0.5 roentgen estimated dose line would be between 25 and 50 miles. There is a fair possibility that an even greater part of the radioactivity will remain in or very near the crater than is the case for shallow bursts, in which case the extent of the 0.5 roentgen line would be still less.

[REDACTED]

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(3) For both shots, there may be a fairly long wait for acceptable winds, if a narrow (30 degree) sector towards the northeast is considered the most desirable.

d. Weapons Test Considerations: Interference with a possible weapons test series apparently would not be of such magnitude as to create undue difficulty. Integration of OXCART into a full-scale test series would be operationally feasible from a support standpoint.

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7. In conjunction with OXCART two special projects relating to public safety are planned.

a. Blast Project: A technical proposal has been prepared by the Sandia Corporation for microbarographic and detailed tower meteorological measurements necessary to establish attenuation constants. Off-site microbarographic recordings from Operation TEAPOT, ESS shot, showed pressure amplitudes in the same range as have been recorded from similar yields fired above ground. If an attenuation due to burial did exist, its effect was lost among the other uncertainties in long range prediction. At some depth, attenuation must become totally effective. The purpose of this proposal is to determine if PLOWSHARE cratering depths result in an appreciably decreased off-site noise. The results obtained will directly affect plans for other PLOWSHARE events.

b. Animal Investigation Project: An animal investigation project of a continuing nature is underway in the area surrounding the NTS. The objective is to provide information as to the level of internal radioisotopes that accumulate in grazing animals ingesting fallout under range conditions. The project serves to enhance the NTS-rancher relationships and provides information as to the status of animals in their environment with special emphasis on the radioactivity from fallout. No expansion

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of the program is planned for Project OXCART. No cost to OXCART is involved. ~~(ONE)~~

8. The total cost of Project OXCART, excluding the charges of the nuclear devices, will be approximately \$1,240,000. ~~(ONE)~~

B. CHARIOT

1. The purpose of Project CHARIOT is to investigate technical problems fundamental to excavation by the use of nuclear explosives and to create a usable harbor on the coast of Alaska near Cape Thompson (see Figure 2). In considering the possible sites for conducting the CHARIOT experiment, early in 1958 it was decided to focus attention on a stretch of Alaskan coast extending from the vicinity of Nome to Point Barrow, an area in which no harbors exist and also an area of low population density. Before selecting a specific site, LRL commissioned the E. J. Longyear Company to make an economic study to determine the long term potential of the area and also, to specify the required size of harbor to support exploitation of the area's resources or other development. The study resulted in the selection of two sites--one in the vicinity of Cape Thompson and one east of Nome on the Darby Peninsula. The Cape Thompson site was preferred since it was near potentially valuable resources and it offered operational advantages that would simplify the execution of CHARIOT. ~~(ONE)~~

2. The U.S. Geological Survey was asked to study the Cape Thompson area, to make a field survey, and to recommend specific sites. A preliminary report specified three possible sites in a 20 mile stretch of the coast. At a conference held on 17-19 July 1958 and attended by members of the U.S. Geological Survey team, the Atomic Energy Commission, LRL, Sandia Corporation, U.S. Army Corps of Engineers, and Holmes and Narver (H&N), it was decided that the Ogotoruk Creek site was the most suitable. Phase I of CHARIOT took place during the summer of 1958. It

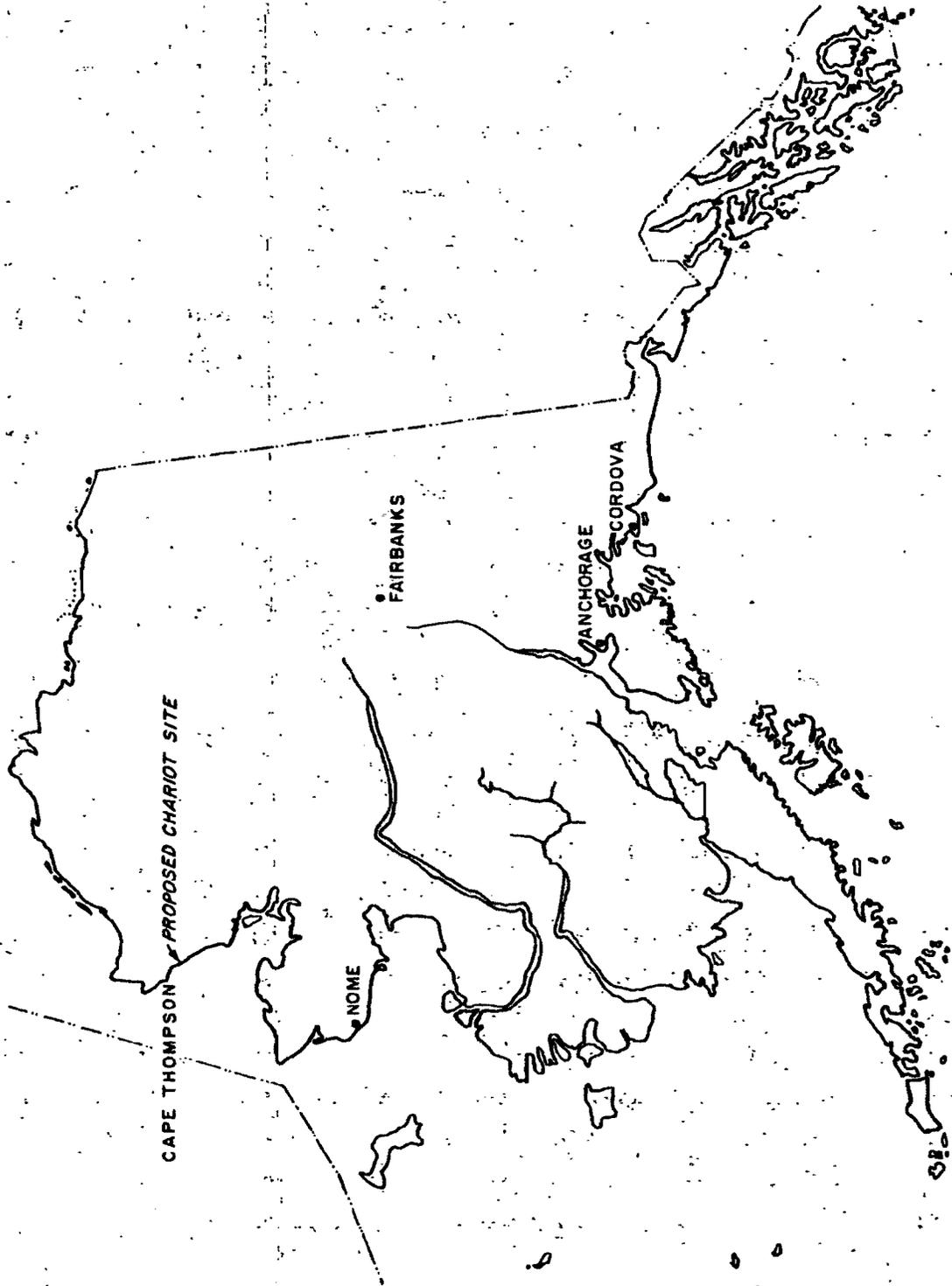


Figure 2

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consisted in part, of an on-site survey conducted by the U.S. Geological Survey. This survey verified that the Ogotoruk Creek area is topographically and geologically well situated for the construction of a harbor. Studies of the submarine topography revealed that the offshore continuation of the Ogotoruk Valley would provide an excellent natural deep water approach channel. Further, it was decided that silting of the harbor by Ogotoruk Creek would be insufficient to create a maintenance problem for a long time. One of the major concerns prior to the field exploration was that of longshore transport (littoral currents) of sand and gravel which would tend to build bars and spits across the harbor entrance. Measurements at the site indicated that some tens of years would be required before a maintenance problem would arise.

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3. The material to be excavated consists of mudstone, siltstone, and sandstone which are probably frozen to a depth of 500 to 800 feet. It is not expected that there will be any large scale slumping into the craters produced.

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4. Studies of the weather in the area indicate that the harbor would be ice-free about four months of the year.

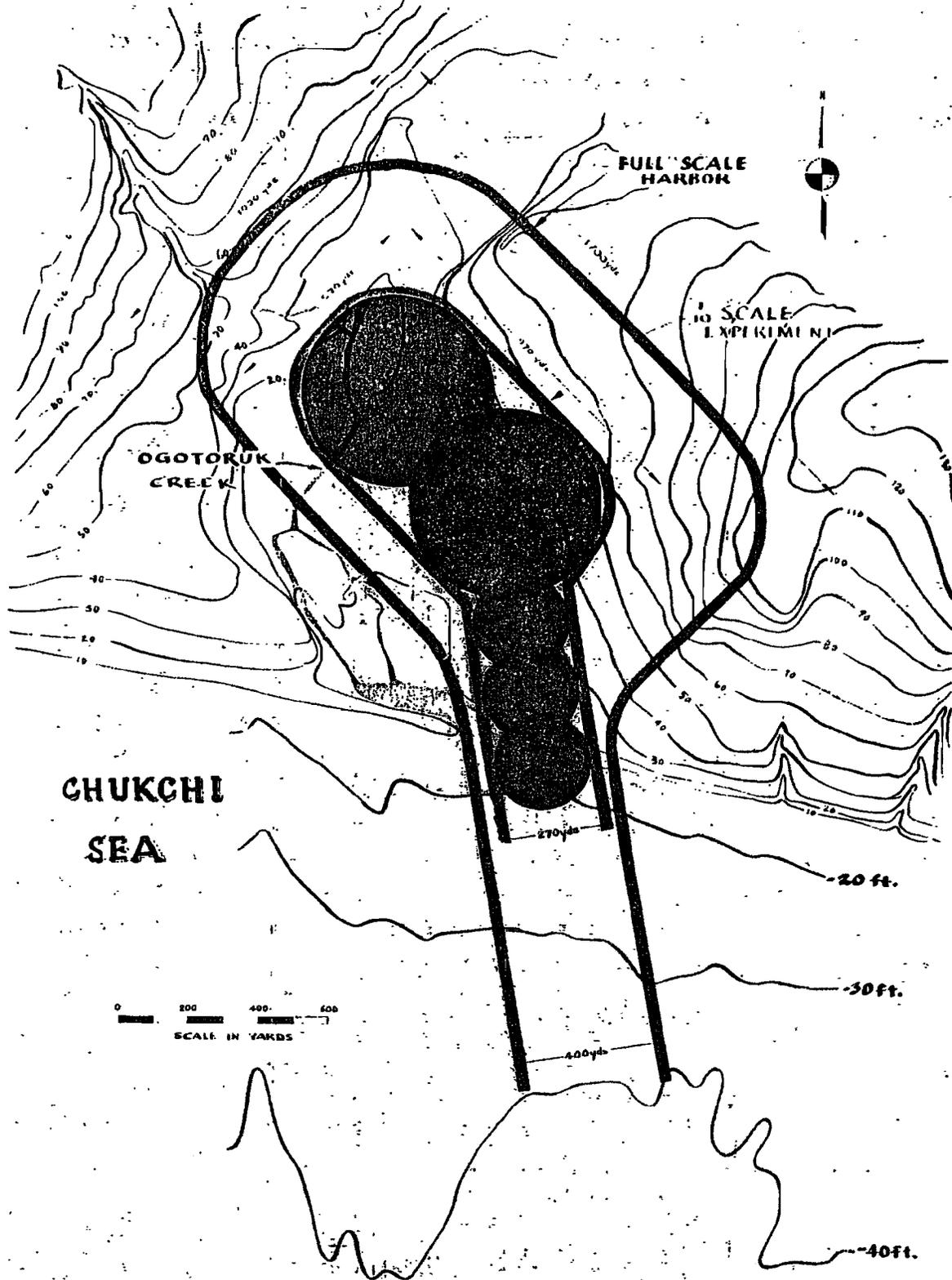
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5. As a result of the E. J. Longyear study, the original plan was to develop a full-scale harbor (1200 yard long channel, 400 yards wide and a turning basin 1000 yards  $\times$  1700 yards) by detonating four 100 KT and two 1 MT devices (see Figure 2). Because of the cost of such a large project, it was decided to revise the plans and attempt to construct a smaller harbor as an experiment. Under the revised plan, the harbor will have a channel 270 yards wide and 600 yards long and a turning basin approximately 600 yards  $\times$  1000 yards. The minimum depth in the harbor will be 30 feet. To accomplish the excavation, three 20 KT and two 200 KT devices will be used.

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CHARIOT SITE  
Figure 3  
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6. As stated earlier in this report, the purpose of Project CHARIOT is to demonstrate the practicability of creating a deep water harbor in Alaska, and in such accomplishment, to ascertain and collect certain specific scientific information fundamental to future applications. To accomplish this mission, CHARIOT has been organized in three phases:

- PHASE I        Preliminary study and on-site survey during summer 1958.
- PHASE II        Investigation of the proposed project site commencing in the summer of 1959 and continuing until June 1960 to obtain data on the geology of the area, hydrology, geo-thermal regime of the area, chemical quality of the water, coastal processes, regional ecology, meteorology, sub-surface drilling conditions, communications, and archeological artifacts.
- PHASE III       Construction and detonation phase. Construction is planned to be accomplished during the summer of 1960, and the detonations are scheduled for April 1961. Authority to proceed with Phase III will be issued upon the successful completion of Phase II, provided the findings of Phase II are favorable.

7. Phase II, which is currently in progress, concerns itself primarily with the question of public safety, and with obtaining additional technical information. To accomplish Phase II, an estimated maximum of seventy-five people will be on-site during the 1959 summer season, and a total of \$1,000,000 will be expended. A partial list of the agencies involved in Phase II includes:

- U.S. Atomic Energy Commission
  - Albuquerque Operations Office
  - San Francisco Operations Office
  - Division of Biology & Medicine
- University of California E. O. Lawrence Radiation Laboratory
- U.S. Army Corps of Engineers
- U.S. Coast & Geodetic Survey
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- U.S. Public Health Service (Arctic Health Research Center)
- U.S. Public Health Service (Division of Radiological Health)
- U.S. Weather Bureau
- General Electric Company

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9. In Phase III it is tentatively planned to drill two 36-inch, cased, holes to a depth of 500 feet for the 200 KT devices, and three 36-inch, cased, holes to a depth of 275 feet for the 20 KT devices. The actual depth of burial of the devices is not established at present but will be determined when data from CHARIOT Phase II and OXCART are available. (C)

10. The total cost of Project CHARIOT, excluding the device cost but including internal LRL costs, is approximately \$7,000,000. (C)

C. TRANS-ISTHMIAN CANAL

1. In 1958 the engineering firm of Parsons, Brinkerhoff, Hall, and Macdonald (PBH&M) completed and submitted to the Panama Canal Company certain long range improvement plans for the Panama Canal. Two plans were for lock canals and a third was for the conversion of the existing canal to a sea level canal. In July 1958, the engineering firm learned of PLOWSHARE and contacted LRL for additional information. As a result, a study group, consisting of Mr. M. N. Quade from PBH&M and members of LRL and Sandia Corporation, was established to evaluate the potentialities of using nuclear explosives for a sea level canal. (C)

2. The route selected for study was the Sasardi-Morti Route which is approximately 110 miles southeast of the present canal. The total length of cut would be approximately 50 miles and the maximum elevation 1100 feet. Two independent studies of the use of NE for excavation of the canal were made:

a. The devices were so selected and placed that the total yield was a minimum, which means that each device was placed at a depth to give maximum crater dimensions.



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- c. San Blas #16 Panama
- d. Caledonia or Sasardi-Morti #17 Panama
- e. Atrato-Truando #25 Columbia

A meeting of the participating agencies is scheduled for 24 September 1959 at LRL. Participating agencies in this study include:

- Panama Canal Company
- Parsons, Brinkerhoff, Hall, & Macdonald
- AEC: DMA & DBM
- LRL
- Sandia Corporation

~~(U)~~

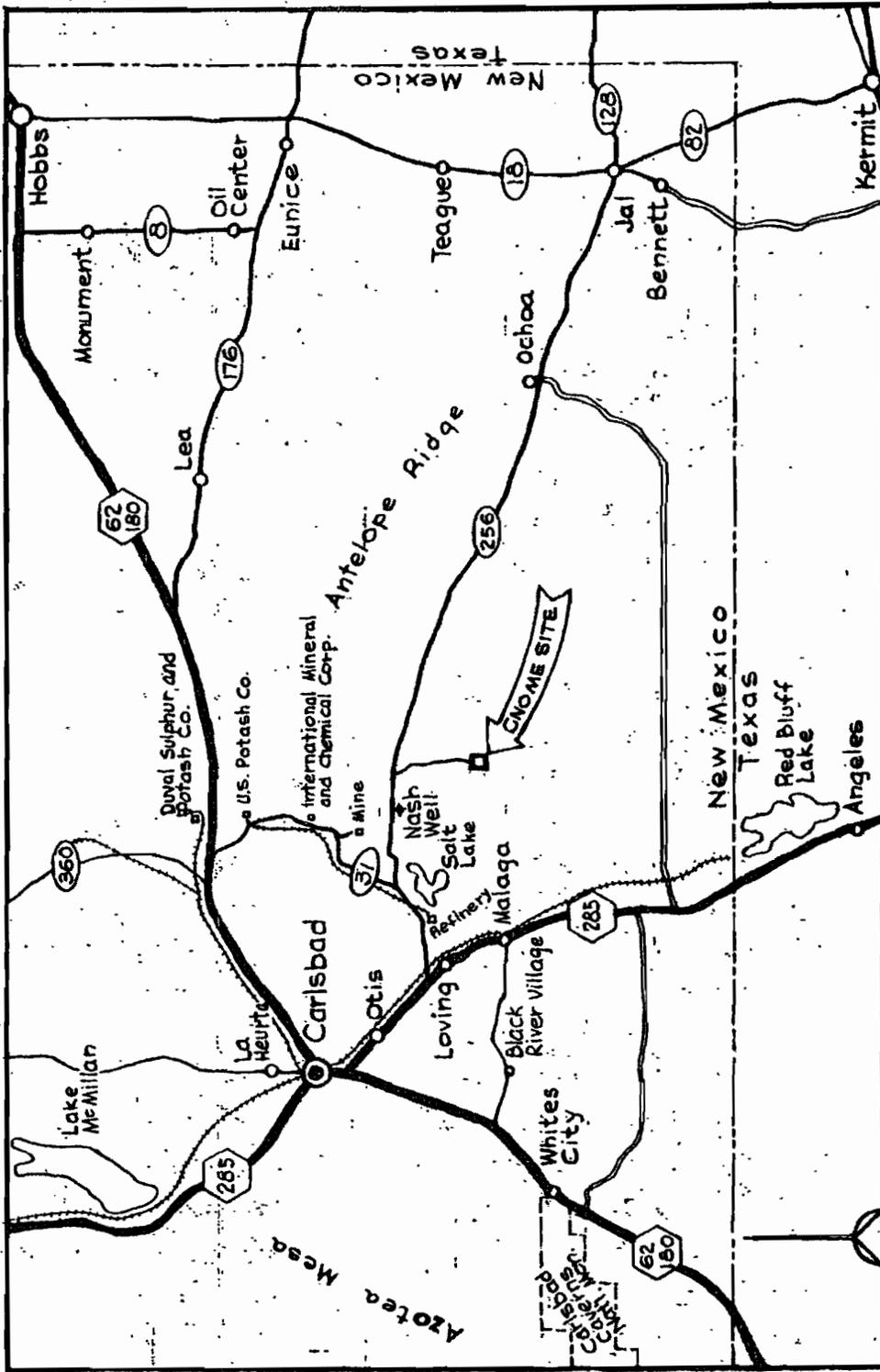
D. GNOME

1. Measurements on the RAINIER explosion showed that soon after the detonation roughly one-third of the bomb energy was deposited in melted rock at temperatures above 2000°F. In the case of RAINIER, there was a large amount of water present (approximately 20% by weight), and the surrounding material was permeable to the degree that the high temperature was rapidly reduced to that of boiling water. The fact that so much energy was available initially at such a high temperature led to the idea that firing in a dry medium might store energy at high temperature long enough to permit efficient recovery. The GNOME project was developed with this in view. Marine salt deposits are dry (less than 1% water); therefore, a nuclear detonation in such a medium might produce a large volume of melted salt (1500°F.) from which heat could be extracted.

(UNCL)

2. Project GNOME is an experiment planned to be conducted near Carlsbad, New Mexico (see Figure 4), involving the detonation of a nuclear explosive with a yield of 10 KT in a sub-surface salt formation and the associated technical measurements to aid in determining the feasibility of recovering heat and isotopes from an underground nuclear explosion. The device will be detonated at a

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# LOCATION OF PROJECT GNOME SITE

Figure 4

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depth of 1200 feet. The ground zero point will be connected to a shaft by an 1100 foot horizontal tunnel. This arrangement will protect the shaft from the effects of the detonation. (C)

3. The general specifications for the required site are:

- a. Depth of not more than 800 feet to the top of the salt.
- b. Region of low population density.
- c. Within the Continental United States.
- d. An area where salt purity in excess of 90% NaCl could be obtained.
- e. Preferably in an area where Federal land is available.

After a site selection study by the U.S. Geological Survey, four general regions were suggested as being suitable for this experiment.

They were:

- a. Salt beds in Michigan
- b. Salt domes along the Gulf Coast
- c. Salt beds in Paradox Valley, Colorado
- d. Salt beds in Delaware Basin, New Mexico

After further investigation, the Delaware Basin in New Mexico was selected as being the most suitable for the experiment. The Michigan salt beds were too deep; the Coast salt domes, while shallow and pure, posed problems of private property which presaged a long delay for land procurement; the Paradox Valley formations were deeper than desired and not as well known as the Delaware Basin formations. In the Delaware Basin, large portions of the land are still Federally owned and land procurement is not thought to be a problem. In the Delaware Basin the salt lies 500 to 1,000 feet below the surface, the population density is very low in the immediate region, and much is already known about the geology of the formation. The salt in the formation averages approximately 90% purity with contaminants of silica-bearing materials being less than 1%. (UNCL)

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4. Detailed site surveys in the Delaware Basin resulted in the selection of Section 34, Township 23 South, Range 30 East, New Mexico Principal Meridian, as the experimental area. The location for the shaft will be approximately the center of this section with ground zero in a northeasterly direction from the bottom of the shaft.

(UNCL)

5. Oil fields are located about 20 miles from the site, a gas well is about six and one-half miles away, a potash refining surface plant is located about 10 miles away, and the closest sub-surface workings connected with the potash industry are about 8 miles away. At a meeting held at Carlsbad, New Mexico on 21 November 1958 between members of the Potash Industry and the AEC, it was decided to perform a series of high explosive experiments at the GNOME site. The purpose of these experiments would be to compare seismic disturbances at the Potash Mines from the proposed nuclear detonations with the normal background disturbances occasioned by the mining activities. Three high explosive (200 lb., 750 lb., and 6,250 lb.) charges were detonated in February 1959 in a program called PRE-GNOME. The results of PRE-GNOME were studied by Dr. N. M. Newmark of the University of Illinois. Dr. Newmark's conclusions in part were, "In general it is concluded that there is no serious danger of major damage to any of the mines that would result from a 10-KT detonation at the proposed location for Project GNOME."

(C)

6. The two major programs in Project GNOME are the power and isotope studies.

a. The purpose of the power program is to determine the amount of energy remaining in the shot cavity as available heat and to study problems connected with the recovery of heat from this region for the generation of power. A method will be developed

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for introducing a working fluid into the cavity for heat recovery. This may be done by simply circulating the fluid over the molten salt (if the cavity remains intact) using two of the sample recovery holes from the isotope program. A second method would be to hydrofrac (break the formation with a fluid under pressure) from nearby holes into the cavity to form a circulating path entering much lower down in the cavity. Studies are presently being conducted to determine the most suitable working fluid. Among the materials being considered are carbon dioxide, nitrogen, dry air, and water. Measurements will be made at the outlet point of the working fluid to determine pressures, temperatures, and flow rates. In addition, a small electrical generating plant may be installed which would utilize the temperature and pressure of the working fluid to drive a turbine generating small amounts of electrical power.

b. The isotope program is to test the possibility of recovering isotopes produced by a contained nuclear explosion and to ascertain the distribution of these isotopes. Various metals may be introduced into the immediate vicinity of the device, and it is anticipated several radioactive materials will be produced from these metals. In addition, the isotopes normally resulting from a nuclear detonation will also be studied. In order to obtain the best information on isotope production and recovery, accurate account will be kept of the materials used within about 100 feet of the device. Prior to the detonation, three holes will be drilled from the ground surface toward the device room. Two of the holes will terminate approximately 15 feet above the salt formation and will be offset from the device position by 20 to 50 feet. The third hole will terminate at a point 50 feet above, and directly in line with the device. In order to prevent escape of gas, the deep hole will be valved off to withstand pressures of 1,000 psi. As soon as possible after the detonation, the sample holes will be extended to the detonation area

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and used for recovery of samples. Depending upon the results of preliminary samples, a decision may be made to re-enter the detonation area by mining and remove gross quantities of the material, after solidification, for recovery of total isotope production. (UNCL)

7. To provide additional data relating to power and isotope production and also to provide information concerning underground nuclear explosions in general, the following technical studies will be made:

- a. Early shock effects.
- b. Temperature and radiation intensity measurements.
- c. Post-shot drilling and media measurements.
- d. Strong motion measurements.
- e. Post-shot noise measurements.
- f. Cavity pressure measurements.
- g. Post-shot subsidence measurements.
- h. Earth deformation studies.
- i. Surface motion photography.
- j. Seismic measurements.
- k. Permanent displacement survey.
- l. Structural response studies. (UNCL)

8. In addition to the technical programs, the normal Project Manager's programs will be conducted to assure that the detonation can be performed without risk to people or property. (UNCL)

9. The total cost for Project GNOME, excluding the nuclear device, is approximately \$3,600,000. (UNCL)

E. CAULDRON

1. The Athabasca oil sands (also called tar sands) underlie an area of some 17,000 square miles in the Province of Alberta,

Canada. It has been estimated that some 350 billion barrels of oil are entrapped in these sands. These sands are buried under varying amounts of overburden ranging in depth from 0 to 1,200 feet. Since the beds of oil sands rarely exceed 200 feet in thickness, it is at present possible to remove up to a maximum of 50 feet of overburden before the strip-mining operation becomes uneconomic. This means that only 2% of the fields can be strip-mined economically. To exploit the remainder, some method of "in situ" recovery must be found.

(UNCL)

2. The Richfield Oil Company has proposed that a nuclear device be detonated in the Athabasca oil sands in order to demonstrate the feasibility of using nuclear energy to effect an "in situ" recovery. The nuclear device would be located in the oil sand formation and upon detonation would heat the surrounding oil sand. One of the properties of the oil sand is that upon heating to 100°C., the viscosity of the oil is reduced sufficiently to permit the oil to flow and to be pumped. The viscosity remains low even upon subsequent cooling of the oil sands. Consequently, the nuclear detonation would in effect produce an oil field.

(UNCL)

3. The site selected for the proposed experiment is the Pony Creek Reservation in the Province of Alberta. In this area the oil sands are about 180 feet thick and are located 1200 feet below the surface.

(UNCL)

4. The Richfield Oil Company has proposed that a 10 KT device be detonated at a depth of 1300 feet. This company in conjunction with other oil companies, has stated that they are prepared to assume the complete cost of the project including the cost of the nuclear device. At present the oil companies are seeking approval of the Province of Alberta and the Dominion of Canada to proceed. It is expected that the Dominion of Canada will request the U.S. Government

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to enter into negotiations which eventually would result in the performance of this experiment. (UNCL)

F. VINTAGE

Studies of extraction of oil from oil shale with the use of NE are presently underway by the Bureau of Mines and some oil companies. This program, known as VINTAGE, contemplates the use of a contained nuclear detonation to shatter an oil shale formation and then to retort the oil in place. At present there is no experiment scheduled in this field. However, studies are continuing and preliminary results suggest that the project is feasible. (UNCL)

G. WATER RESOURCES DEVELOPMENT

Studies are being conducted to determine if NE can be used to increase the supply of underground water. These studies, informally known as Project AQUIFER, are investigating the possibility of using NE to produce underground water storage areas by producing a crushed region in an existing impermeable region and to shatter impervious layers that are found over existing potential water storage sites. The island of San Clemente, off the coast of California, is presently being studied as a possible site for the creation of an artificial aquifer. San Clemente is U.S. Navy property, and the U.S. Navy is performing, in conjunction with LRL, meteorological and geological studies of the island. (UNCL)

H. MISCELLANEOUS INDUSTRIAL PROJECTS

In addition to the projects described above, several other industrial applications of NE have been suggested. These projects are being studied in various degrees but none of them have advanced to the point where a specific site or project has been chosen. Some of the suggested projects are:

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1. Increasing yield of conventional oil wells.
2. Construction of underground oil storage tanks.
3. Ore mining --
  - a. Block caving mining--NE would be used to crush a large ore body and the ore then drawn off from the bottom of the deposit.
  - b. Leaching--NE would be used to crush a large ore body through which a fluid would be circulated to leach the ore.
4. Construction of geothermal steam plants--NE would be used to increase the permeability in the region of an existing steam-bearing formation.
5. Construction of various harbors and canals.
6. Production of crushed rock. (UNCL)

#### I. SCIENTIFIC APPLICATIONS

1. This report has concerned itself primarily with the industrial applications of NE; however, it is felt that, for completeness, some mention should be made of the various suggested purely scientific experiments involving NE. (UNCL)

2. The tremendous flux of neutrons emitted from a nuclear detonation suggests that many experiments, previously considered beyond the realm of possibility, can now be performed. Among the experiments being investigated at LRL are:

- a. Neutron--neutron scattering.
- b. Neutron spectroscopy.
- c. Neutron polarization by double scattering. (UNCL)

3. There has been an expression of interest by several agencies in the application to seismological studies of the high energy release available in a nuclear detonation. (UNCL)

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4. The Los Alamos Scientific Laboratory (LASL) is pursuing a program called Scientific Applications of Nuclear Explosives (SANE), whose name is self-explanatory. This is a new program for LASL and no attempt is made in this paper to report on it. Pertinent information on SANE, however, will be reported subsequently as it becomes available.

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### III. NUCLEAR DEVICES

#### A. DEVICE CHARGES

1. The AEC has released the following information as to size and charge for nuclear detonations for peaceful uses. The figures apply only to PLOWSHARE and are not to be used for nuclear weapons.

"The charge for fabricating and firing a device 30 inches in diameter and of a few KT yield, all from fission, would approximate \$500,000 when made available in small numbers.

"The charge for fabricating and firing a device 30 inches in diameter of a few  $10^9$  s of KT yield, all from fission, would approximate \$750,000 when made available in small numbers.

"The charge for fabricating and firing a device 60 inches in diameter in the yield range up to 5 MT, of which 5% of the yield was from fission and 95% from fusion, would be approximately \$1,000,000 in small quantities.

"In the event of multiple firing in the same location, or in using large numbers of devices, the charge for firing would be substantially reduced.

"These charges are only those incident to the fabrication of the device, emplacing it in its firing location, making the firing attachments, firing, and studies to assure public safety and to determine the results of the detonation. It does not involve such possible activities as preparing a hole or other structure for the firing or studies to determine the results of industrial utility." (UNCL)

2. Figure 5 was derived from the above guidance and may be used for interpolations of charges and yield information. (UNCL)

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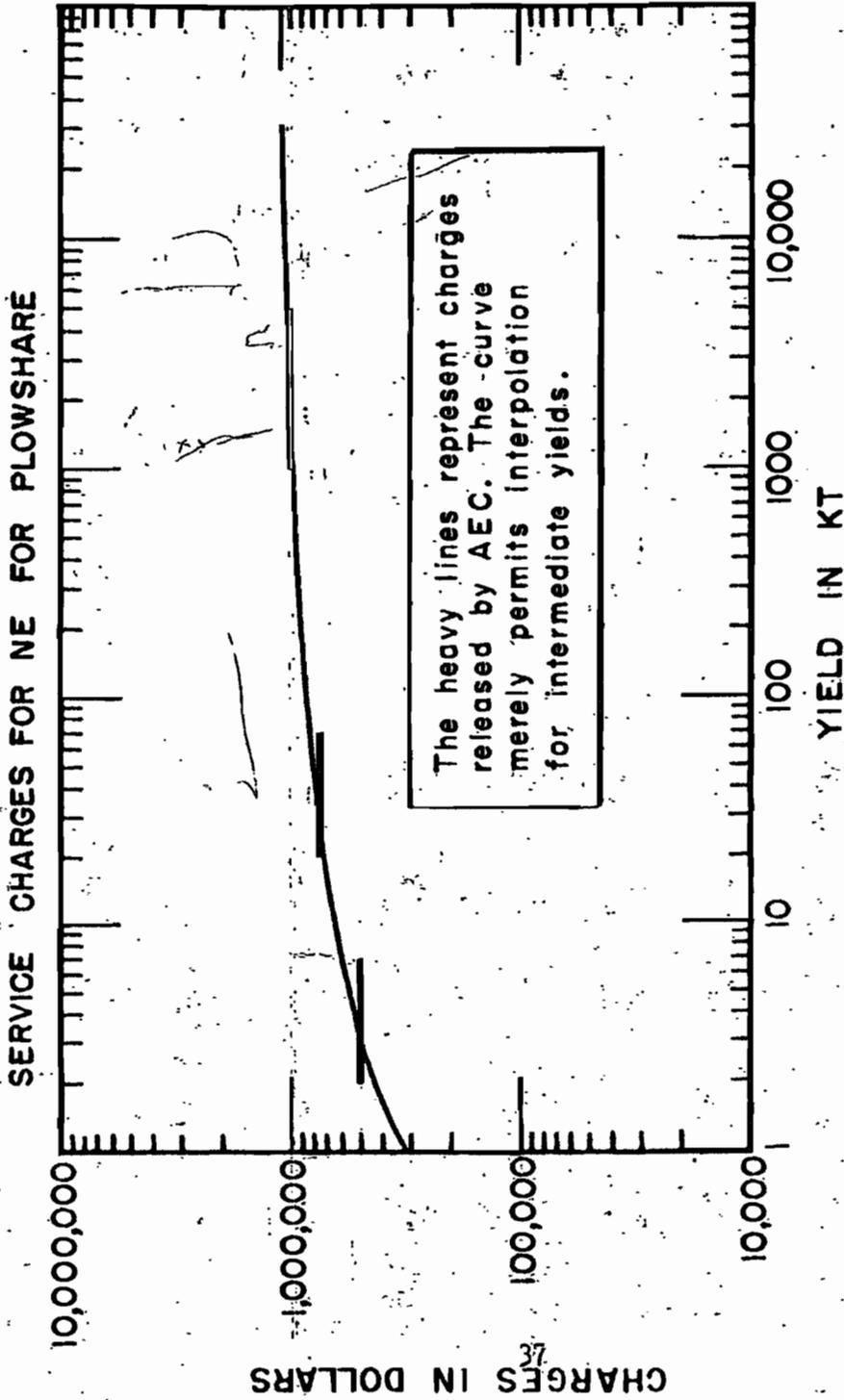


Figure 5

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B. DESIGN OF NEW DEVICES

LRL is investigating the feasibility of designing special nuclear devices that are more economical and cleaner than those described in paragraph A above. Devices that are to be used in PLOWSHARE projects are not necessarily governed by limitations of weight, size, vulnerability to enemy action, and other characteristics of importance to the military. The elimination of these restraints makes possible a completely different class of nuclear devices.

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