DL 868

UCRL-51418

**KRA CANAL PROJECT:
A PRELIMINARY ASSESSMENT OF NUCLEAR EXCAVATION
FEASIBILITY FOR ROUTE 5A**

June 1974

Prepared for U.S. Atomic Energy Commission under contract No. W-7405-Eng-48

**LAWRENCE
LIVERMORE
LABORATORY**

University of California/Livermore

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$ ____*; Microfiche \$0.95

<u>* Pages</u>	<u>NTIS Selling Price</u>
1-50	\$4.00
51-150	\$5.45
151-325	\$7.60
326-500	\$10.60
501-1000	\$13.60

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California/94550

UCRL-51418

**KRA CANAL PROJECT:
A PRELIMINARY ASSESSMENT OF NUCLEAR EXCAVATION
FEASIBILITY FOR ROUTE 5A**

John Toman, Howard Tewes, Kendall Peterson, Donald Emerson,
Donald Monten, Thomas Gibson, Wayne Woodruff, John Button,
William Robison, Yook Ng, Milo Nordyke, and Fred Holzer

MS. date: June 1974

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

34

Preface

This document is the final version of a draft issued on 1 September 1973 as Appendix D of a report by TAMS and RRNA.* The only noteworthy revisions of the draft report are in the section "Predicted Effects of the Nuclear Detonations: Bio-Environmental Considerations" and in Table 4. These changes reflect a recalculation of the amount of radioactivity deposited on the Nicobar Islands and Sumatra, as well as a revision of some of the deposition/dose conversion factors. As a result of these changes, the pasture-meat food pathway has been eliminated as a major contributor to population dose in Sumatra. Estimated radiation doses to the populations of both Nicobar and Sumatra are significantly lower than had previously been indicated.

* TAMS: Tippetts-Abbett-McCarthy-Stratton, Consulting Engineers, New York, NY.

RRNA: Robert R. Nathan Associates, Inc., Consulting Economists, Washington, D.C.

Contents

Abstract	1
Introduction	1
Assumptions	1
Uncertainties	2
Route Locations and Characteristics	3
Nuclear Excavation Plan	6
Predicted Effects of the Nuclear Detonations	7
Local Fallout and Associated Radioactivity	7
Long-Range Cloud Trajectories	8
Bio-Environmental Considerations	10
Ground Motion Predictions	11
Airblast Considerations	11
Nuclear Operations	13
Operation Concepts and Schedules	13
Evacuation Area	15
Summary and Conclusions	16

Frontispiece

KRA CANAL PROJECT: A PRELIMINARY ASSESSMENT OF NUCLEAR EXCAVATION FEASIBILITY FOR ROUTE 5A

Abstract

A preliminary survey of the possibility of excavating a portion of a canal across the Isthmus of Kra with nuclear explosives has been completed. For the proposed route (designated 5A), a conservative approach has been used to determine "upper limit" values for potential adverse

effects resulting from the nuclear and conventional construction phases of the project. Within the limitations of the study, it has been concluded that there are no technical, safety, or operational factors which would preclude the successful implementation of this project.

Introduction

This paper summarizes the finding of a preliminary survey by Lawrence Livermore Laboratory (LLL) of the possibility of excavating a portion of Route 5A across the Isthmus of Kra with the aid of nuclear explosives. It is based on an earlier study of January 1973 which was updated during March and April 1973. This survey does not claim to be a detailed design, nor, indeed, a feasibility study. Emphasis has been on evaluating those issues which

might rule out the possibility of nuclear excavation at this stage, and on providing a basis for comparing the safety, operational, and economic factors of the nuclear option with those of conventional excavation.

Within the limitations of the present study, it is concluded that the nuclear excavation could be successfully accomplished; no technical, safety, or operational issues have been found which would preclude carrying out this project.

Assumptions

The assumptions used in evaluating this project include:

- 1) A canal that is wide and deep enough in cross section (i.e., one having a sufficiently large "navigation prism") to accommodate tankers of 500,000 DWT.

Concepts for two cross sections were investigated: one for two-way traffic 1600 ft X 110 ft; and a second for one-way traffic, 850 ft X 110 ft. Figure 1 shows two such vessels in a two-way nuclear cut.

Fig. 1. Cross section of proposed two-way Kra Isthmus canal showing 1600-by-100-ft navigation prism. Black rectangles represent two 500,000-DWT vessels passing in the canal.

2) Crater dimensions based on scaling relations developed from a large number of high-explosive experiments and from the U.S. nuclear excavation experiments. These relations are the same as those used in the 1970 Interoceanic Canal Studies reports.

3) A maximum yield for any individual explosive of 1 Mt (megaton).

4) A maximum salvo yield of about 5 Mt.

5) Initial quantities of radionuclides consistent with a modest extrapolation of existing nuclear excavation explosive technology.

6) Quantities of radionuclides injected into the atmosphere consistent with U.S. nuclear cratering experience.

7) Ground motion experience from U.S. detonations applicable to the Isthmus of Kra.

Uncertainties

We believe a number of areas presently not known or imprecisely known should be enumerated so that the limitations of this survey may be understood. This enumeration will also serve to indicate some of the answers which should be obtained during any subsequent feasibility and design studies.

1) The largest U.S. cratering experiment had a yield of 100 kt (kilotons) in alluvium, and the largest U.S. row-charge experiment consisted of five 1-kt explosions. While extrapolating to a 5-Mt salvo is uncertain, there exists no evidence to support significant departures from known scaling relations.

2) Details of the geology, hydrology, and rock properties on Route 5A are not known, but would have to be obtained to refine the present detonation plan.

3) No nuclear experiments (cratering or contained) have taken place in limestone, which is apparently the dominant rock of the divide portion of Route 5A.

4) Detailed ground motion and structural damage predictions must await a more complete study.

5) Times needed to drill the emplacement holes — especially those in material

disturbed by previously fired salvos — are not known for the rocks of Route 5A.

6) The amount of conventional remedial work in the connecting areas between the individual salvos is unknown, but it is not expected to exceed a tenth of the nuclearly excavated volume.

7) Details of the pathways by which radioactivity can reach the local population depend on food chains and the retention of activities along such pathways. These have not been studied in detail.

Route Locations and Characteristics

The location of Route 5A in relation to several other routes previously examined is shown in Fig. 2. Route 5A was selected because of the relatively low population density of the area that would have to be evacuated, its low average elevation, and other economic considerations. Its total length is about 100 km. As can be seen in Fig. 3, a surface profile along the alignment shows a maximum elevation of about 150 m.* A similar

profile which includes surface geology is shown in Fig. 4. This geology comes from published reports. (A more detailed study from field observations is in Appendix B, Part V, of the TAMS/RRNA report referenced in the Preface.)

* The maximum elevation of the highway along Route 5A is 100 m. Because of the rugged terrain and the width of the canal, a maximum elevation of 150 m has been used in the present work.

Fig. 2. Possible sea-level canal routes across the Kra Isthmus.

Fig. 3. Surface elevations along Route 5A.

Fig. 4. Schematic surface geology along Route 5A.

Nuclear Excavation Plan

Two detonation plans, corresponding to one-way and two-way navigation prisms for 500,000-ton tankers, have been developed. Table 1 summarizes yields, salvos, tentative locations, and number of explosives for the two-way 1600-ft X 110-ft navigation prism, while Table 2

presents the corresponding data for the one-way 650-ft X 110-ft prism. As these tables show, the excavation for the large prism requires 113 explosives distributed among 21 salvos for a total yield of 105 Mt. The small prism requires a larger number of explosives, 139, but

Table 1. Detonation plan for the two-way canal (1600 ft X 110 ft) along Route 5A. (The first 10.9 km at the west end of the route and the final 45.6 km at the east end would be done by conventional excavation, and the 45.1 km in between would be done by nuclear excavation.)

Salvo number	End point locations (km) ^a		Total yield (Mt)	Total number of explosives	Number of explosives by yield (Mt)	
	West end	East end			0.7	1.0
—	0	10.9	—	—	—	—
1	11.00	13.70	4.9	7	7	—
2	14.15	16.85	4.9	7	7	—
3	17.30	19.99	4.9	7	7	—
4	20.44	23.14	5.2	7	6	1
5	23.64	25.64	5.0	5	—	5
6	26.14	28.15	5.0	5	—	5
7	28.65	30.55	5.0	5	—	5
8	30.99	32.56	5.0	5	—	5
9	32.88	34.11	5.0	5	—	5
10	34.44	35.59	5.0	5	—	5
11	35.83	36.84	5.0	5	—	5
12	37.11	38.19	5.0	5	—	5
13	38.49	39.77	5.0	5	—	5
14	40.10	41.44	5.0	5	—	5
15	41.78	43.23	5.0	5	—	5
16	43.62	45.19	5.0	5	—	5
17	45.59	47.19	5.0	5	—	5
18	47.58	49.13	5.0	5	—	5
19	49.52	51.21	5.0	5	—	5
20	51.64	53.43	5.0	5	—	5
21	53.93	55.93	5.0	5	—	5
—	56.0	101.6	—	—	—	—
21	Totals		104.9	113	27	86

^aLocations with respect to the kilometer scale shown in Figs. 3 and 4.

Table 2. Detonation plan for the one-way canal (650 ft X 110 ft) along Route 5A. (The first 10.9 km at the west end of the route and the final 45.6 km at the east end would be done by conventional excavation, and the 45.1 km in between would be done by nuclear excavation.)

Salvo number	End point locations (km) ^a		Total yield (Mt)	Total number of explosives	Number of explosives by yield (Mt)						
	West end	East end			0.1	0.15	0.2	0.3	0.5	0.7	1.0
—	0	10.9	—	—	—	—	—	—	—	—	—
1	11.0	24.04	5.30	53	53	—	—	—	—	—	—
2	24.29	31.37	4.95	24	—	9	9	6	—	—	—
3	31.71	34.72	5.0	8	—	—	—	1	1	6	—
4	35.17	37.11	5.0	5	—	—	—	—	—	—	5
5	37.61	40.36	5.2	7	—	—	—	—	6	—	1
6	40.81	44.87	5.5	11	—	—	—	—	11	—	—
7	45.28	48.94	5.0	10	—	—	—	—	10	—	—
8	49.35	55.98	5.4	21	—	—	11	9	1	—	—
—	56.0	101.6	—	—	—	—	—	—	—	—	—
8	—	Totals	41.35	139	53	9	20	16	29	6	6

^aLocations with respect to the kilometer scale shown in Figs. 3 and 4.

only 8 salvos and a total yield of about 41 Mt. Moreover, 98 of these 139 explosives have an individual yield of about 300 kt or less, and thus represent a smaller extrapolation from present experience than the 1-Mt craters. As

will be seen later, the relatively small number of salvos for the small prism permits a considerably more rapid operation than that needed for the large prism, which may offset the cost inherent in the small prism's larger number of explosives.

Predicted Effects of the Nuclear Detonations

LOCAL FALLOUT AND ASSOCIATED RADIOACTIVITY

The required direction for the deposition of fallout was chosen to be to the west, in the sector between 255 and 285°. Assuming that the main cloud from each salvo would rise to a height of 55,000 ft, 26 days with favorable winds occurred during the period 1956-1972, for an average of about four days per year (see Table 3). If experience shows that such a cloud height is not reached, the number

of acceptable days would be larger than those shown in Table 3. Consideration was given to depositing fallout to the east with summer monsoon winds. However, such winds extend to an altitude of only 30,000 ft. Above that altitude, the winds almost always blow to the west. Consequently, fallout would extend in both directions. In addition, the stronger wind speeds associated with the monsoon winds would carry higher levels of radioactivity to greater distances. It is

Table 3. Acceptable detonation days for 55,000-ft cloud height. (Data based on the period 1866-1972 when there were 26 days on which wind conditions were such that a nuclear detonation of the size proposed here, assuming a 55,000-ft-high cloud, would have been acceptable. This table shows the monthly distribution of acceptable days during the period.)

Month	Number of acceptable days
January	2
February	2
March	3
April	3
May	1
June	1
July	0
August	0
September	0
October	5
November	4
December	5

likely that fallout deposited on Cambodia and South Vietnam would result in greater exposures than those calculated for the Nicobar Islands and Indonesia with winds to the west for the Route 5A example. The integrated fallout pattern for all Route 5A salvos has been calculated to define the downwind exclusion area. An exposure of 0.30 R would be one of the controlling elements of the exclusion zone boundary if the nuclear excavations are carried out in two separate calendar years. Figure 5 shows the 0.17-R life-time dose contours, resulting from three salvos in the center of the alignment, for people reentering the area at various times after the detonation. This provides

a guide to the time required until evacuated areas can be resettled by the general population.

LONG-RANGE CLOUD TRAJECTORIES

Figure 6 shows a typical debris cloud trajectory for either the base surge or the main cloud. The possible reversal of the cloud over Sumatra is well established in the climatological wind studies published for the Indian Ocean and Southeast Asia. Because of weather data uncertainty, the possibility that a few clouds may turn northward to the Bay of Bengal cannot at this time be ruled out. Other clouds may travel further west before reversing. Large cloud diffusion calculations were made for the six acceptable detonation days in 1970 and were summed for all salvos. Those nuclides which gave the largest doses were identified and are tabulated in Table 4 for the Nicobar Islands and Sumatra. Estimates for both prism sizes are shown. The values given are significantly lower than those in a similar table in previous studies for two reasons: in the case of the Nicobar Islands, it has been more realistically assumed that the clouds from only some of the salvos will pass over the islands; for Sumatra, a more thorough assessment of the major food pathways has eliminated the pasture-meat pathway as a significant factor.

Rainout is unlikely in Thailand or the Nicobar Islands since detonations are planned to occur during the dry season. Sumatra has its heaviest rains in the winter and early spring, but rainclouds seldom exceed 25,000 ft. This would rain out most of the base surge, but less than

Fig. 5. Calculated fallout pattern from three 5-Mt slavs in the center of the nuclear alignment.

Fig. 6. Typical trajectory for both the base surge cloud (BS) and the main cloud (MC).

half of the main cloud. Local "hot spots" may develop but they would not be in the same place for each salvo. For such very limited areas, dose enhancement might amount to a factor of 10 to 100 for a single detonation, but the total dose from the entire project would increase only by a factor of 3.

BIO-ENVIRONMENTAL CONSIDERATIONS

Internal radiation doses will occur via the inhalation and food-chain pathways. The primary sources of ingested radionuclides via the food chains are fish and

rice, the two major components of the Southeast Asian diet. As shown in Table 4, the total exposure from inhalation and food pathways for the Nicobar Islands is approximately 5 mrem for the one-way canal. An additional 10 mrem would result from direct fallout. Exposures from external gamma irradiation, inhalation, and food pathways for Sumatra for clouds following trajectories similar to that shown in Fig. 6 is less than 1 mrem.

In this region of the world, aquatic biota contribute the major portion of protein to the diet. Included are fresh-water species, which are raised and harvested in the rice

Table 4. Potential exposures at Nicobar Islands (650 km) and Sumatra (2000 km) calculated for two-way and one-way canal concepts, assuming dry deposition (no rainout). (Based on long-range cloud trajectories from the six acceptable detonation days in 1970, with contributions from all salvos summed.)

Exposure pathway	Contributing radionuclides ^a	30-yr integral dose (mrem)			
		Nicobar Islands		Sumatra ^b	
		Two-way	One-way	Two-way	One-way
External gamma	Fission products, <u>181</u> W, <u>187</u> W, <u>203</u> Pb	10	10	0.05	0.05
Inhalation ^c	<u>3</u> H, <u>131</u> I, <u>133</u> I	0.2	0.08	0.2	0.07
Pasture-meat ^d	<u>3</u> H, <u>203</u> Hg, <u>181</u> W	— ^e	— ^e	0.0007	0.0003
Rice ^f	<u>137</u> Cs, <u>90</u> Sr, <u>3</u> H	4	4	0.3	0.3
Seafood ^{f,g}	<u>32</u> P	2	0.6	0.2	0.08

^aUnderlined nuclides are the more significant ones for the given pathway.

^bFor other areas of Indonesia and Malaysia, the individual doses are lower than those for Sumatra.

^cThe ¹³¹I and ¹³³I dose is to the thyroid; the ³H dose is to the whole body.

^dIn the model for the meat pathway, it is assumed that consumption begins several weeks after cloud passage. Hence, potential contributions from relatively short-lived nuclides such as ¹³¹I and ³²P have not been included in this pathway.

^ePasture-meat pathway is apparently nonexistent in the Nicobar Islands.

^fDose from ⁹⁰Sr and ³²P is to bone; ¹³⁷Cs dose is to whole body.

^gIn the models for the rice and seafood pathways, it is assumed that consumption begins immediately after cloud passage. In the seafood pathway, as an example, there would be a lag time between cloud passage, catch, and consumption. Therefore, the actual dose from the short-lived ³²P via the seafood pathway would be much less than in this table.

paddies, as well as seafood. The dose models used in the Kra calculations are based upon observed concentration factors in marine and freshwater species¹ and the predicted radionuclide depositions. The dose model for the rice pathway for nuclides other than tritium is based upon observed concentration factors in rice and hulled grain. A special model has been developed to assess the transfer of ³H through the large volumes of water involved during the production cycle of rice.

The meat pathway is one for which considerable data is available for determining the transfer of radionuclides to man and for determining the subsequent dose commitment. However, this pathway is essentially nonexistent in the Nicobar Islands and is of minor importance in Sumatra.

All the above pathways have been evaluated using the latest dietary information concerning the average daily consumption of these foods in the Thailand/Malaysia/Indonesia area. As shown in Table 4, the external gamma exposure potentially contributes the greatest dose in the Nicobar Islands. The rice pathway is second in order of importance. For Sumatra, the rice pathway is potentially the primary contributor to the dose, with both the inhalation and seafood pathways being roughly equivalent but lesser in magnitude than the rice pathway. The total doses from

all pathways for the Nicobar Islands and Sumatra are about 15 mrem and 1 mrem, respectively. For comparison, the average sea-level natural background radiation dose in this area is approximately 100 mrem per year.

GROUND MOTION PREDICTIONS

Predictions of ground motion have been made to aid in establishing the exclusion zone. The acceleration contours for Route 5A are plotted in Fig. 7. Evacuation of nonproject personnel is probably required within the area bounded by the 0.3-g contour. We note that the 0.3-g contour is a controlling element only on the southeastern side of the route alignment.

The extent of minor architectural damage can be estimated by surveying structures and their foundation materials out to about the 0.01-g contour. For Route 5A this contour extends from the southern end of Burma to the middle of West Malaysia, as shown in Fig. 8. The detail to which such a structure survey would need to be made has not been investigated.

AIRBLAST CONSIDERATIONS

Direct or close-in airblast is not a controlling factor in establishing the exclusion area and therefore is not a major consideration in nuclear operations. Long-range airblast effects, consisting of the reflection of acoustic energy back to the ground surface at distances of 200 to 300 km, are governed by wind speeds and directions; they can therefore be controlled by constraints on the acceptable

¹S. E. Thompson, C. A. Burton, D. J. Quinn, and Y. Ng, Concentration Factors of Chemical Elements in Edible Aquatic Organisms, Lawrence Livermore Laboratory Rept. UCRL-50564 Rev. 1 (1972).

Fig. 7. Ground acceleration contours for Route 5A. (Evacuation of nonproject personnel would probably be required within the 0.3-g contour.)

Fig. 8. Long-range ground accelerations. (Minor architectural damage might be expected at points within the 0.01-g contour.)

weather conditions. About 75% of the days shown in Table 3 to be acceptable from a radioactivity standpoint should also be acceptable from an airblast standpoint.

Detailed upper-air observations on the Isthmus followed by calculations are needed to refine these estimates and to make specific predictions.

Nuclear Operations

OPERATION CONCEPTS AND SCHEDULES

For either the one-way or the two-way option, completing the excavation in two passes should utilize manpower and material resources most efficiently. We have assumed employing a total of eight drill rigs for emplacement hole construction. By employing more rigs, the total time could be shortened; the economic tradeoffs have not been studied. This plan envisions that most of the holes would be drilled before any detonation takes place, with only those holes which might be damaged by the first pass being drilled between the first and the second passes. Tables 5 and 6 summarize the

construction details for the one-way and two-way options.

Figures 9 and 10 show conceptual schedules for these two options. In both cases, salvo 1 is at the western limit of the nuclear excavation. As mentioned earlier, the one-way option includes many low-yield explosives; therefore, each salvo contains a relatively large number of explosives, totaling about 5 Mt. The eight salvos can be executed in four detonation days; including four months for contingencies, the nuclear phase for the one-way option could be concluded in 16 months.

Because each of the craters for the larger navigation prism option is bigger,

Table 5. Emplacement-hole drilling plan for the one-way canal. (On the first drilling pass, all the holes for the first detonation pass are drilled as well as many of those for the second detonation pass. The second drilling pass is made after the first detonation pass, to drill the remaining holes for the second detonation pass.)

<u>First drilling pass</u>	
Number of holes for first detonation pass	78
Number of holes for second detonation pass	<u>45</u>
Total number of holes	123
Total drilling time	18.5 months
(based on 8 drill rigs at 1.2 mo/hole = 18.5 mo = 1.54 yr)	
<u>Second drilling pass</u>	
Number of holes (for second detonation pass)	16
Total drilling time	6 months
(based on 8 drill rigs at 3.0 mo/hole = 6 mo = 0.5 yr)	

Table 6. Emplacement-hole drilling plan for the two-way canal. (On the first drilling pass, all the holes for the first detonation pass are drilled as well as some of those for the second detonation pass. The second drilling pass is made after the first detonation pass, to drill the remaining holes for the second detonation pass.)

First drilling pass	
Number of holes for first detonation pass	59
Number of holes for second detonation pass	14
Total number of holes	73
Total drilling time	11 months
(based on 8 drill rigs at 1.2 mo/hole = 11 mo = 0.92 yr)	
Second drilling pass	
Number of holes (for second detonation pass)	40
Total drilling time	15 months
(based on 8 drill rigs at 3.0 mo/hole = 15 mo = 1.25 yr)

Fig. 9. Schedule of nuclear operations for the one-way canal.

Fig. 10. Schedule of nuclear operations for the two-way canal.

fewer explosives are needed to cover the same length of excavation. Because of the large individual yields, however, many more salvos and two more detonation days than for the one-way option are required. Again, allowing four months for contingency time, 30 months might be required for the nuclear phase of the two-way option.

EVACUATION AREA

A factor in considering any nuclear excavation option will be the number of people who have to be evacuated during and following the period of the nuclear detonations. Figure 11 is a map showing the evacuation area for Route 5A.

FIGURE 11

Fig. 11. Evacuation area for Route 5A.

Evacuation limits to the north, south, and east are roughly determined by the 0.3-g seismic acceleration limit; to the west, boundaries reflect the 255-285° fallout sector chosen. Natural terrain features

have been used to define the exclusion area as much as possible.

It should be noted that none of the population of Malaysia, India, or Indonesia would need to be evacuated.

Summary and Conclusions

This preliminary assessment of the practicality of constructing, by means of nuclear excavation techniques, a portion of a sea-level canal following Route 5A across the Isthmus of Kra has not turned up any factors which would preclude building such a canal. We believe the nuclear explosions could be carried out in complete safety without danger to either project personnel or the general population. By excluding nonproject personnel from within the 0.3-g acceleration contour and exercising selective control outside this region, the possibility of personal injury from ground motion will be eliminated.

Exclusion will also be necessary to prevent any exposure of people to radioactivity above safe levels, such as those

recommended by the International Commission on Radiological Protection. Within the national boundaries of Thailand, this requirement can be met by establishing an exclusion area from which the local residents will be evacuated during the detonation phases and for some time afterward. Based on preliminary estimates, fewer than 200,000 people should be affected. No evacuation will be necessary outside the borders of Thailand.

A number of uncertainties remain to be determined during later study and design phases, many dealing with the specifics of the route topography and geology. In addition, a more precise estimate of the nuclear excavation costs needs to be developed. Based on studies which were done for the Interoceanic

Table 7. Comparative statistics for two-way and one-way canal concepts.

	Two-way	One-way
Navigation prism width and depth (ft)	1600 X 110	650 X 110
Length of nuclear excavation (km)	45	45
Equivalent conventional volume (m ³)	2.4×10^9	1.2×10^9
Number of explosives	113	139
Number of salvos	21	8
Total nuclear yield (Mt)	105	41
Number of detonation days	6	4
Time (months) from first detonation to last, including contingency time (months)	30	16

Canal, a cost of \$2 million per detonation appears at this time to be a reasonable estimate useful for planning purposes. This amount should cover the nuclear explosive, the emplacement hole, safety studies, and all work related to the detonation. Not included are the costs for relocating local residents and any remedial excavation which might be necessary following the detonation phase.

Table 7 summarizes some of the relevant quantities for the wide and narrow canal options and permits some comparisons to be made. Costs might be about comparable, so the cost per unit

volume excavated for the two-way canal is about one-half of that for the one-way canal. Their relative utility depends on ship size and traffic projections, but should be in favor of the two-way canal. These advantages for the two-way canal are gained at a price — larger total yield (but fewer explosives), more salvos (hence, more potentially troublesome connections), more detonation days, a longer operational period, and larger collateral effects such as radiation doses. If the Kra project is pursued beyond the present survey, all these factors must be considered in arriving at the best overall design.