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EXPEDIENT MEASURES IN POSTATTACK INDUSTRIAL RECOVERY: PETROLEUM REFINING

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Definitions, assumptions, and needs for procedures and facilities for the rapid recovery of the United States, petroleum-based fuel industry in a nuclear, postattack environment are explained. Principal components of a typical refinery and two versions of an expedient crude oil unit (ECOU) are identified, along with their damage levels incurred with respect to nuclear blast, static overpressures. Repair or reconstruction efforts and schedules for primarily recovery essential diesel fuel are compared between

the typical refinery and the ECOU versions. Expedient, preattack component hardening, critical components requiring stockpiling consideration, and component substitutions for ECOU construction are briefly discussed. Recommendations to evaluate infrastructural and other damage mechanism influences on the expedient recovery concept and to expand that concept to other essential industrial sectors in the United States are offered.

SUMMARY

The main objectives of this study were: (1) to describe the damage that various major components of a typical U.S. refinery would suffer from the blast effects of a nuclear detonation in the megaton yield range and the effort, resources, and general procedures required to restore the production of petroleum-based products in the period following a nuclear attack on the United States; and (2) to identify and define innovative or expedient techniques by which needed fuel could be produced with the shortest possible delay time and with the expenditure of the least amount of effort and scarce resources. In addition, consideration was to be given to the likely effects of expedient protective measures on component damage and reconstruction effort.

A typical refinery, for the purposes of this study, is defined as having 32 major types of components and an overall crude-oil throughput volume of about 75,000 bpd. Damage to these components at selected values of the blast-wave overpressure is summarized in descriptive terms, and the repair effort is defined by interpolation equations. These equations, with coefficients evaluated empirically from previously reported data, describe the dependence of the repair effort on the overpressure within specified limits, for several alternative component situations or conditions. These are: (1) nonsecured (NS) without missile effects; (2) nonsecured (M) with missile effects; (3) secured (S) without missile effects; (4) an H/B ratio (the height of the component divided by the breadth of the profile-drag area perpendicular to the direction of propagation of the blast wave) that is equal to or less than 2; and (5) an H/B ratio greater than 2. The interpolation equations permit the estimation of the repair effort for any incident overpressure within the specified limits, usually up to the overpressure causing essentially total destruction of the component.

In the overall refinery reconstruction process, the repair effort for a given component is assumed to convert to a replacement effort at

all overpressure for which the estimated repair effort exceeds the replacement effort. This assumption is used in all estimates of reconstruction effort. The effort term consists basically of the labor of skilled and unskilled crewmen, the crew supervisors (engineers and foremen), and the field-staff supervisor (top management personnel); each component is accounted for separately. Finally, the effort-estimating equations contain a term to account for the effect of the overall random orientations of the components to the direction of the blast wave front.

The maximum effort for refinery reconstruction occurs at the lowest overpressure for which all components are scheduled to be replaced by undamaged material or units. This occurs, in the estimates, at an overpressure of 22 psi, at which point the maximum sum of direct-labor effort (skilled and unskilled) is about 480,000 man-hours. The total effort of the full complement of repair men plus team and staff supervisors would be about 1.3 times larger, or about 630,000 man hours. About 1.12 (12%) or 57,600 man hours of effort would be associated with staff supervision only. In addition, reconstruction effort is allocated to mobilization and the preparation of temporary facilities. Estimates of the effort and delay time due to site clearing are included, but the amounts are not counted specifically as part of the facility restoration effort. The tabulations for each component by successive increments of overpressure reveal which ones consume the greater repair effort and which are critically "soft" with respect to destruction and failure due to blast effects. The derived repair effort/overpressure relationships suggest that repair operations should convert completely to replacement operations when the incident overpressure is greater than about 10 to 15 psi. At these and higher incident overpressures, restoration of refinery operations would require about one year after an attack, if a full complement of skilled and staff personnel of about 250 workers were available and each worked an average of 56 hours per week.

The innovation introduced into this study was derived from the recognition that one of the major fuels used in train and truck transport, in many industrial plants, and in farm tractors and construction equipment (all required for a variety of postattack recovery operations) is diesel fuel, which is a major product of the front line of the typical refinery. This resulted in the design of an Expedient Crude Oil Unit (ECOU), which utilizes a relatively small number of units of 15 of the major refinery components to process crude-oil at a throughput rate of 50,000 bpd. The maximum labor effort to construct the ECOU on the original refinery foundations is estimated to be about 44,000 man-hours (and as much as about 75,000 man-hours for a full-complement work force), expended over a period of 9 weeks with a total work force of about 130 persons, each working 56 hours per week.

Complete details of construction materials, equipment, and manpower estimates by skill are presented in the appendices for the designed ECOU and for an alternative, prefabricated, Skid-Mounted Expedient Crude Oil Unit (S-ECOU). The tabulations include estimates for construction of these units on new sites, and examples of schedules are presented for their construction. The S-ECOU assembly, of course, requires the least post-attack effort and time to achieve diesel fuel production. The total postattack effort, including crew and equipment mobilization, preparation of temporary facilities, and new site preparation, is estimated to be about 70,000 man-hours for the ECOU and about 20,000 man-hours for the S-ECOU. The schedules, with a work force of about 130 people for the ECOU and about 60 people for the S-ECOU, would have the ECOUs operational 9 weeks after mobilization, and the S-ECOUs would be operational about 3 weeks earlier.

In all the effort and time estimates, the delivery of people and materials to the site is not included; also, delays in such delivery are not considered. The results are meant to establish requirements for the needed component repair and replacement tasks and the range of delay times involved in the accomplishment of these tasks. For the ECOU and the S-ECOU, estimates of the efforts involved in the construction omit storage facilities at the site(s), under the assumption that the products would be transported immediately and continuously to user facilities.

The effect of fire damage on the typical refinery and on the reconstruction of the refinery--or its first-stage partial reconstruction to ECU status--was not considered in the study. Results of previous studies have indicated that, if an attack occurred while a refinery was in full operation, the resulting fires would completely destroy the facility and a new facility would have to be constructed before plant operations could be resumed. This situation is more or less equivalent to that which would be caused by an incident overpressure of about 22 psi without fire; in each case, the maximum reconstruction effort would be required. Results of previous studies also indicate that, with preattack shutdown, the fire hazard is essentially eliminated or reduced to a very low probability or a very low level of damage if a few small fires are ignited. Consequently, all the estimates of the reconstruction effort that are given for incident overpressures less than 22 psi apply to the case of refinery shutdown prior to attack.

The simple expedient protective measures assumed for the so-called secured (S) condition for each refinery component include such actions as adding guy wires and additional bracing and frame supports, and topping off tanks and filling columns and vessels with water or other nonflammable fluids. Such measures are effective in reducing estimated repair efforts by 20% to 60% in the incident overpressure range of 2 to 10 psi. Above about 10 psi, the force of the blast overrides the "hardening" effect of these measures. The hardening effect amounted to a differential decrease in the incident overpressure of no more than 2 to 2.5 psi over the entire array of components in the overpressure range of 2 to 10 psi.

In summary, the results of this investigation show that the ECOU and the expediency concept underlying its evolution to a design stage represent a viable and promising option for the rapid postattack recovery of production of a vital survival item, diesel fuel. Side issues that arose during the study but that were outside its scope included the stockpiling of required resources, the preattack preparations, the infra-structural and other inputs, the management coordination of manpower sources in the postattack period, and the fallout radiation problem. Furthermore, it became clear that the expediency concept developed here may well have application to the postattack recovery of other critical industries.

CONVERSION FACTORS FOR U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

To Convert From	To	Multiply By
barrel (petroleum, 42 gallons)	meter^3 (m^3)	1.589 873 × E -1
British thermal unit (thermo-chemical)	joule (J)	1.054 350 × E +3
degree Fahrenheit	kelvin (K)	$t_K = (t_F + 459.67)/1.8$
foot	meter (m)	3.048 000 × E -1
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 × E -3
horsepower (electric)	watt (W)	7.460 000 × E +2
inch	meter (m)	2.540 000 × E -2
mil	meter (m)	2.540 000 × E -5
mile (U.S. statute)	meter (m)	1.609 344 × E +3
pound-force/inch^2 (psi)	kilopascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 × E -1
ton (short, 2000-pound)	kilogram (kg)	9.071 847 × E +2
yard	meter (m)	9.144 000 × E -1

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SECTION 1
INTRODUCTION

1-1 BACKGROUND

For several decades, petroleum refineries have been considered to be prime targets in a nuclear attack on the United States. Consequently, both the vulnerability of refineries to weapons effects and the problems of recovering the production of petroleum-based fuels and chemicals after an attack have been of concern to the government and the petroleum industry. Military operations as well as industrial recovery operations in the postattack period could use up available stockpiles or on-site inventories of petroleum-based fuels (diesel fuel, jet fuel, gasoline, etc.) rather quickly. The continuation of such operations would require the rapid repair of damaged refineries or the rapid construction of simple, expedient plants for the production of critical fuels, such as diesel fuel.

Some key civil defense measures in industrial strategies for limiting facility damage, for protecting personnel, and for expediting national recovery in case of attack are listed in Table 1 for petroleum refining and for another basic industry, metal fabrication. The table shows at what stage in a nuclear attack scenario the repair effort would be scheduled to take place and how its implementation would depend on protective and other actions taken in peacetime, during the crisis period, and even during the attack itself.

Previous studies related to this one were concerned with the vulnerability of individual refineries and their component parts and processes, as well as with the time and effort required to restore damaged units to an operable state. One of the early studies on the damage and repair of refineries is that of Fernald, Entwide, and Bull;[1] three actual refineries, ranging in capacity from 100,000 to 360,000 bpd of crude oil, are used as examples for vulnerability to blast and thermal effects from

Table 1. Key civil defense measures in industrial strategies for postattack recovery.

Industry	Measures Taken at Various Stages of Attack Scenario			
	Peacetime	Crisis	Transattack	Early Postattack
Petroleum refining	Large inventories Stockpiling of critical replacement components User equipment design Provision of personnel shelters	Innovative storage Dispersal of mobile equipment Dispersal of personnel Component hardening	Protection of workers Protection of inventories Damage control	Assembly of prefab components or stockpiled parts Repair of damaged components Rationalized product use
Metal fabrication	Dispersed construction Structure hardening Provision of personnel shelters Product standardization	Expedient hardening Fire protection Dispersal of personnel	Protection of workers Control of plant fires	Expedient repair Product substitution Expedient production

nuclear weapons in the megaton yield-range and for postattack repair effort and delay time. The general conclusions are that the most vulnerable components of these refineries are the control houses and cooling towers and that, although wooden cooling towers could be replaced relatively rapidly, the repair or replacement of the control house would require almost 200 8-hour calendar days. The control house is considered essential because it serves as the operating center of the highly complex and automated network of processes that constitute a modern petroleum refinery. Fernald et al. found that the crude-oil still, damaged at about 3.5 psi of blast-wave overpressure, might require 150 days and about 4000 man-days of effort to repair. At about 7.0 psi, the time and effort would increase to almost 300 days and 18,000 man-days, respectively.

The problem of fire was also addressed by Fernald et al., and the conclusion is that any considerations of component damage are irrelevant for a nuclear explosion near an operating refinery, whose heated and pressurized combustibles would ignite or explode when pipes are broken and major components are tipped or displaced, at overpressures no greater than 5 psi, causing total destruction of the refinery. However, rapid shutdown can be accomplished in about 15 minutes with only minor damage (the normal shutdown period is around 4 hours) and, with the units emptied of all combustibles, the fire hazard becomes negligible in the operating refinery components. Hence, with a rapid shutdown capability, blast effects are the most important in the refinery proper (but not in the storage areas). The authors also conclude that the order in which the various processing units are repaired should be based on forecasts of postattack fuel requirements, giving as an example: (1) the crude-oil still for diesel fuel, furnace fuel, jet fuel, and straight-run gasoline; (2) the catalytic cracker for high-octane gasoline and light naphtha; (3) the vapor recovery units for butane and propane; and (4) the alkylation plant for high-octane alkylates.

A comparable study of damage and repair effort has been reported by Singer et al.[2] for a crude-oil refinery of 50,000 bpd capacity. They estimated the times to resumption of production for all the products of a completely repaired refinery, as did Fernald et al. For the recovery from damage due to a combination of blast, fire, and debris for peak overpressures of 5, 10, 15, and 20 psi, the labor estimates are 5000, 18,000, 27,000, and 28,000 man-weeks, respectively.* A breakdown of this effort into broad skill categories is given, along with estimates of materials needs.

Foget, Van Horn, and Staackman[3] investigated the damage characteristics, the repair effort, the repair-team skill composition, the materials and supplies required, and other related factors in the recovery of the components of various types of chemical plants, including refineries. Their study includes the development of a rough relationship between repair effort and overpressure, on a component basis. (This model provided the basis for the information and data on component damage and repair effort given in this report.) The tabular information on component damage due to blast effects includes considerations of damage caused by projectiles and alternative pressure effects (diffraction and drag). Descriptions of typical damage and estimates of the repair effort for each type of refinery component are given for several values of the peak overpressure, with blast-wave characteristics similar to those from nuclear detonations in the megaton yield range (low airburst). Values are given for all parameters of the above-mentioned repair effort/overpressure model.

At any given overpressure, the type and severity of damage are shown by Foget et al. to be very sensitive to the orientation of the component to the direction of propagation of the blast-wave front and to the position of one compoment relative to another, nearby component. The tabulated results are for the "worst-case" orientation rather than for a random orientation, so their direct use would give high estimates of damage at any given overpressure, along with somewhat high estimates of the required repair effort. However, since no direct experience in the repair of a nuclear weapon blast-damaged refinery is available as a

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*For the purposes of this report, a man-week is defined as 168 man-hours, i.e., the equivalent of three 8-hour shifts per day, 7 days per week.

reference point for the effort actually required in a repair operation, the apparent overestimates of damage do not necessarily translate to overestimates of repair effort. The fire damage to components, presumably in a shutdown condition, is found to be relatively insignificant.

The information from reference 3 was used by Walker[4] to examine repair efforts for a set of "typical" refineries. In his report, repair efforts are considered for several types and sizes of refineries, emphasizing the recovery of production of motor fuels. The discussion includes the postattack repair of a crude-oil unit for early production of a limited array of fuels, but real delay times to production are not discussed.

The overall vulnerability of the U.S. petroleum-refining system has been reviewed by Stephens,[5] of the Office of Oil and Gas. The report describes the system as of 1973, but is now only qualitatively representative. It utilizes general information on vulnerability from several of the above-discussed reports, especially references 1 and 3.

Since the component-orientation damage-repair studies cited above consider only peak overpressures equal to or less than 20 psi, Block and Hullings[6] assumed, in a study for the Ballistic Missile Defense Systems Command of the U.S. Army, that the USSR, with its large weapons stockpile, might assign as many as two nuclear weapons to each refinery as a prime target. The expected result, of course, is the total destruction of essentially all parts of all components at peak overpressures much in excess of 20 psi everywhere. The "repair" would then consist of the replacement of all components in the construction of a new facility on an expedient or normal basis, as may be feasible, depending on preattack planning and preparation for this contingency.

Additional information on damage to industrial equipment and structures has been provided by Zaccor, Kamburoff, and Wilton[7] in their study on the general effects of hardening on both the damage and the subsequent repair effort. The information developed by these investigators generally parallels and extends that developed previously by Foget et al.;[3] it was used in the present study to refine, supplement, and extend interpolation functions that were derived in the course of this study. Zaccor et al. grouped industrial equipment by types, shapes, and sizes that would fit within selected rectangular volumes. Specific damage characteristics, calculated by drag-profile specifications using empirically derived relationships, are associated with each group.

In summary, the emphasis in previous research on the postattack recovery of production of petroleum-based fuels has been on the damage and repair of the individual components of a petroleum refinery. Most studies dealing with the overall recovery of U.S. refineries are more than a decade old, and they focus on recovery of the whole array of products at the time that repair is completed. Although an expedient staged recovery process has been considered as a possible alternative,[1] no comparable estimates of effort, manpower, and delay times have been reported.

Because front-line products such as diesel fuel are utilized by most trucks and farm machines and even by some automobiles, their early postattack production should have high priority in the recovery schedule of essential items for national survival. The expedient staged recovery process for petroleum products would then consist of first recovering the front line of a lightly to moderately damaged refinery, to the point where diesel fuel and one or two associated products could be produced. Afterward, other lines could be repaired and activated when ready, as in the sequence suggested by Fernald et al.[1] Depending on postattack damage or on recovery requirements for a given product or array of products, the repair work could be held indefinitely at any desired stage of production recovery.

In a moderately to severely damaged refinery, the repair effort may become so great and the time to recover production may be so long as to require an alternative approach to the repair in order to meet the survival demand for a critical fuel such as diesel fuel. The alternative suggested here is to construct a number of small, expedient, front-line crude-oil units that could be assembled rather quickly, ideally from stockpiled parts, to produce diesel fuel. For the petroleum industry, this simple refinery will be called the Expedient Crude Oil Unit (ECOU), two types of which are described in this report.

1-2 OBJECTIVES

The objectives of this study were to:

1. Develop estimates of (a) the severity of damage likely to be sustained by components of a typical refinery, (b) the resultant repair effort required and the general manner in which it might be accomplished, and (c) the time(s) after attack at which production of vital fuel supplies might be resumed.

2. Identify and define, where feasible, innovative or expedient processes by which needed fuel could be produced in the shortest possible time, with the least amount of repair effort, and/or with the least use of scarce resources (even with inefficient processes) to prevent critical fuel shortages.

1-3 SCOPE

The scope of this study includes the following four tasks:

1. Establish detailed descriptions and characteristics of the components of a typical refinery and of the blast damage to those components.

2. Develop quantitative relationships among (or between pairs of) the following variables: component(s) damaged, damage level, repair resource requirements, repair effort (or time), and production rate.

3. Identify approaches to the postattack repair of damaged refineries and to alternate production methods, estimate repair resource requirements, and prepare examples of repair schedules along with production start-time schedules for selected damage levels.

4. Identify and evaluate preattack protective measures that might significantly reduce the postattack repair effort (or time).

To obtain useful results within the budget and time constraints, the following limitations on the types and extent of parameters considered in this study were established:

1. The effects of fire on the degree of damage to typical refinery components and on the subsequent repair effort were not considered. This implies complete refinery shutdown prior to attack.

2. The delay time(s) and radiological hazards due to fallout were not considered. This would correspond to the case in which a refinery was damaged by blast effects from an airburst that did not reach the ground.

3. The availability and effects of external inputs such as water, electric power, manpower, stockpiled parts and supplies, local civil defense capabilities, government controls, and the like on the recovery effort were not considered. However, the study does consider the demands that the contemplated recovery effort would make on most of these inputs. All, of course, would be contributing factors to the feasibility of the recovery effort in a postattack situation.

4. A limited set of alternative repair situations was considered. The extensive repair of a damaged typical refinery is compared with partial repair sufficient only to produce diesel fuel and allied products. In addition, the design, fabrication, and assembly from stockpiled parts of two versions of an ECOU are described for comparison with the repair efforts for the damaged refinery.

5. In the recovery process, the replacement of components was given precedence over their repair when the former would require less effort. This tends to result in a proportionally lower estimate of repair effort as the incident overpressure, and hence the damage, increases. The replacement option would require a stockpile or on-site inventory of undamaged critical parts and components.

6. Efficiency of operation of the repaired refinery or of the ECOUs was not considered. For ECOUs, the use of older, simpler, low-technological components was taken to be appropriate.

The overall approach in this project was to use a multidisciplinary team consisting of systems analysts experienced in nuclear weapons effects and civil defense matters, together with engineers experienced in the design, construction, and operation of refineries. The engineering experts were from the Jacobs Engineering Group, Inc., of Concord, California, as a subcontractor. The working arrangement proved to be mutually beneficial and productive.

SECTION 2
CONCEPTS AND METHODOLOGY

2-1 DEFINITIONS AND ASSUMPTIONS

It is assumed, for all recovery operations, that the materials, parts, and supplies are on site or are delivered to the site when needed, so that the tabulated repair or replacement efforts refer only to on-site working times.

The total recovery effort for a given component of a refinery consists of the effort of the skilled and unskilled workers (carpenters, welders, electricians, pipe fitters, equipment operators, etc.), the team engineers and foremen, and the supervisory staff. For repair work only, the level of effort of the skilled and unskilled workers will tend to vary strongly with the degree of component damage (i.e., with the peak overpressure). Also, the composition of skills required for the repair of a given component may vary with the overpressure, because the type of damage changes from superficial damage of fragile equipment (e.g., instruments with glass covers) [illegible] vere buckling of heavy steel framing and steel-walled units. Further, it is assumed that the level of effort of the team engineers and foremen will be proportional to that of the skilled and unskilled workers, maintaining the same ratio for repair work as for replacement work; this assumption is somewhat arbitrary and, in practice, could change according to the available manpower and the experience of the available supervisors. The effort associated with staff supervision, administration, and coordination is assumed to be 12% of that of the skilled and unskilled repair team (not including the effort of the team engineers and foremen).

In this report, three terms are used quite often and require definition to avoid misunderstanding; these terms and definitions are:

1. Reconstruction: The repair or replacement of damaged or destroyed components of a facility at its previous site. Here the initial objective would be to reestablish the capacity to process crude

oil to produce diesel fuel. (In the repair-effort estimates given later, it is assumed that component foundations are not damaged and can be used.)

2. Repair: The fixing (by straightening, welding, soldering, resetting, realigning, reconnecting, etc.) and installation (including hookups) of damaged components of a facility. (In the repair-effort estimates given later, it is assumed that the needed skilled and unskilled personnel, materials, parts, equipment, and supplies are on site or are delivered to the site as needed.)

3. Replacement: The assembly and installation (including hookups) of undamaged, stockpiled components. (As above, the replacement-effort estimates do not include delivery of the needed items to the site.)

In general, repair refers to the reconstruction of a damaged refinery component on its previous foundation, whereas replacement can refer either to reconstruction or to construction of a new component or facility at either the original or a new site.

The effort and time required for recovery of fuel production after a refinery receives blast damage from a nearby nuclear (airburst) detonation will depend on the average incident overpressure to which the entire installation is subjected. If this is such as to cause little to moderate damage to most components, it may be feasible to repair some of the components and replace others. If the damage to many or most of the components is severe, repair would be difficult and time consuming. The likely overpressure ranges and limits for different repair situations are discussed later.

For on-site repair, the site is first cleared of debris (the delay time for a survey of damage and an inventory of operable and repairable items if neglected). Orders and instructions for situations of site preparation of a new location (ECOU only) could be given within days after the cessation of hostilities has been verified. The assembly of repair teams and materials from inventories and stockpiles would follow and would probably continue during the reconstruction or construction period.

It is assumed that at the end of this period--for either the whole refinery or for the equivalent ECOU built from damaged but repaired refinery components--all resources (electric power, water, crude oil, etc.) will be available to start production of diesel fuel or a more extensive array of products. The same applies for those ECOUs built from stockpiles of components at previously used or new sites. The main concern is with the eff[illegible] time, resource needs, and related factors applicable to these parti[illegible]ular reconstruction/construction activities.

For almost any situation following a nuclear war, it can be assumed that the usual peacetime sources of components, parts, equipment, and labor skills will not be readily available and hence that working efficiency and quality will be considerably lower than peacetime levels. In expediency, therefore, the approach should be to simplify the design and construction of equipment, such as that in an ECOU.

2-2 RATIONALE FOR RAPID RECOVERY OF FUEL PRODUCTION

Although the rationale for rapid recovery of fuel production after a nuclear attack on the United States, including its petroleum industry, was stated previously, it is repeated here for emphasis as a new general approach to the study of, and planning for, postattack industrial recovery.

The first step is to identify the critical product or group of products among all of those in the production array. With regards to petroleum products, the transportation, agricultural, and industrial needs for diesel fuel are well known, and the demand for it should be high very early in the postattack period. Since diesel fuel can be obtained from the relatively simple distillation of crude oil, only a simple processing unit should be needed to produce it. Also, it was noted that diesel is currently obtained from the front-line processors in a regular refinery. Therefore, initial efforts in the recovery of production of petroleum fuels should focus on the repair of the front line of the refinery in the case that it is not severely damaged, and on the assembly of a simplified ECOU (specially designed for the purpose) if the refinery is heavily damaged. The specially designed unit should be as simple as possible, easily assembled, and easily operated.

This innovative, expedient approach should reduce the delay time to production of a critical product and should reduce the repair effort in terms of manpower, skills, equipment, and supplies (as well as cash outlays) for stockpiled items of all kinds. And, as already pointed out, other, less critical products can be obtained in a staged repair sequence for the whole facility.

2-3 COMPONENTS OF THE TYPICAL REFINERY AND THE SUGGESTED ECOUs

The numbers of various types of components in a typical refinery, with a throughput capacity of about 75,000 bpd of crude oil, and in a designated expedient crude oil unit (ECOU), with a throughput capacity of about 50,000 bpd, along with component substitution possibilities, are presented in Table 2. The refinery is at the low end of the throughput capacities of U.S. refiners, but damaged refineries of about a 75,000-bpd throughput appear to be more easily converted to ECOUs than refineries of greater capacity. Hence this was selected as "typical" for the purposes of this study.

The typical refinery is a high-technology facility that uses catalytic cracking as well as topping or skimming to acquire processed end products. Some units in such a refinery operate at pressures between 1500 and 2900 psi and at temperatures up to 1100 F. The products of a typical refinery include fuel oil, distillate fuels, gasoline, asphalt, kerosene, and petroleum gases. The total number of major components found in such a refinery is about 1900—not including equipment for handling steam, water, electricity, and heating fuel. Lubricants, motor oils, grease, and wax are not normally end products of refineries of this size; they are usually produced by refineries with throughput capacities in excess of 300,000 bpd.

An ECOU derived from damaged refinery components and erected on existing foundations would probably use the existing area layout. However, an ECOU constructed from new components or a new site with new foundations

Table 2. Number of components in a typical refinery and in the designated Expedient Crude Oil Unit (ECOU), and component substitutes.

Component	Typical Refinery	ECOU	Substitutes (Component Numbers)
1. Cooling towers, thin-walled	10		20,36
2. Catalytic cracking columns	2		
3. Liquid extraction columns	8		
4. Packed columns	20		
5. Distillation columns	45	3[a]	2, 29, 35
6. 55-gal drums	500		
7. Storage tanks, cylindrical		8[b]	5, 29, 35
8. Storage tanks, solids			
9. Storage tanks, open	100		
10. Storage tanks, conical-roof			
11. Storage tanks, spherical, heavy			
12. Skid- or frame-mounted equipment, small	12		
13. Small panels, racks, and mounted equipment	45	4[a]	
14. Electrical panels and racks	120	6[a]	
15. Large panels and racks	20	1[a]	
16. Pipe arrays and racks	225,000[c]	7,000[a,c]	
17. Box-type furnaces	10	2	18, 19
18. Cylindrical furnaces, vertical	12		
19. Package boiler units	2		
20. Heat exchangers	200	8	
21. Generators, ac, heavy-duty	2		
22. Electric motors, large	4		
23. Electric motors, small	200	12	
24. Transformers and capacitors, large	15	2[a]	
25. Steam turbine drives	80		
26. Blowers	25		

Table 2 continued

Component	Typical Refinery	ECOU	Substitutes (Component Numbers)
27. Centrifugal pumps	250	12	
28. Reciprocating compressors	15		
29. Pressure vessels, cylindrical			
A. horizontal, glass-lined	1		
B. horizontal, unlined	48	1	
C. horizontal, near ground	2		
D. vertical	75	2	
30. Package refrigerator units	10		
31. Motor control centers	12	2[a]	
32. Prefab buildings (control houses)	12	1[a]	
33. Automatic dryer units	15		
34. Liquid-phase reactors	14[d]		
35. Crude columns, large		1	
36. Box coolers		2	

[a] Critical components.

[b] Can be omitted if alternative storage (pools, tank cars, etc.) is used.

[c] Square feet of double-deck pipeway.

[d] Eight low-pressure (<500 psi) and six high-pressure (>500 psi) reactors.

could have a more convenient layout, designed primarily for rapid assembly and early production of diesel fuel. A suggested design of such a unit is shown in Figure 1, with the corresponding area plot plan shown in Figure 2. It can be seen that the ECOU is the front-line topping or skimming unit of the typical refinery. The major components are the crude column or distillation tower, the cooling towers or box coolers, and the necessary pumps, pipes, and heaters to perform a single rudimentary distillation of crude oil. A few nonessential components, such as the preheaters, are shown in the drawings but were omitted in the construction-effort estimates.

The designed ECOU requires a much smaller area than the typical refinery. For example, whereas the complete refinery might cover a square mile or so, the area needed for the ECOU is only 150,000 square feet, or about 0.005 square miles. Also, whereas the typical refinery has about 1900 units of around 30 major components (depending on how the storage tanks and a few other items are classified and counted), the ECOU has only about 70 units of no more than 15 major components. Despite these great differences, the designed ECOU entails only a relatively small drop in rated throughput of crude oil, from 75,000 bpd to 50,000 bpd.

The selection of a 50,000-bpd throughput capacity of crude oil for the ECOUs was based in part on the assumption that the postattack demand for petroleum fuels would be much lower than the current demand--possibly as low as 10% of it. There are now about 300 operating refineries in the United States, and it would require about 45 ECOUs to process the same throughput of crude oil that 30 typical refineries would handle, although diesel fuel would be the major end product of the designed ECOU.

Depending on the type of crude oil available, the diesel fuel output could be about 10,000 bpd for 23° API, typical California crude oil, or about 6000 bpd for 30° API, typical Texas crude oil. End products other than diesel fuel include heavy residuals, kerosene, stove oil, low-octane gasoline (or straight-run gasoline--this could be used to supplement diesel fuel in many essential applications), sour water, and off-gas. These products could be either stored or pumped away, according to need and available undamaged storage facilities.

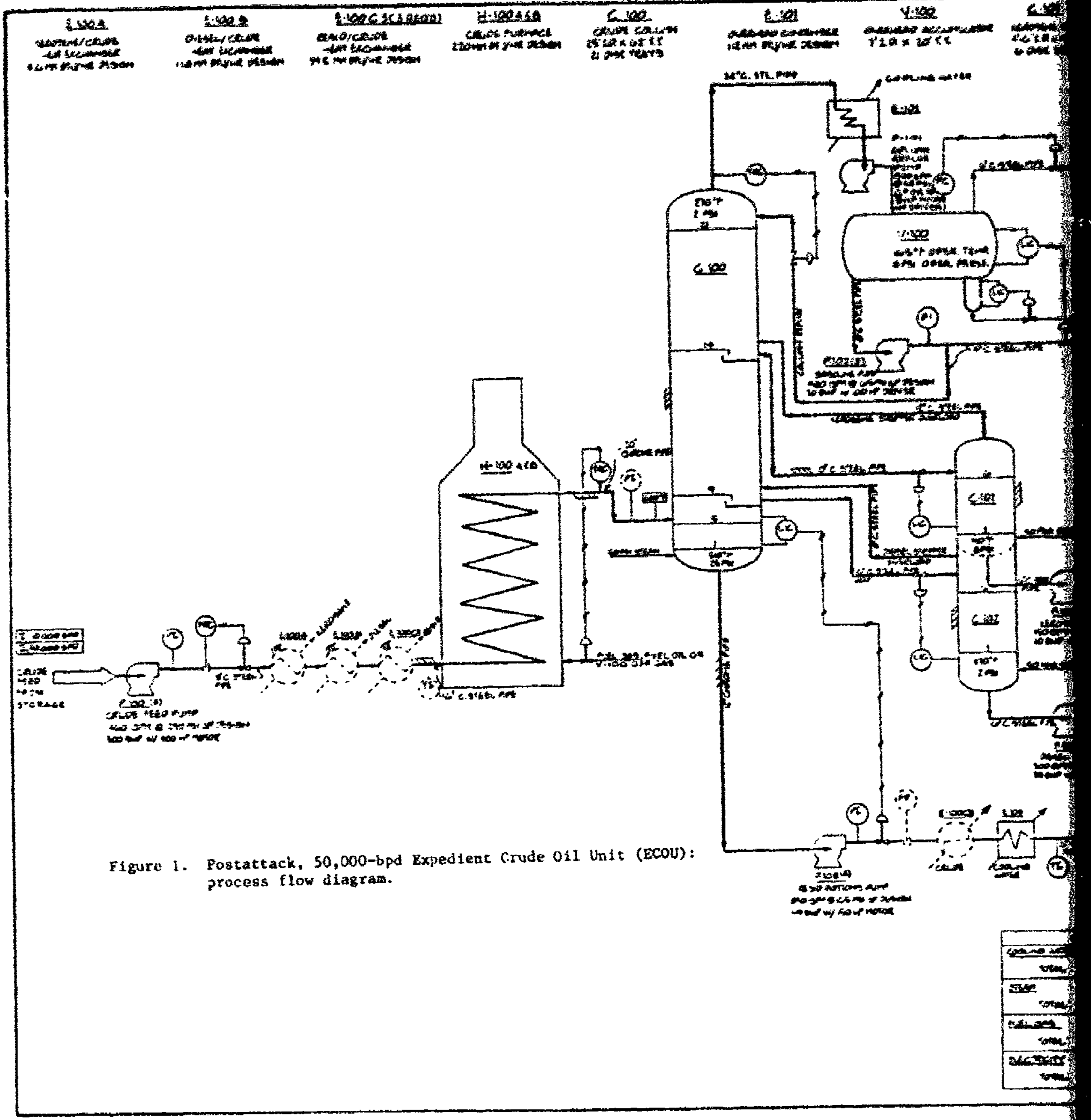
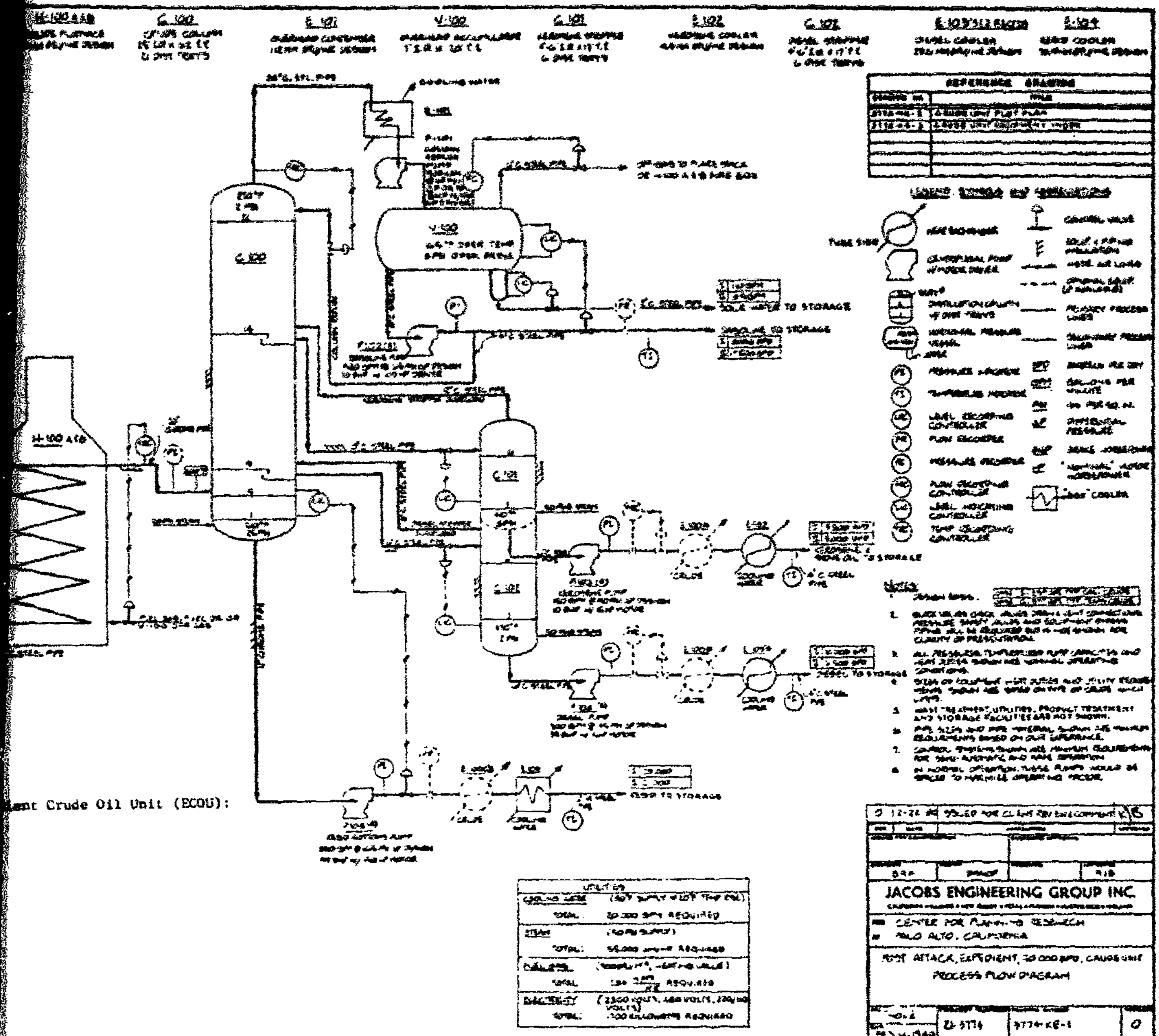


Figure 1. Postattack, 50,000-bpd Expedient Crude Oil Unit (ECOU): process flow diagram.



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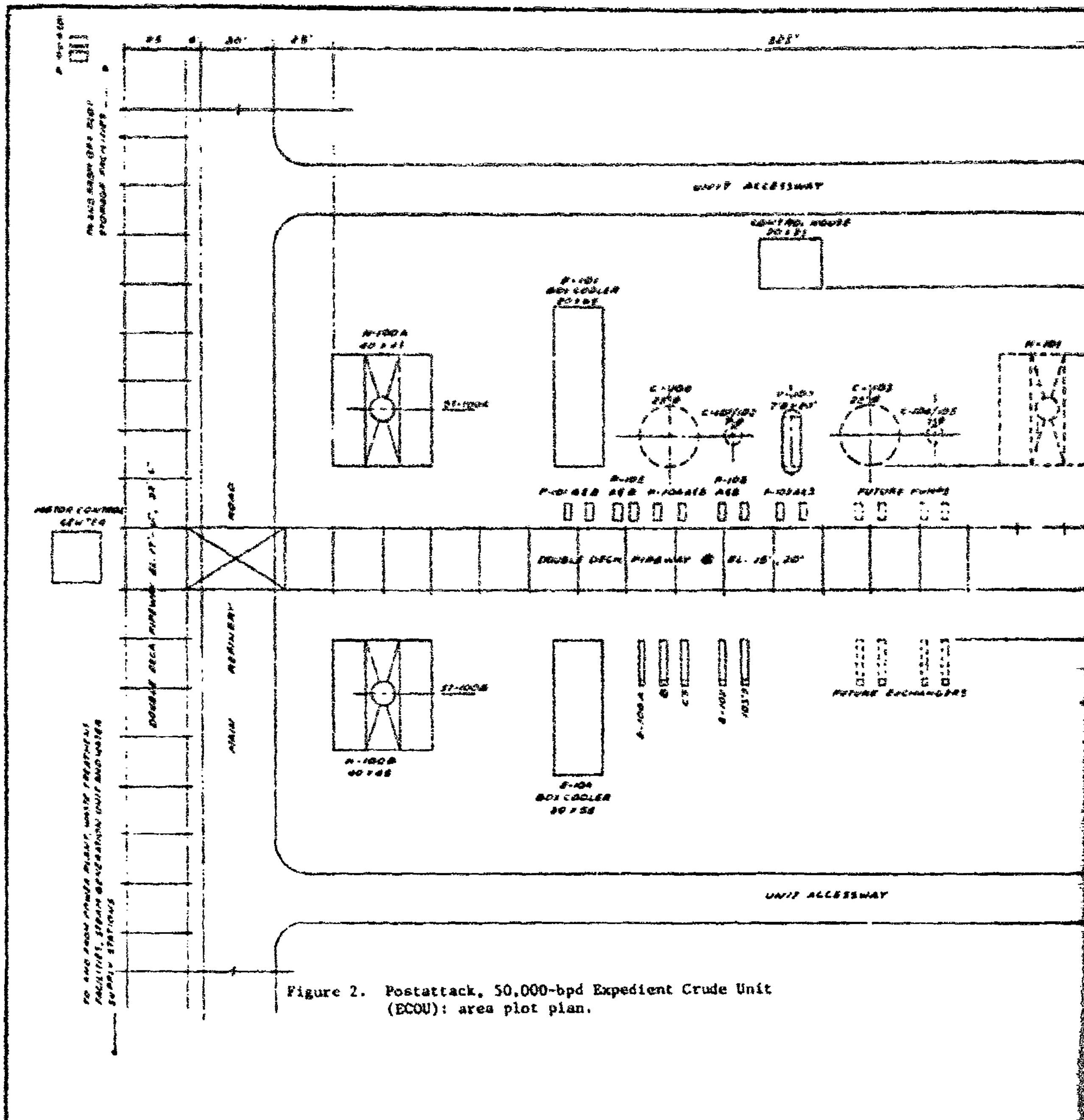
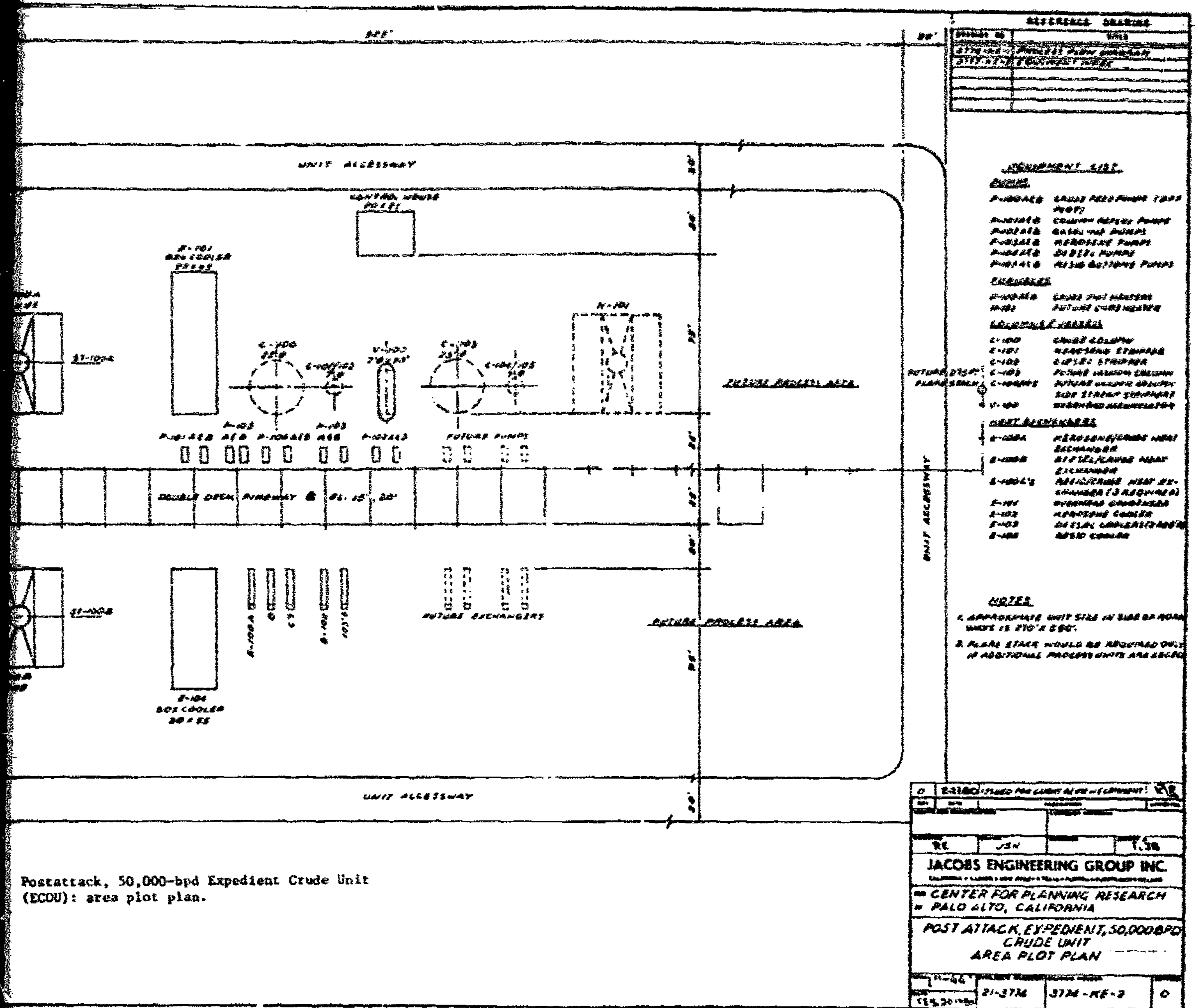


Figure 2. Postattack, 50,000-bpd Expedient Crude Unit (ECOU): area plot plan.



Postattack, 50,000-bpd Expedient Crude Unit
(ECOU): area plot plan.

ck, 50,000-bpd Expedient Crude Unit
area plot plan.

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As described in Section 1-3, certain constraints and limitations were set for this study of a typical refinery and the ECOU system. Certain inputs and some auxiliary systems that would affect the operation of the refinery or ECOU when it comes on line have not been considered. The utility inputs would include steam, water, electricity, and fuel gas. Steam is used to distill crude oil and to drive the turbines of standby pumps, water is used to cool distillates, electricity is used to drive motors, and fuel gas fires the crude furnaces. An ECOU would require about 55,000 lb/h of steam, 20,000 gal/min of water, 17,000 kW of electricity, and 284,000 ft^3/h of fuel gas. Also, the crude-oil supply would require a delivery mechanism, and the end products would require one or more delivery and/or storage systems.

The second, or alternate, form of the ECOU is a skid-mounted unit (S-ECOU). It would consist of modularized units mounted on 25 skids that could be shipped by either flatbed trucks or train cars. This design would reduce the need for storing component replacement parts and supplies in hardened or dispersed stockpiles, but it would require prefabrication of the modules, along with the cash outlay for peacetime labor and parts, long before a conflict was expected. At normal work rates, it might require a year or more to prefabricate the components of a 50,000-bpd S-ECOU.

Except for the skid mounts, the components of the ECOU and the S-ECOU would be the same. Requiring only site assembly, the S-ECOU would entail no true repair effort. Normally it would be assembled on a new, cleared site by placing the skids in proper arrangements and connecting the pipes, wires, and necessary inputs. Storage of the modules in dispersed, protected sites until needed is not considered here. A form of the S-ECOU reportedly has been designed and fabricated with throughput capacities of as much as 30,000 bpd, for use in peacetime crises or in natural disasters causing damage to existing refineries.*

*Howe-Baker Engineers, Inc., a refinery construction firm located in Tyler, Texas, is the manufacturer. See Appendix C for a complete list of skid-mounted refineries constructed by this company.

2-4 REPAIR AND CONSTUCTION EFFORTS AND DAMAGE RELATIONSHIPS FOR COMPONENTS OF THE TYPICAL REFINERY

An empirical formula for representing mathematically the dependence of the repair effort on the peak overpressure for any component piece of equipment in the chemical industry was proposed by Foget et al.[3] The formula contains a number of empirically evaluated coefficients and has the general form of the law of diminishing returns. Assuming a maximum "repair" effort for construction of a new component from a stockpile or inventory (presumably required at the peak overpressure for destruction of the whole component), it appears that the formula would best apply to those components for which the mode of damage is the same over the whole range of overpressure, but the effect becomes numerically greater as the overpressure increases.

Because of these possible limitations and because of the approximate nature of both the data and their likely application for planning, a simplified set of interpolation formulas was derived for use in this study. (No one has yet reported experimental data on the damage and repair of a modern operating refinery. Also, almost all of the available computed information is conservative with respect to the offensive, or attack, application.)

The selected interpolation relationships between repair effort (skilled and unskilled labor inputs only) and peak overpressure (as a parameter of "damage) are defined as follows:

$$e_i = e_i^o(\Delta P/\Delta P_0)^{m_i} \quad \text{(m-h/unit)} \quad , \qquad (1)$$

in which e_i is the repair effort in man-hours per unit of refinery component i, ΔP is the incident peak (static) overpressure in psi received by component i, ΔP_0 is a reference overpressure whose value is set at 1 psi, and e_i^o and m_i are empirically evaluated coefficients.

In the general case, Equation 1 is specified to be applicable only over a given range of ΔP for a given set of numerical values of e_i^o and m_i. For several components, the repair effort information (and the damage descriptors) suggests that the mode of damage of a component changes drastically with a change in overpressure (e.g., it may range from the stripping off of light external fixtures and instruments at low overpressures to the severe deformation of steel walls and frames at high overpressures). In some cases, the repair effort/overpressure relationship for the new damage mode could be roughly represented by Equation 1 with different values for the empirical coefficients; in other cases, a second form of the interpolation relationship was employed, namely:

$$e_i = A_i(\Delta P - B_i) \quad \text{(m-h/unit)} \quad , \tag{2}$$

in which A_i and B_i are empirically evaluated coefficients. In all cases, the coefficients were evaluated from graphical representations of reported estimates of e_i at selected values of ΔP.

Available values of e_i were generally derived for the orientation giving the maximum response of a component to the blast-wave front (a 50% probability of compoment failure was used in the coefficient evaluation). These tabulated values (calculated for maximum response) required modification to account for the random orientations of similar components to the direction of propagation of the blast wave. For all units of component i, the total repair effort is defined by:

$$E_i = N_i F_i e_i \quad \text{(m-h)} \quad , \tag{3}$$

in which N_i is the total number of i units per recovered refinery and F_i is the fraction of the unit repair effort required when the latter is averaged over all units of component i, owing to random orientation of the components to the blast wave and, in part, to the assumed 50% probability of the stated failure to occur. The value of F_i is assumed to be 0.5 for all ΔP values through 1/2 of that ΔP value estimated for component destruction. At higher overpressures, the value of F_i is assumed to increase linearly on a probit scale from 0.5 to 0.99 as ΔP increases from ΔP(dest)/2 to ΔP(dest).

In the general case, five different damage-repair conditions may occur, for which five sets of coefficients may exist. Two of these conditions depend on the overall shape of the component with respect to an incident blast wave. This geometrical dependence of damage on overpressure is defined in terms of the ratio of the height of the component to the breadth of the profile-drag area perpendicular to the direction of propagation of the blast wave, H/B. One condition pertains to those components with shapes for which $H/B > 2$, and a second to those with shapes for which $H/B \leq 2$.

The other three conditions are: (1) the unprepared, or not secured case (NS), (2) the not secured case with missiles (M), and (3) the prepared, or secured case (S). The NS refers to components of a refinery that have not been hardened or altered in any way to reduce damage from blast effects; this condition would apply to a peacetime operating refinery. The NS case does not include damage due to shock-wave-propelled debris projectiles, called missiles, that could puncture many items in a refinery; the effect of the missiles is included in case M. In case S, the effects of expedient rudimentary protective measures are included.

During a crisis period, actions such as adding more and stronger guy wires to essentially vertical components ($H/B > 2$) and strengthening framing and anchors would be beneficial. Also, storage tanks could be filled with fuels and/or water, and the tank-farm dikes could be enlarged. Most critical, however, would be an appropriate shutdown procedure, upon attack warning, that included the flooding of as many columns and towers as possible with noncombustible fluids.

For a given overpressure and component, the value of e_i is greatest for case M and smallest for case S. Values for the coefficients of the above-defined interpolation equations relating the unit repair effort and peak overpressure for various typical refinery components are summarized in Table 3. The values of e_i^0 are in man-hours per unit, whereas those of A_i are in man-hours per unit per psi; the values of m_i are dimensionless; and the values of B_i and ΔP are in psi. Estimates of the construction-team effort for the replacement of destroyed components or their construction with new parts and structures, as in the construction of an ECOU at a new site, are presented in Table 4. In the repair of a damaged refinery, the effort of the team supervisors (engineers and foremen) is assumed to have the same ratio as in Table 4; thus for component no. 1, the relative effort for the team supervisors would be 150/750, or 0.2, times the calculated value of E_i; thus the total effort for repairmen plus team supervisors would be $1.2E_i$ and the overall effort with staff supervision would be about $1.3E_i$.

Examples of construction schedules for the ECOU are given in Figure 3 for Case A situations (see footnote a in Table 4) and Figure 4 for Case B situations; an example for the S-ECOU, Case B, is given in Figure 5. Summaries of the labor mix required for specific jobs, applicable either to the component listing of Table 4 or to the skilled construction activities of Figures 3, 4, and 5, are given in Appendix A; detailed estimates of these quantities and of associated supplies, parts, and equipment for the ECOU and S-ECOU construction activities are given in Appendix B.

The construction schedules in Figures 3, 4, and 5 are examples only, since the actual times will depend not only on the effort in man-hours or man-weeks but also on the size of the available work force and its skill composition. Assuming that the average working time for each person over the period of any construction task is 8 hours/day, or 56 hours/week, the number of people required is simply the total effort in man-weeks divided by the working time in weeks, multiplied by 3 (see footnote on page 16). Thus the site-clearing task of Figure 3, requiring an estimated effort of 30 m-w to be accomplished in 2 weeks, would require a team of (30/2)x3, or 45 people. If none of the people required for the schedule of Figure 3 were assigned to more than one activity, the total construction work force would be no more than 313. It is clear, of course, that if the time to production were not a factor and a single 8-hour shift per day were scheduled, no more than 104 people would be required. However, the overall scheduled construction time would be increased from about 9 weeks to about 27 weeks. Similarly, the schedule of Figure 4 would require no more than 309 people, and that of Figure 5, no more than 207 people. Many other alternative combinations of number

Table 3. Coefficients of the interpolation equations relating unit repair effort and peak overpressure for various typical refinery components (derived from information in references 3 and 7).

Component	Case	H/B	Equation 1 Values: e_i^o $\left(\frac{\text{m-h}}{\text{unit}}\right)$	Equation 1 Values: m_i	Equation 1 Values: ΔP limits[a] (psi)	Equation 2 Values: A_i $\left(\frac{\text{m-h}}{\text{unit}\cdot\text{psi}}\right)$	Equation 2 Values: B_i (psi)	Equation 2 Values: ΔP limits[a] (psi)
1. Cooling towers, thin-walled	NS	All	104	1.15	≤6	-	-	-
	M	All	125	1.15	≤6	-	-	-
	S	≤2	45	1.50	<7	-	-	-
	S	>2	59	1.50	≤6	-	-	-
2. Catalytic cracking columns	NS	≤2	32	1.08	<7	1120	6.77	7≤ΔP≤9
	NS	>2	32	1.20	<7	1160	6.72	7≤ΔP≤9
	M	≤2	32	1.08	<6	2300	5.91	6≤ΔP≤7
	M	>2	32	1.20	<6	2400	5.90	6≤ΔP≤7
	S	≤2	16	1.32	<10	540	9.38	10≤ΔP≤14
	S	>2	2.5	2.38	<8	575	7.39	8≤ΔP≤12
3. Liquid extraction columns	NS	>2	56	0.86	<10	2260	9.82	10≤ΔP≤N
	M	>2	67	0.86	<9	2050	8.78	9≤ΔP≤10
	S	>2	22	1.14	<10	1175	9.74	10≤ΔP≤12
4. Packed columns	NS	>2	27	1.24	≤9	880	8.03	9<ΔP≤10
	M	>2	40	1.22	≤9	1420	8.59	9<ΔP≤10
	S	>2	16	1.49	≤10	855	9.43	10<ΔP≤12
5. Distillation columns	NS	>2	27	1.24	≤9	1820	8.77	9<ΔP≤10
	M	>2	32	1.25	≤9	1800	8.73	9<ΔP≤10
	S	>2	11	1.50	≤10	840	9.62	10<ΔP≤12
6. 55-gal drums (per drum)	NS	All	0.02	1.00	≤3	-	-	-
	M	All	0.03	1.00	≤2	-	-	-
	S	All	0.01	1.00	≤6	-	-	-
7. Storage tanks, cylindrical	NS,M	≤2	36	0	<0.8	-	-	-
			71	2.71	0.8≤ΔP≤3	-	-	-
	S	≤2	52	0	<2.2	-	-	-
			9.8	2.16	2.2≤ΔP≤10	-	-	-
	NS,M	>2	54	0	<0.8	-	-	-
			107	2.71	0.8≤ΔP≤2.6	-	-	-
	S	>2	77	0	<1.3	-	-	-
			51	1.59	1.3≤ΔP≤8	-	-	-

8.	Storage tanks, solids	NS	>2	195	0.241	<6	–	–	–
				0.13	4.21	6≤ΔP<9	–	–	–
9.	Storage tanks, open	NS	>2	48	0	<5	–	–	–
				0.70	2.63	5<ΔP≤12	–	–	–
10.	Storage tanks, conical-roof	NS	≤2	140	1.12	≤12	–	–	–
11.	Storage tanks, spherical, heavy	NS	≤2	50	1.36	≤13	–	–	–
		NS	>2	280	0.75	≤10	–	–	–
		M	≤2	130	1.00	≤12	–	–	–
		M	>2	330	0.76	≤8	–	–	–
		S	≤2	3.5	1.71	≤13	575	12.3	13≤ΔP≤15
		S	>2	54	0.77	≤12	615	11.4	12<ΔP≤14
12.	Skid- or frame-mounted equipment, small	NS	≤2	7.3	1.46	<8	–	–	–
		NS	>2	11	1.63	<5	–	–	–
		M	≤2	11	1.63	≤5	–	–	–
		M	>2	12	1.89	≤4	–	–	–
		S	≤2	7.0	1.16	≤10	–	–	–
		S	>2	8.5	1.16	≤9	–	–	–
13.	Small panels, racks, and mounted equipment	NS,M	≤2	32	1.00	≤3	–	–	–
		S	≤2	33	0.78	≤4	–	–	–
		NS,M,S	>2	32	1.00	≤3	–	–	–
14.	Electrical panels and racks	NS,M	≤2	40	1.33	<1	–	–	–
				40	1.12	1.0≤ΔP<4	–	–	–
		NS,M	>2	50	1.22	≤3	–	–	–
		S	≤2	20	1.00	<2	–	–	–
				27	1.03	2≤ΔP≤6	–	–	–
		S	>2	25	1.13	≤6	–	–	–
15.	Large panels and racks	NS,M	>2	26	2.59	<1.0	–	–	–
				26	1.00	1.0≤ΔP≤3	–	–	–
		S	>2	11	1.24	<2	–	–	–
				13	1.00	2≤ΔP≤6	–	–	–

(cont.)

Table 3 (continued)

Component	Case	H/B	Equation 1 Values: e_i^0 $\left(\frac{m\text{-}h}{unit}\right)$	m_i	ΔP limits[a] (psi)	Equation 2 Values: A_i $\left(\frac{m\text{-}h}{unit \cdot psi}\right)$	B_i (psi)	ΔP limits[a] (psi)
16. Pipe arrays and racks[b]	NS	≤2	0.010	0	< 2.4	-	-	-
			0.00027	4.26	2.4≤ΔP≤8	-	-	-
	M	≤2	0.0102	0	<1.4	-	-	-
			0.0039	2.95	1.4≤ΔP≤8	-	-	-
	NS,M	>2	0.0098	2.47	≤8	-	-	-
	S	≤2	0.025	0	< 2.7	-	-	-
			0.0056	2.48	2.7≤ΔP≤10	-	-	-
	S	>2	0.0111	1.96	≤13	-	-	-
17. Box-type furnaces	NS	≤2	1300	1.00	≤4	-	-	-
	M	≤2	1700	1.00	≤3	-	-	-
	S	≤2	1050	1.00	≤5	-	-	-
	NS,M,S	>2	1250	1.00	≤4	-	-	-
18. Cylindrical furnaces, vertical	NS	≤2	300	1.00	≤8	-	-	-
	NS	>2	160	1.19	≤10	-	-	-
	M	≤2	400	1.00	≤6	-	-	-
	M	>2	210	1.19	≤8	-	-	-
	S	≤2	240	1.00	≤10	-	-	-
	S	>2	130	1.23	≤11	-	-	-
19. Package boiler units	NS	≤2	11	2.04	≤10	-	-	-
	M	≤2	14	2.14	≤8	-	-	-
	S	≤2	9.5	1.95	≤12	-	-	-
20. Heat exchangers	NS	≤2	2.4	1.19	≤27	-	-	-
	NS	>2	6.0	1.00	≤20	-	-	-
	M	≤2	3.1	1.19	≤22	-	-	-
	M	>2	6.00	1.00	<20	-	-	-
	S	≤2	1.9	1.19	≤33	-	-	-
	S	>2	4.8	1.00	≤25	-	-	-
21. Generators, ac, heavy-duty	NS,M	All	100	1.00	≤4	-	-	-
	S	All	67	1.00	≤6	-	-	-

22. Electric motors, large	NS	≤2	22	2.00	<3	-	-	-
			47	1.32	3≤ΔP<12	-	-	-
	NS	>2	34	2.00	<2	-	-	-
			70	1.26	2≤ΔP≤10	-	-	-
	M	≤2	50	2.00	<2	-	-	-
			80	1.32	2≤ΔP≤8	-	-	-
	M	>2	52	2.32	<2	-	-	-
			108	1.26	2≤ΔP≤7	-	-	-
	S	≤2	13	2.00	<4	-	-	-
			38	1.23	4≤ΔP≤17	-	-	-
	S	>2	3.5	3.96	<3	-	-	-
			94	0.96	3≤ΔP≤15	-	-	-
23. Electric motors, small	NS,M,S	≤2	23	1.00	≤23	-	-	-
A. ac, <1000 hp	NS,M,S	All	11	1.00	≤15	-	-	-
B. dc, <1000 hp	NS,M,S	All	14	1.00	≤12	-	-	-
24. Transformers and capacitors, large	NS	<2	81	1.02	≤8	-	-	-
	NS	>2	90	0	<1.7	-	-	-
			26	2.34	1.7≤ΔP≤4.5	-	-	-
	M	≤2	90	0	<1.2	-	-	-
			63	1.52	1.2≤ΔP≤5	-	-	-
	M	>2	90	0	<1.2	-	-	-
			58	1.94	1.2≤ΔP≤4	-	-	-
	S	≤2	45	1.16	≤10	-	-	-
	S	>2	81	0	<2.2	-	-	-
			10	2.75	2.2≤ΔP≤5	-	-	-
25. Steam turbine drives	NS,M,S	≤2	0.28	1.98	<23	-	-	-
26. Blowers	NS,S	≤2	2.3	1.77	≤10	-	-	-
27. Centrifugal pumps	NS,M,S	≤2	0.0062	3.33	7≤ΔP≤17	1.0	3.0	3≤ΔP<7
28. Reciprocating compressors	NS,M,S	≤2	11	0.98	≤26	-	-	-

(cont.)

Table 3 (continued)

	Component	Case	H/B	Equation 1 Values: e_i^o $\left(\frac{\text{m-h}}{\text{unit}}\right)$	m_i	ΔP limits[a] (psi)	Equation 2 Values: A_i $\left(\frac{\text{m-h}}{\text{unit}\cdot\text{psi}}\right)$	B_i (psi)	ΔP limits[a] (psi)
29.	Pressure vessels, cylindrical								
	A. Horizontal, glass-lined, at height of 6 ft	NS,M,S	≤2	30	1.15	≤9	-	-	-
	B. Horizontal, unlined, at height of 6 ft	NS,M,S	≤2	13	1.33	≤11	-	-	-
	C. Horizontal, near ground	NS,M,S	≤2	3.8	1.44	≤20	-	-	-
	D. Vertical	NS,M,S	>2	20	1.15	≤14	-	-	-
30.	Package refrigerator units	NS,M,S	All	7.9	1.41	≤6	-	-	-
				50	0.434	7<ΔP≤24	-	-	-
31.	Motor control centers	NS	All	2.8	2.00	≤4	-	-	-
		M	All	32	1.95	≤4	-	-	-
		S	All	22	1.88	≤5	-	-	-
32.	Prefab buildings (control houses)	NS,M	≤2	22	2.92	≤2	-	-	-
				222	0.40	3≤ΔP≤5	-	-	-
		S	≤2	15	2.70	≤3	-	-	-
				164	0.50	3≤ΔP≤7.5	-	-	-
33.	Automatic dryer units	NS	≤2	6.3	1.00	≤10	-	-	-
		M	≤2	7.4	0.93	≤10	-	-	-
		S	≤2	4.7	1.08	≤11	-	-	-
34.	Liquid-phase reactors	NS,M	≤2	3.1	2.32	≤7	-	-	-
		S	≤2	1.2	2.00	≤15	-	-	-
35.	Crude columns, large	NS	>2	81	1.24	≤9	5460	8.77	9<ΔP≤10
		M	>2	96	1.30	<9	5400	8.73	9<ΔP<10
		S	>2	33	1.50	≤10	2860	9.62	10<ΔP≤12
36.	Box coolers	NS,M,S	<2	390	1.11	<12	-	-	-

[a] The maximum value of the ΔP limit denotes the overpressure for destruction of the component.

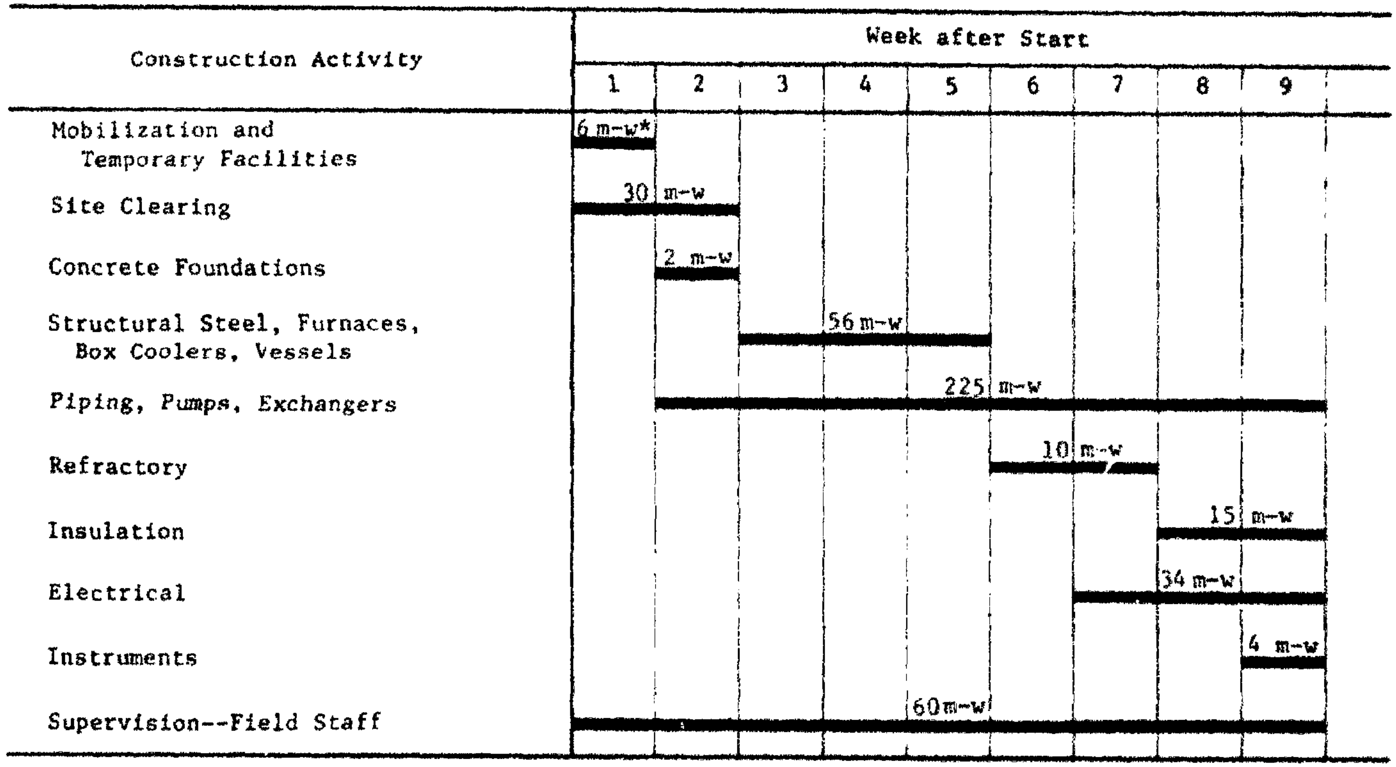
[b] Here, e_i^o is in m-h/ft^2 of double-deck pipeway (does not include effort for preparation of concrete foundations, etc.).

Table 4. Estimates of effort (in man-hours per unit) for the replacement or construction of refinery components from stockpiled resources.

Component	Skilled and Unskilled Labor[a] Case A	Case B	Team Supervisors
1. Cooling towers, thin-walled	750	780	150
2. Catalytic cracking columns	2200	2250	550
3. Liquid extraction columns	2100	2150	500
4. Packed columns	1600	1640	400
5. Distillation columns	1900	1950	480
6. 55-gal drums	0.04	0.04	0.002
7. Storage tanks, cylindrical	800	820	100
8. Storage tanks, solids	700	720	80
9. Storage tanks, open	350	370	40
10. Storage tanks, conical-roof	1360	1400	220
11. Storage tanks, spherical, heavy	1300	1340	200
12. Skid- or frame-mounted equipment, small	16	26	2
13. Small panels, racks, and mounted equipment	80	85	30
14. Electrical panels and racks	160	170	60
15. Large panels and racks	70	75	24
16. Pipe arrays and racks	1.54[b]	2.25[b]	0.25[b]
17. Box-type furnaces	4900	6250	400
18. Cylindrical furnaces, vertical	2300	3100	280
19. Package boiler units	1100	1300	100
20. Heat exchangers	100	130	40
21. Generators, ac, heavy-duty	64	90	20
22. Electric motors, large	160	190	50
23. Electric motors, small	100	100	40
24. Transformers and capacitors, large	480	480	180
25. Steam turbine drives	60	60	10
26. Blowers	24	24	2
27. Centrifugal pumps	50	80	9
28. Reciprocating compressors	180	220	30
29. Pressure vessels, cylindrical			
A. horizontal, glass-lined	320	350	30
B. horizontal, unlined	260	290	48
C. horizontal, near ground	230	250	48
D. vertical	375	410	80
30. Package refrigerator units	48	70	6
31. Motor control centers	230	270	30
32. Prefab buildings (control houses)	60	100	10
33. Automatic dryer units	32	50	4
34. Liquid-phase reactors	220	250	70
35. Crude columns, large	6100	6600	2000
36. Box coolers	5450	6100	330

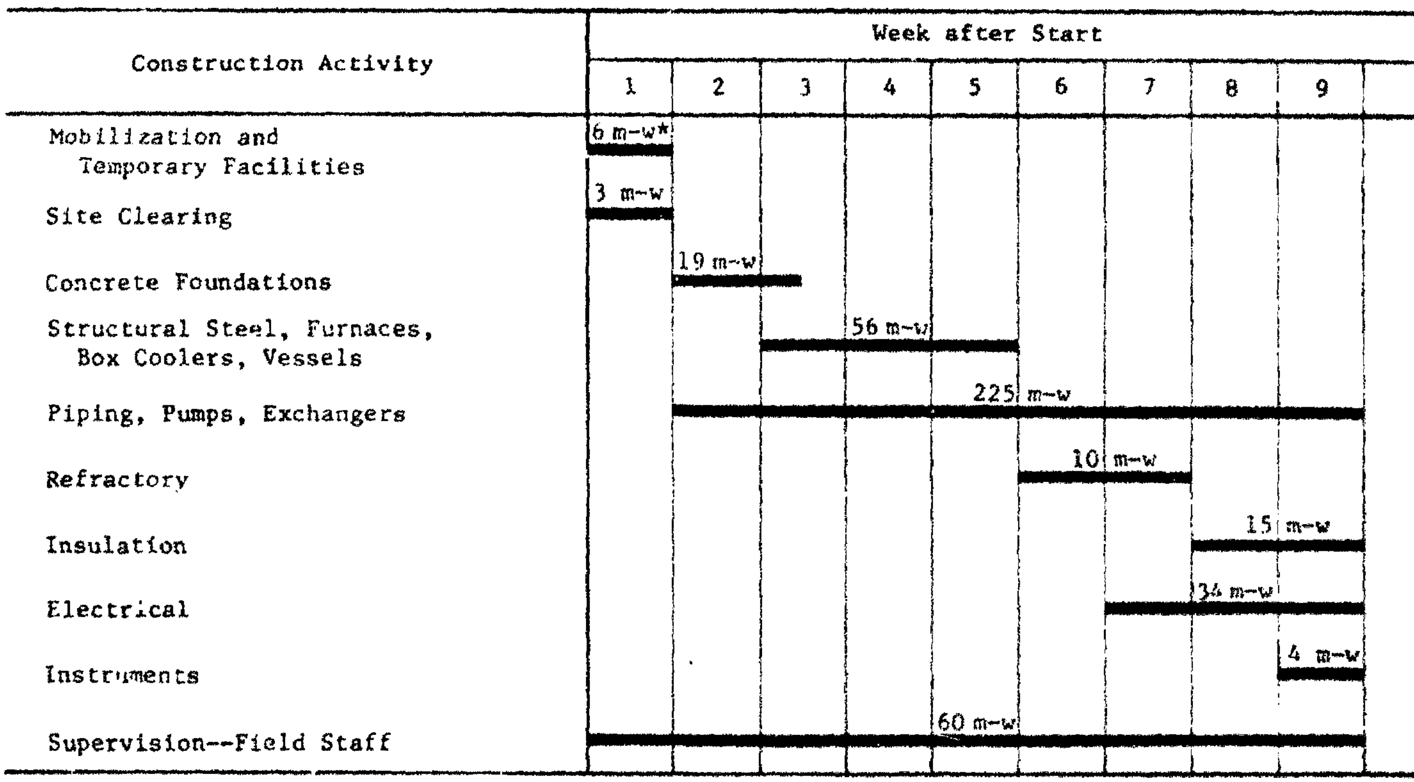
[a] Case A: existing refinery foundations are used in the replacement of the components. Case B: new foundations are laid out and poured prior to construction; in this study Case B inputs are utilized only for the construction of the ECOU.

[b] In m-h/ft^2 of double-deck pipeway.



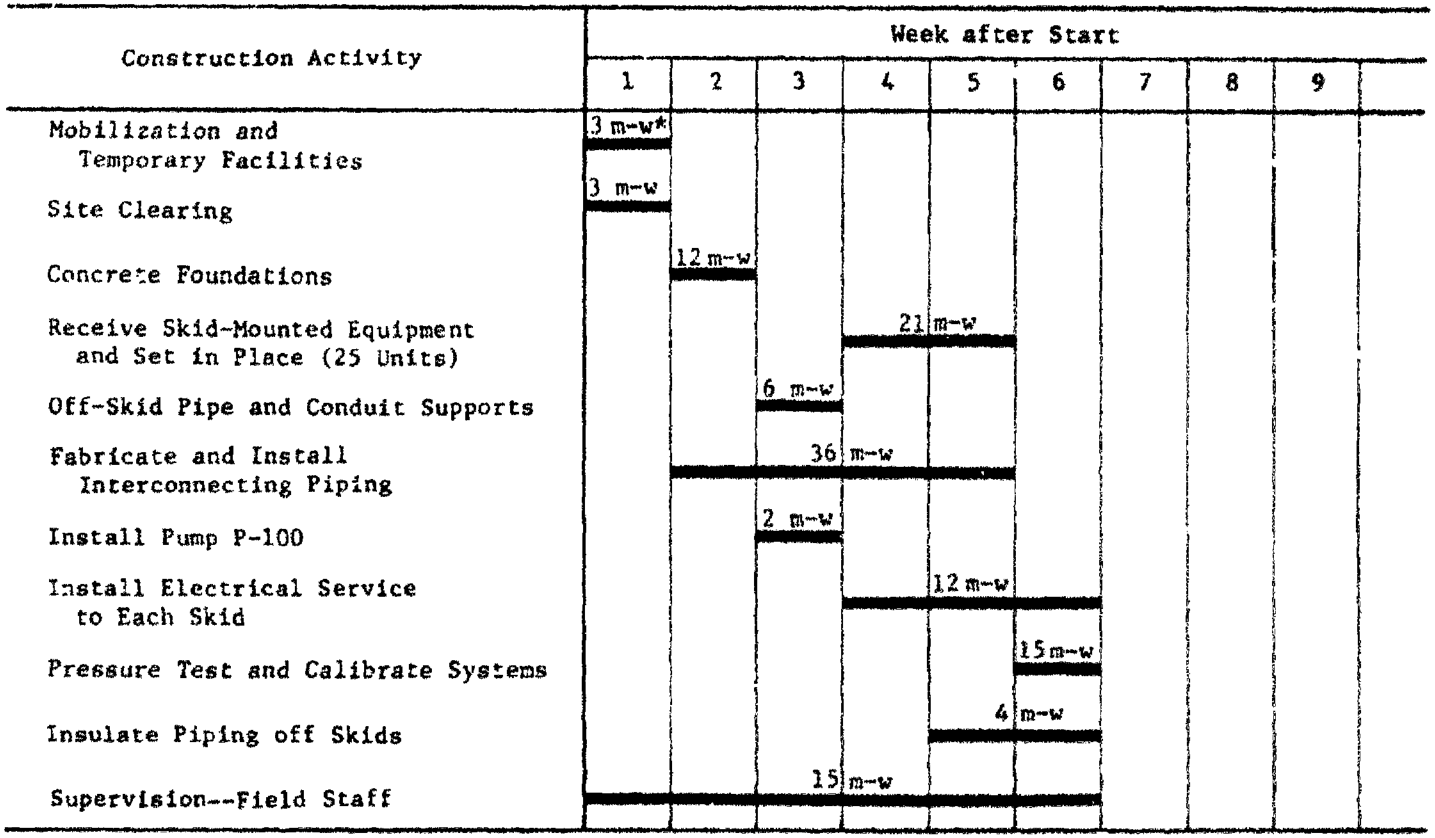
*m-w: man-week @ 168 hours/week (three 8-hour shifts by separate crews at optimum productivity)

Figure 3. Construction schedule for an ECOU, using existing refinery-component foundations (Case A).



*m-w: man-week @ 168 hours/week (three 8-hour shifts by separate crews at optimum productivity)

Figure 4. Construction schedule for an ECOU at a new site, including new foundations for component parts (Case B).



*m-w: man-week @ 168 hours/week (three 8-hour shifts by separate crews at optimum productivity)

Figure 5. Construction schedule for an S-ECOU at a new site, including new foundations for component parts (Case B).

of workers and working times are possible. In any case, the S-ECOU would require the smallest work force, and its construction could be performed in about 6 weeks.

The times and sizes of work force are about the same for both Case A and Case B in constructing the ECOU. The "equal" trade-off tasks are the clearing of debris when the old refinery site is used (Case A) and the forming and pouring of the concrete foundations for the new site (Case B). In the schedule for the S-ECOU, delivery of the prefabricated, skid-mounted components is not due to occur until the beginning of the fourth week of the 6-week schedule; the first 3 weeks are spent in preparing the site and in connecting facilities for the operating components.

To facilitate estimates of the repair, replacement, and construction effort for various assumed conditions of damage, a computational system was developed and was used to produce several of the numerical results in the following section.

SECTION 3
COMPUTATIONS AND RESULTS

3-1 DAMAGE DESCRIPTIONS FOR COMPONENTS OF THE TYPICAL REFINERY

Damage descriptions for components of the typical refinery are summarized in Table 5 for selected values of the peak (static) overpressure due to a blast wave from a nuclear detonation in the megaton yield range. The information is a combination of that reported by Foget et al.[3] and provided by Zaccor et al.[7] This compilation provides the reader with a detailed description of the damages to the components at the selected overpressure values in association with the repair-effort levels described in the following pages.

3-2 RECONSTRUCTION OF THE DAMAGED TYPICAL REFINERY

The reconstruction effort for a typical refinery was computed by first selecting an appropriate set of parametric values among those possible for the ratio H/B and the conditions NS, M, and S and then substituting consecutive values of ΔP in the appropriate interpolation formulas for each of 32 major components. Multiplying by the factors N_i and F_i (see Equation 3) and then summing over i gives the total estimated reconstruction effort (repair plus replacement) for the damaged refinery. In the computations it is arbitrarily assumed that, at the overpressure for which the estimated repair effort becomes equal to the estimated replacement effort, a damaged component is replaced rather than repaired; for that component, the replacement effort would then apply at all higher overpressures. This assumption tends to minimize the reconstruction effort at the higher levels of damage, where the repair effort would almost always exceed the replacement effort. The assumption also presupposes that new components are available on demand for delivery to the construction site from a nearby stockpile. Thus, a summation of "replaceables" is equivalent to a list of needed stockpiled parts and components. Note that in Table 3 the maximum value of the

ΔP limit for any given component denotes the overpressure for destruction of that component.

Calculated levels of reconstruction effort for the damaged typical refinery (32 of the major listed components) are shown in Figure 6 as a function of peak (static) overpressure. The results are for conditions NS, M, and S, which were defined in Section 2-4. The effort scale refers to skilled and unskilled labor only. As previously stated, when foremen and engineers are included, the total effort would be about 1.2 times that estimated for just the skilled and unskilled workers. And when staff supervisors and engineers are included, the total effort overall would be about 1.3 times as great. This last level of effort is representative of more or less normal peacetime supervision practices in engineering and construction projects. In a postattack setting, foremen and engineers, and perhaps even some of the staff supervisors, may have to serve as skilled craftsmen and even as laborers in welding, pipefitting, electrical hookup, etc. Thus the estimate for the basic reconstruction effort (repair plus replacement) refers to the minimum number of people working at maximum productivity, with essentially no one acting only in a supervisory capacity.

Estimated repair or replacement efforts for the various components, at selected values of the peak (static) overpressure, are summarized in Table 6 for the secured (S) condition to indicate which components would require the greatest repair effort and to show the overpressures at which component replacement is likely to be required. The latter is indicated by the lowest overpressure at which the estimated effort becomes constant. The maximum effort for the repair crews, i.e., the replacement of all components, occurs at incident overpressures of 22 psi or greater. About 95% of the maximum effort of about 479,000 m-h of skilled and unskilled labor would have to be expended in the reconstruction of a typical refinery that was damaged by an overpressure of about 14 psi. Hence, in general, a refinery that was damaged by an overpressure of about 12 psi or greater would probably be reconstructed of new or otherwise undamaged components rather than repaired, provided that the necessary materials and parts were stockpiled or were available from normal, undamaged inventories. The data suggest that repair efforts can probably be

Table 5. Damage descriptions for components of the typical refinery (compiled from references 3 and 7).

Component	Dimensions (ft)	Weight (lbs)	Overpressure (psi) M	Overpressure (psi) NS	Overpressure (psi) S	H/B	Damage Description
1. Cooling towers, thin-walled	<15x15x20	<30,000	0.75	1.5	1.5	All	Corrugated asbestos louvres shattered and blown into interstices of the tower; tower perforated by missiles (mainly on the blast-loaded side(s).
			1.6	2	3	All	About 25% of interior lathwork destroyed; some fixtures broken.
			2.2	2	3	All	Fan cylinders shattered, fan blades deformed.
			6	6	6-7	All	Tower frame fails; tower body collapses; all piping broken; all interior lath and filling destroyed.
2. Catalytic cracking columns	>15x15x20	>30,000	1	1	2	All	Instruments damaged (glass, thin-walled cases, etc.).
			2	2	3	All	Light components bent or crushed; some piping broken or loosened at connections (leaking).
			4	4	6	≤2	Most piping bent or broken, connections leaking; frame and supports distorted; unit displaced from foundation.
			4	4	4	>2	
			7	9	12-14	All	Column collapses.
3. Liquid extraction columns	<4x4x90	>30,000	-	-	6.6	>2	Column deflection results in breakage at ground level of pipes to upper half of column.
			-	-	10	>2	Column moves on foundation; anchor bolts begin to stretch or become loosened.
			10	11	12	>2	Anchor bolts fail and column overturns; all external connections severed; all internal trays disarrayed, bent, or crushed.

4.	Packed columns	< 4x4x90	>30,000	-	-	6.6	>2	Column deflection results in breakage at ground level of pipes to upper half of column.
				-	-	8.8	>2	Column moves on foundation; anchor bolts begin to stretch or become loosened.
				10	10	12	>2	Anchor bolts fail and column overturns; all external connections severed; all internal trays disarrayed, bent, or crushed.
5.	Distillation columns	<4x4x90	>30,000	0.5	0.5	0.5	>2	Top caps moved aside or blown off; light outside wall attachments bent.
				0.5	1	1	>2	Some guy wires broken; side wall dented, slightly buckled; stacks truncated, column deflection.
				-	-	6.6	>2	Column deflection results in breakage at ground level of pipes to upper half of column.
				-	-	8.8	>2	Slight shifting of column due to yielding of anchor bolts.
				10	0	12	>2	Anchor bolts fail and column overturns; all external connections severed; all internal trays disarrayed, bent, or crushed.
6.	55-gal drums	< 4x4x8	< 1000	0.5	0.5	0.5	≤2	Some drums dented.
				0.5	0.5	2	≤2	Deformation and buckling; dents and holes from missiles; loss of fluids; some separation of end plates.
				0.5	0.5	1	>2	
				1	1.5	3	≤2	End plates separated; many drums buckled or flattened.
				1	1	2	>2	
				2	3	6	All	Almost all drums buckled or flattened beyond repair.
7.	Storage tanks, cylindrical	>15x15x20	>30,000	0.5	0.5	1	All	Slight distortions in side walls.
				1	1	3	≤2	Sides bent in; top or end plates bent or buckled; some leakage of filled tanks.
				1	1	2	>2	
				1.5	1.5	5	≤2	Connecting pipes broken, substantial leakage; increased distortion of sides and end plates; some separation of walls from foundation and end plates
				1.5	1.5	4	>2	
				3	3	10	≤2	Tanks overturned, destroyed.
				2.6	2.6	8	>2	

(cont.)

Table 5 (cont.)

Component	Dimensions (ft)	Weight (lbs)	Overpressure(psi) M	NS	S	H/B	Damage Description
8. Storage tanks, solids	~21x21x72	-	-	1.1	-	>2	Roof fails at joints to wall and collapses into tank.
			-	6.3	-	>2	Conveyor loading system deformed, connections to tank broken.
			-	7.7	-	>2	Tank shifts on foundation; anchor bolts begin yielding.
			-	9.0	-	>2	Anchor bolts fail and tank overturns; severe deformation to 25% or more of tank walls and ends.
9. Storage tanks, open	~10x10x25	-	-	1.5	-	>2	Tank wall distorted or bent.
			-	5.0	-	>2	Tank raised on blast-loaded size; bottom ruptures along joint with shell plates along 1/3 of circumference of tank; pipe connections break at entrance to tank.
			-	12	-	>2	Tank overturns; about 25% of shell deformed or dented.
10. Storage tanks, conical-roof	~50x50x20	-	-	1.0	-	≤2	Roof fails at joints to wall and collapses into tank.
			-	1.5	4.4	≤2	Tank raised on blast-loaded side; bottom ruptures along joint with shell plate; pipe connections break at entrance to tank.
			-	12	-	≤2	Tank overturns.
11. Storage tanks, spherical, heavy							
A. Small	>15x15x20	< 30,000	0.5	1	1	≤2	Damage to instrumentation (glass, thin-metal cases, dials, gauges).
			1	1	1	≥2	
			2	3	4	≤2	Panels, covers, etc., broken or blown off tank; some pipes bent; connections loosened or broken.
			2	2	3	≥2	
			4	5	6	All	Piping bent and broken; frames and supports bent; some anchor cables broken; heavy missile damage to external components.

	B. Large	~50x50x36	>30,000	–	8	–	≤2	Wind-bracing that connects tank to supporting column fails.
				–	13	–	≤2	Column deformation begins; inlet and outlet piping breaks.
				12 8	13 10	15 12	≤2 >2	Supporting columns deform and collapse; tank overturns.
12.	Skid- or frame-mounted equipment, small	≤4x4x8	≤1000	1.5 1.5	2 1.5	2 2	≤2 >2	Pipes bent or broken; gauges damaged (glass, pointers); control boxes broken; fan belts off pulleys or broken; small valves broken.
				4 3	6 4	10 8	≤2 >2	Motors broken; frame bent, broken, distorted; control equipment destroyed.
				5 3.5	8 5	10 10	≤2 >2	Equipment and skid or frame destroyed.
13.	Small panels, racks, and mounted equipment	≤4x4x8	≤1000	0.5	0.5	0.5	All	Damage to some meters and electronic equipment.
				1	1	1	All	Panels and covers bent; meters broken; vacuum tubes broken.
				2 2	2 2	3 2	≤2 >2	Mechnical linkages pulled apart, bent; cathode ray tubes broken; front panels bent; covers bent and jammed against internal components of recorders, amplifiers, flowmeters, etc.; some panels and racks overturned.
				3 3	3 3	4 3	≤2 >2	Units destroyed.
14.	Electrical panels and racks	<15x15x20	<30,000	1 1	1 1	2 1	≤2 >2	Meter movements broken; cover glasses broken; metal covers and panels bent; instruments out of calibration.
				2 2	2 2	4 3	≤2 >2	Faces of panels bent or buckled; electrical components torn loose, smashed, and broken; controls broken; covers and cases smashed against electronic components; circuit boards cracked or broken.
				3 3	3 3	6 6	≤2 >2	Units destroyed.

(cont.)

Table 5 (cont.)

	Component	Dimensions (ft)	Weight (lbs)	Overpressure (psi) M	NS	S	H/B	Damage Description
15.	Large panels and racks	>15x15x20	>30,000	0.5	0.5	1	>2	Glass broken; some covers bent.
				1	1	2	>2	Covers bent, broken, and blown into components; some plastic components broken; external instrument components broken.
				2	2	4	>2	External panels pushed inward against internal components; external controls broken.
				3	3	6	>2	Units destroyed.
16.	Pipe arrays and racks	>15x15x20	>30,000	1	2	2	≤2	Deformation of some piping and bus covers.
				1	1	1	>2	
				2	3	3	≤2	Extensive pipe deformation; many fasteners broken; some electrical components broken; air lines cracked.
				2	2	2	>2	
				3	4	6	≤2	Pipes torn from mounts and terminations; many pipes bent, buckled, and broken; buses, insulators, and standoffs cracked and broken.
				3	3	4	>2	
				-	5	-	≤2	Supporting columns deformed.
				8	8	10	≤2	Supporting columns buckle and fail; pipes and pipe racks collapse onto the ground; array destroyed.
				8	8	13	>2	
17.	Box-type furnaces							
	A. Small	>15x15x20	>30,000	0.5	-	1	≤2	Distortion and breakage of some external light components.
				1	-	2	≤2	Doors bent or dented and removed from tracks or hinges; cracks in masonry; some bricks knocked loose; few cement blocks cracked or broken.
				3	-	3	≤2	Brick and masonry walls and linings partly blown down; many cement blocks and bricks fractured; some walls fail; doors wrenched loose; accessory components crushed and destroyed.
				4	-	5	≤2	Bricks and blocks broken into pieces which then become missiles.

B. Large	~25x60x30	–	–	–	1.5	≤ 2	Heater-lining firebrick jarred loose, falls into bottom of furnace and causes damage to burners and tubes.
			–	–	2	≤ 2	Heater frame begins to buckle, causing inlet and outlet connections to heater to shear off and internal tubing to bend and deform.
			2	4	5	≤ 2	Heater frame buckles and fails; furnace overturns.
			4	4	4	> 2	
18. Cylindrical furnaces, vertical	> 15x15x20	> 30,000	1	1	1	≤ 2	Instrumentation damaged (covers and panels bent or buckled).
			0.5	0.5	1	> 2	
			2	2	3	≤ 2	Instrumentation components cracked, crushed, or broken; refractory cracked and spoiled; flues bent and buckled; boiler sides bent in, distorted; fans and housings bent and distorted.
			1.5	2	2	> 2	
			4	4	6	≤ 2	Refractory removed from walls, broken into pieces; instrumentation destroyed; pipes and pipe connections broken; stacks and flues deformed, buckled, or destroyed; components displaced from mountings.
			3	3	4	> 2	
			6	6	10	≤ 2	Unit overturned, destroyed.
			4	4	8	> 2	
19. Package boiler units	~12x20x15	–	2.2	–	–	≤ 2	Gauges smashed and inoperable; small control tubes and pipes ruptured.
			3	–	–	≤ 2	Flues crushed, ruptured.
			4.4	–	–	≤ 2	Boiler sides buckled; some side-wall tubes distorted, bent; refractory lining cracked.
			8	–	–	≤ 2	Anchor bolts fail; boiler displaced from foundation and overturned; all connections severed; unit destroyed.

(cont.)

Table 5 (cont.)

	Component	Dimensions (ft)	Weight (lbs)	Overpressure (psi) M	NS	S	H/B	Damage Description
20.	Heat exchangers							
	A. Large	>15x15x20	>30,000	1	1	2	All	Instrument damage (glass broken, light covers and panels bent).
				2	2	3	All	External light components smashed, broken loose from mounting; piping bent or broken, leaks at connections.
				4	4	6	≤2	All piping bent or broken; frames and supports bent or distorted; unit displaced off foundation.
				4	4	4	>2	
				6	8	14	≤2	Unit destroyed.
				6	8	12	>2	
	B. Small	-3x3x20	-	-	7.7	-	≤2	Anchor bolts begin yielding, exchanger deflects; pipe connections broken.
				-	8.8	-	≤2	Anchor bolts begin failing; exchanger overturns; external piping severed; some internal tubes rupture or are misaligned.
				14.3	-	-	All	External pipes sheared at connection to exchanger.
				22	27	33	≤2	Unit destroyed.
				20	20	25	>2	
21.	Generators, ac, heavy-duty	<15x15x20	<30,000	0.5	0.5	0.5	All	Thin, light covers bent.
				1	1	1.5	All	Radiator tubes bent or broken, radiators leaking; instrumentation with broken glass, bent gauges; plate rectifiers distroted or broken; controls bent and broken loose from mounts.
				2	2	3	All	Solid-state components cracked or broken by missiles; units displaced; controls and accessory components loosened, distorted, or broken.
				4	4	6	All	Unit destroyed.
22.	Electric motors, large	<15x15x20	<30,000	1	-	2	All	Power-connection covers bent, access panels bent and deformed.
				2	-	4	≤2	Covers blown into splices, commutator, or slip-ring assemblies; some wires loose at terminals.
				2	-	3	>2	
				4	-	8	All	Motor mounts broken; windings damaged by missiles; shaft misaligned.
				8	12	15	≤2	Anchor bolts sheared; motor displaced or overturned; casing cracked (likely missile damage).
				8	12	14	>2	

23. Electric motors, small							
A. ac (<1000 hp)	<4x4x8	<1000	1	2	2	≤2	Power-connection covers bent, access panels bent and deformed.
			2	3	4	≤2	Covers blown into splices, commutator, or slip-ring assemblies; some wires loose at terminals.
			4	6	8	≤2	Motor mounts broken; windings damaged by missiles; shaft misaligned.
			-	12	15	All	Unit overturned; casing cracked or broken; destroyed.
B. dc (<1000 hp)	<4x4x8	<1000	5.0	-	-	≤2	Motor windings broken or stripped of insulation by missiles, causing short circuits.
			8.8	-	-	≤2	Electric wires to motor severed; circuit boxes bent, deformed, or broken (largely by missiles).
			23	-	-	≤2	Anchor bolts sheared; motor displaced or overturned; casing cracked or broken; unit destroyed.
24. Transformers and capacitors, large	<15x15x20	< 30,000	1 0.5	1 0.5	2 1	≤2 ≥2	Radiator tubes bent; cover plates distorted.
			2	2	3	All	Radiators deformed and leaking; some insulators broken; wiring broken loose, disconnected, insulation removed.
			3 3	4 4	6 4	≤2 ≥2	Insulators broken; cases bent or deformed; switch gear crushed or broken (missiles and displaced covers); units displaced from foundation or mounts.
			5 4	8 4.5	10 5	≤2 ≥2	Units overturned, destroyed.
25. Steam turbine drives (25 hp, single stage)	-	-	7.7	-	-	≤2	Cooling-water pipe and drain connections to turbine severed.
			12.5	-	-	≤2	Governor linkage and valve deformed.
			14.3	-	-	≤2	Steam inlet and outlet pipes to turbine severed.
			23	23	23	≤2	Anchor bolts sheared; turbine displaced from mountings; all external pipe connections severed.

(cont.)

Table 5 (cont.)

	Component	Dimensions (ft)	Weight (lbs)	Overpressure (psi) M	NS	S	H/B	Damage Description
26.	Blowers (150 hp, (12,500 cfm)	–	–	–	5	–	≤2	Blower hood or casing buckled; outlet separated from casing.
				–	10	–	≤2	Blower crushed; duct crushed; all connections severed; unit destroyed.
27.	Centrifugal pumps (25 hp, 200-ft tdh, 300 gpm)	–	–	13	–	–	≤2	Inlet and outlet pipes broken off.
				16	–	–	≤2	Base-plate anchor bolts sheared off pump; motor shaft misaligned; packing seals leaking; some damage (cracks, dents) from missiles.
				17	–	–	≤2	Unit destroyed.
28.	Reciprocating compressors (1000 hp, 450 rpm, 2-stage, 4 cylinders)	–	–	3	–	–	≤2	Small control pipes ruptured; indicating gauges smashed.
				14	–	–	≤2	Deformation and breakage or rupture of external pipes.
				–	22	–	≤2	Misalignment of compressor and motor.
				–	26	–	≤2	Unit destroyed.
29.	Pressure vessels, cylindrical							
	A. Horizontal, glass-lined, at height of 6 ft	< 15x15x20	30,000	0.5	0.5	1	≤2	Denting or bending of accessories on outside of vessel.
				1	1	2	≤2	Controls bent; small leaks at pipe connections; missile punctures of tires on mobile units.
				2	2	4	≤2	Pipe connections broken (many); destruction of control gauges and pipes; vessel dented, cracked, leaking.
				9	9	9	≤2	Vessel destroyed.
	B. Horizontal, unlined, at height of 6 ft	< 15x15x20	30,000	0.5	0.5	1	≤2	Denting or bending of accessories on outside of vessel.
				2	3	4	≤2	Pipes bent and leaking at connections; panels and covers bent or buckled, some blown off; controls smashed and pipes bent; instrumentation smashed.
				4	6	8	≤2	Piping deformed, ruptured, and leaking; structural supports bent and twisted; anchors begin to fail; some units displaced from foundation.
				9	9	9	≤2	Unit destroyed.

C.	Horizontal, near ground (10 ft dia, 30 ft long, 6 3" pipes)	–	–	–	3	–	≤2	Glass lining shattered, tank inner surface begins to corrode.
				–	6	–	≤2	Two leeward support columns buckle, some pipe connections shear off or rupture.
				–	9	–	≤2	All support columns begin to buckle, all pipe connections leak or shear off (vessel may roll over on its side).
				–	16.5	–	≤2	Anchor bolts fail, vessel shifts on its supports, severing all pipe and wire connections completely.
				–	20	–	≤2	Anchor bolts shear off; unit destroyed.
D.	Vertical (10 ft dia, 45 ft high, steel shell)	–	–	–	13	–	>2	Anchor bolts begin to fail; slight shifting of vessel on foundation; pipe connections loosen and leak.
				–	14	–	>2	Anchor bolts fail and vessel overturns; unit destroyed.
30.	Package refrigerator units (100-hp compressors, 100-hp motors)	–	–	2.2	–	–	All	Control gauges smashed (inoperable).
				6.2	–	–	All	Control panels smashed and torn from mountings; control wires and pipes severed at panel.
				7.7	–	–	All	Water-pipe connections to lube-oil cooler severed.
				14.3	–	–	All	Inlet and outlet water pipes to cooler and condenser ruptured.
				24	24	24	All	Compressor(s) and motor(s) misaligned, broken; unit destroyed.
31.	Motor control centers	>15x15x20	>30,000	0.5	0.5	0.5	All	Some side-wall distortion; block separation.
				1	1	1	All	Windows broken; doors removed from hinges; partitions broken and pulled apart; some siding removed (or cement blocks dislodged); roller doors bent and jammed.
				2	2	3	All	Panels blown off; walls (cement block) blown apart; metal siding ripped off and buckled; frame bent and twisted.
				3	4	5	All	Unit destroyed.

(cont.)

Table 5 (cont.)

	Component	Dimensions (ft)	Weight (lbs)	Overpressure (psi) M	NS	S	H/B	Damage Description
32.	Prefab buildings (control houses) (5600 sq ft sheet-steel panels, steel frame)	-	-	-	1.5	-	≤2	About 50% of roof and side panels torn off and buckled.
				-	2.5	-	≤2	All roof and side panels removed, buckled; frame distorted.
				-	5.0	-	≤2	Unit destroyed (foundation intact).
33.	Automatic dryer units (200 cfm, 100 psig, 16" dia, 6 ft high)	-	-	2.2	-	-	≤2	Control gauges smashed (inoperable).
				6.2	-	-	≤2	Control panels deformed, removed from mountings; wires and pipes to panel severed.
				8.8	-	-	≤2	Same.
34.	Liquid-phase reactors (6 ft dia, 8 ft high)	-	-	2.2	-	-	≤2	Control gauges broken (smashed).
				3.0	-	-	≤2	Glass lining shattered.
				-	7.0	15.0	≤2	Reactor overturns; all connections to vessel severed.
35	Crude columns, large (20-25 ft dia, 60-65 ft high)	-	-	-	-	-	-	Assumed to be similar to the distillation and other smaller-diameter columns.
36.	Box coolers	-	-	-	-	-	-	Assum·d to be similar to reinforced concrete s· ıctures setting at ground level. Cracking ·d severe pipe breakage at 12 psi (main application is in the expedient crude unit).

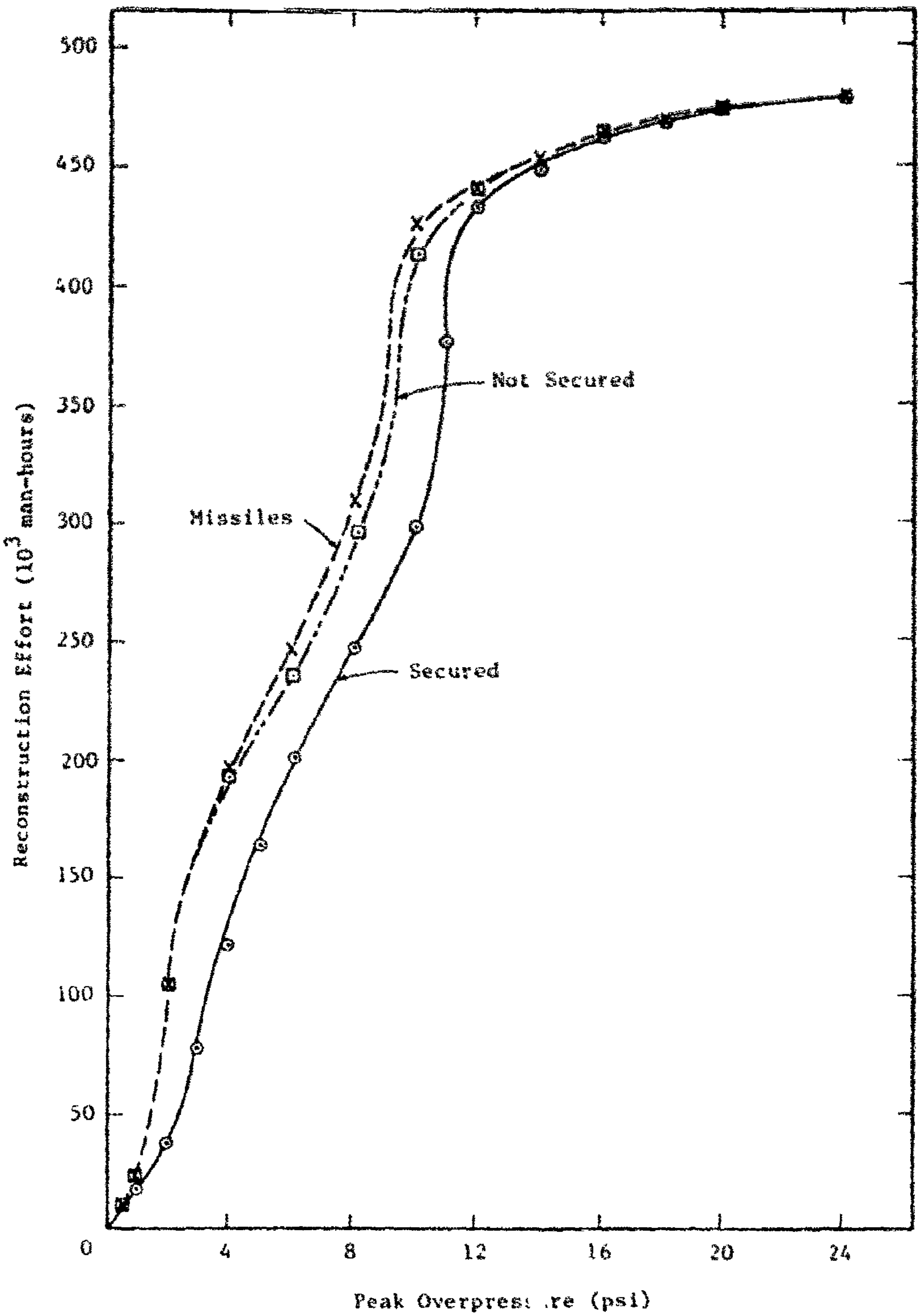


Figure 6. Reconstruction effort as a function of peak overpressure for the typical refinery.

considered as a reasonable option for refineries with secured components that had been subjected to overpressures up to about 10 psi. For non-secured refineries (with or without consideration of the likely effect of missile-caused damaged on the repair effort), the upper limit for component repair options would be about 2 psi lower, i.e., about 8 psi.

The curves of Figure 6 show that, relative to the NS (no missiles) condition, missiles have very little effect on the reconstruction effort at overpressures less than about 4 psi or greater than about 14 psi. The effect of damage-prevention measures, as represented by the S condition, is quite large within the overpressure range of 2 to 10 psi; within this range, the apparent reconstruction effort "saved" by these measures varies from a minimum of about 40,000 m-h at an overpressure of 7 psi to a maximum of about 110,000 m-h at an overpressure of 10 psi. In these estimates, the protective effect of rapid shutdown procedures is not included.

The numbers of "replaced" component types at various incident overpressures up to 22 psi are listed in Table 7, which does not give the number of individual components, but only the kind (e.g., cooling towers). The first component to be replaced, at 2 psi, is component no. 21, which is the ac generator; in this instance, the low overpressure for replacement is due mainly to the low replacement effort and the small number of units. The hardest component, no. 20, is the small heat exchanger, which would be replaced only at overpressures of 22 psi or greater. The greatest efforts (60,000 m-h or more) occur for components 5 and 7, the distillation columns and the storage tank--both, in part, because of the relatively large number of units involved. Other components requiring relatively great effort to repair or to replace when severely damaged or destroyed are the packed columns, the skid- and frame-mounted equipment, the small panels, and the electrical panels.

Although the clearing of debris should be done by crews who would not normally be included as part of the refinery reconstruction teams, the effort of site clearing for the typical refinery covering an area of about one square mile would be quite large. Although a detailed analysis of such operations was beyond the scope of this study, an

Table 6. Estimated direct-labor effort (man-hours) for the repair or replac

construction of the typical refinery (secured condition, original foundati

Component Number	Peak Overpressure (psi) 0.5	1	2	3	4	5	6	7	8	9	10	11	12	13
1	104	295	834	1553	3568	6255	7500	7500	7500	7500	7500	7500	7500	7500
2	1	2	13	34	68	115	178	346	530	1629	2846	4047	4400	4400
3	40	88	194	308	427	551	679	1091	1424	1895	2317	11545	16800	16800
4	57	160	449	[illegible]	1262	1760	2310	3921	5361	7436	2942	26170	32000	32000
5	88	248	700	1286	1980	2767	3637	6185	8466	11758	14842	50848	85500	85500
6	1	2	5	8	19	20	20	20	20	20	20	20	20	20
7	3850	3850	7677	[illegible]	23111	47686	77478	80000	80000	80000	80000	80000	80000	80000
12	23	51	114	[illegible]	192	192	192	192	192	192	192	192	192	192
13	360	720	2177	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600
14	685	1500	3283	5191	10862	17533	19200	19200	19200	19200	19200	19200	19200	19200
15	47	110	260	[illegible]	786	1233	1400	1400	1400	1400	1400	1400	1400	1400
16	40	155	605	[illegible]	2352	3643	5207	8305	13089	17706	25692	32549	39564	43120
17	3125	6250	12500	32950	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000
18	333	780	1830	30.3	4292	5647	8544	12495	17200	21859	25790	27600	27600	27600
19	2	10	37	[illegible]	142	219	313	570	828	1213	1606	1988	2200	2200
20	240	480	960	1440	1920	2400	2880	3360	3840	4320	4800	5280	5760	6833
21	34	67	128	128	128	128	128	128	128	128	128	128	128	128
22	1	7	109	500	640	640	640	640	640	640	640	640	640	640
23	550	1100	2200	3300	4400	5500	6600	7700	10174	13821	16630	20000	20000	20000
24	608	608	608	[illegible]	6323	7200	7200	7200	7200	7200	7200	7200	7200	7200
25	3	11	44	[illegible]	174	271	389	528	688	868	1070	1292	1693	2315
26	8	29	98	201	334	496	600	600	600	600	600	600	600	600
27	0	0	0	0	125	250	375	505	788	1328	2260	3353	4692	7182
28	42	[illegible]	163	[illegible]	321	399	478	555	633	711	788	865	942	1019
29A	7	15	33	53	74	119	178	256	318	320	320	320	320	320
29B	[illegible]	325	[illegible]	[illegible]	2054	2764	4259	6324	8823	11346	13000	13000	13000	13000
29C	53	142	[illegible]	[illegible]	1049	1447	1881	2348	2846	3372	3925	5529	7124	8450
30	15	40	105	[illegible]	279	382	480	480	480	480	480	480	480	480
31	36	132	486	1454	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760
32	14	90	585	[illegible]	720	720	720	720	720	720	720	720	720	720
33	17	35	75	[illegible]	157	200	295	422	480	480	480	480	480	480
34	2	8	34	[illegible]	134	210	302	[illegible]	622	950	1270	1741	2253	2728
Total (m-h/refinery)*	10515	17392	37510	[illegible]	123253	166107	209423	228763	249550	274452	300318	[illegible]	437768	447387
Percent of complete refinery-replacement effort	2.2	3.6	7.8	16.3	25.7	34.7	43.7	47.7	52.1	57.3	62.7	79.3	91.4	93.4

*Refers to column totals; when used in other calculations or in text discussions, the to

le 6. Estimated direct-labor effort (man-hours) for the repair or replacement of components in the re-
nstruction of the typical refinery (secured condition, original foundations, H/B > 2 where feasible).

	Peak Overpressure (psi)																		
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
33	3568	6255	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
34	68	115	178	346	530	1629	2846	4047	4400	4400	4400	4400	4400	4400	4400	4400	4400	4400	4400
8	427	551	679	1091	1424	1895	2317	11545	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800
2	1262	1760	2310	3921	5361	7436	2942	26170	32000	32000	32000	32000	32000	32000	32000	32000	32000	32000	32000
6	1980	2767	3637	6185	8464	11758	14842	50848	85500	85500	85500	85500	85500	85500	85500	85500	85500	85500	85500
8	19	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
7	23111	47686	77478	80000	80000	80000	80000	80000	80000	80000	80000	80000	80000	80000	80000	80000	80000	80000	80000
2	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192	192
00	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600
1	10862	17533	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200	19200
0	786	1233	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
08	2352	3643	5207	8305	13089	17706	25692	32549	39564	43120	43120	43120	43120	43120	43120	43120	43120	43120	43120
0	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000	49000
13	4292	5647	8544	12495	17200	21859	25790	27600	27600	27600	27600	27600	27600	27600	27600	27600	27600	27600	27600
1	142	219	313	570	828	1213	1606	1988	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
0	1920	2400	2880	3360	3840	4320	4800	5280	5760	6833	8521	10052	11265	12453	14708	16466	17884	19260	20000
8	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
00	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640
00	4400	5500	6600	7700	10174	13821	16630	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
48	6323	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200
99	174	271	389	528	688	868	1070	1292	1693	2315	2949	3526	4172	4800	4800	4800	4800	4800	4800
01	334	496	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
0	125	250	375	505	785	1328	2260	3353	4692	7182	9614	12360	12500	12500	12500	12500	12500	12500	12500
42	321	399	478	555	633	711	788	865	942	1019	1292	1558	1786	1959	2153	2529	2700	2700	2700
53	74	119	178	256	318	320	320	320	320	320	320	320	320	320	320	320	320	320	320
01	2054	2764	4259	6324	8823	11346	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000
93	1049	1447	1881	2348	2846	3372	3925	5529	7124	8450	9814	12381	14386	16130	17250	17250	17250	17250	17250
66	279	382	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480
54	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760	2760
20	720	20	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720
35	157	200	295	422	480	480	480	480	480	480	480	480	480	480	480	480	480	480	480
76	134	210	302	412	622	950	1270	1741	2253	2728	3080	3080	3080	3080	3080	3080	3080	3080	3080
59	123253	[illegible]107	209423	228763	249550	274452	300318	380047	437768	447387	454130	461817	466049	469782	473351	475485	477074	478450	479190
totals;	[illegible] used in other calculations or in text discussions, the totals should be rounded to 2 or 3 significant numbers.																		
.3	25.7	[illegible].7	43.7	47.7	53.1	57.3	62.7	79.3	91.4	93.4	94.8	96.4	97.3	98.0	98.8	99.2	99.6	99.8	100.0

Table 7. Estimated number of component types replaced as a function of peak overpressure in the reconstruction of the typical refinery (secured condition, original foundations, $H/B > 2$ where feasible).

Overpressure (psi)	Number of Component Types
1	0
2	1
3	3
4	7
5	9
6	14
7	15
8	16
9	17
10	18
11	20
12	25
13	26
14	27
15	27
16	28
17	29
18	30
19	30
20	31
21	31
22	32

allowance of 10 m-h per 10^3 ft^2 for a moderately to severely damaged refinery would lead to an estimated effort of approximately 300,000 m-h. Depending on the overpressure and the availability of bulldozers, cranes, trucks, metal-cutting equipment, etc., the actual effort could range from about 150,000 m-h to more than 600,000 m-h. At an effort level of 300,000 m-h, around-the-clock operations (168 working hours per week) using three shifts per day over a period of 3 weeks would require a work force of about 1800 persons.

The time required for refinery reconstruction (repair plus replacement) is inversely proportional to the number of persons available with the appropriate spectrum of skills, as well as to the availability of tools, materials, parts, and supplies. The maximum reconstruction effort of 479,000 m-h of skilled and unskilled labor would expand, by the factor 1.3, to a total effort of about 623,000 m-h with a full complement of foremen, engineers, and staff administrators. If the work force remained fairly constant over the whole period of reconstruction, the latter effort over an 8-week period (comparable to that given for the construction schedule of Figure 3) would require a total manpower of about 1400 persons (about 470 per shift) if each person or team worked 8 hours per day and the work continued around the clock. In other words, the time in weeks required to repair or replace the refinery would be estimated from 11,200 (i.e., 8 × 1400) divided by the total number of persons in the work force.

For reconstruction teams with an appropriate distribution of skills and with adequate tools and supplies, the reconstruction time, Δt, can be estimated from the equation

$$\Delta t = E/(S \cdot N) \quad \text{(weeks)} \qquad (4)$$

in which E is the total reconstruction effort in man-hours (at any given overpressure), S is the average number of hours per week that each person or team works, and N is the total number of workers available (all categories). Thus, from Table 6, where the repair-crew effort is estimated to be about 300,000 m-h for an overpressure of 10 psi the completely staffed work-force effort would be about 390,000 m-h. Then, for a total work force of 1000 persons working an average of 48 hours per week, the reconstruction time, Δt, would be estimated to be just over 8 weeks.

Mobilization of the 1000 persons and provision of temporary facilities for them and the repair work would probably require an effort of 10,000 m-h or more. If that effort were to be expended in 2 weeks, a work force of about 90 persons, each working 56 hours per week, would be required. If these persons were used in the reconstruction effort, the overall work force would remain at 1000 persons, but the time to initiation of production after site clearing would be increased from 8 to 10 weeks. However, a work force of 200 persons, under similar working conditions, could reconstruct the refinery in less than about 40 weeks; the mobilization effort would be reduced to around 2000 m-h and could be accomplished by about 36 people in 1 week. Since the 200-person crew could probably be assembled much more easily than the 1000-person crew, it appears that the expected recovery time for the typical refinery damaged by 10 psi overpressure would be closer to 9 months than to 2 months.

3-3 RECONSTRUCTION AND CONSTRUCTION OF THE DESIGNED ECOU

Two general cases have been considered for the rapid postattack establishment of an ECOU and the earliest possible recovery of diesel fuel production. The reconstruction case (Case A) entails the use of a damaged refinery's foundations and the repair/replacement of refinery components, where feasible. The construction case (Case B) entails the assembly and/or construction of undamaged components at a new site, to build either the designed ECOU or the prefabricated S-ECOU.

The computed levels of effort required for the reconstruction of damaged refinery components to make a functional ECOU are plotted as a function of incident peak (static) overpressure in Figure 7. The results are shown only for the NS and S conditions; the effect of missiles on the reconstruction effort is about the same as for the typical refinery, in relative degree. The major effect of the protective countermeasures in reducing the recovery effort occurs in the overpressure range of 4 to 11 psi, and the effort "saved" varies from about 1000 m-h

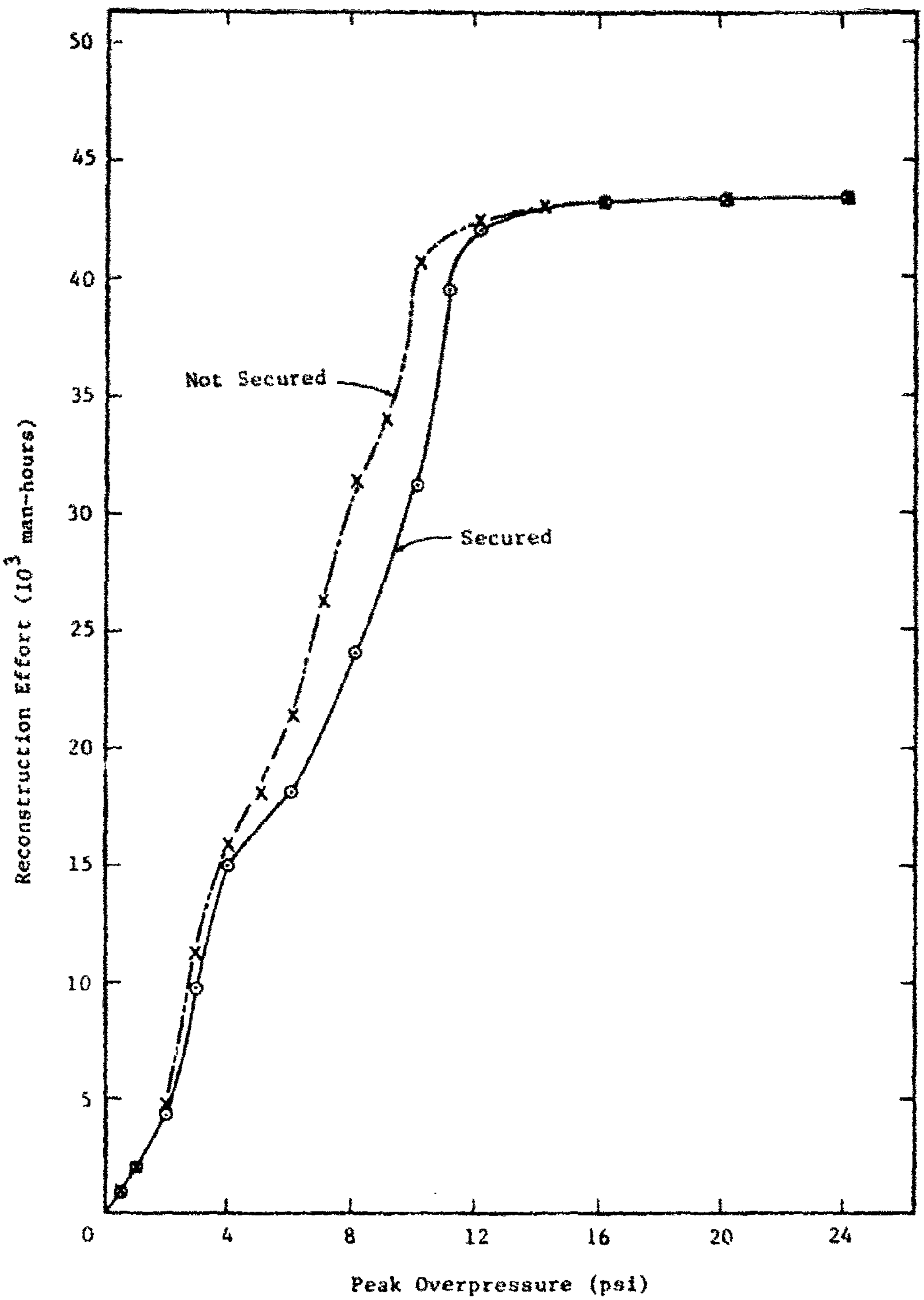


Figure 7. Reconstruction effort as a function of peak overpressure for the ECOU.

at 4 psi to a maximum of about 85000 m-h at 10 psi. In the overpressure range of 5 to 11 psi, the apparent hardening effect of the protective measures is equivalent to 1 psi at the extremes and to 2 psi at about 8 psi.

The repair/replacement efforts required for each component of the ECOU at various peak overpressures from 0.5 to 22 psi are summarized in Table 8. Note that storage tanks, which are items of rather high repair/replacement effort for the typical refinery, are not included; this implies that the diesel fuel would not be stored at the site, but would be transported by tank car or truck (or even pipeline) to some other site for storage or use. In the calculations, it is also assumed that components nos. 35 and 36 are not part of the original refinery and that when the refinery has been damaged by low blast overpressures, the 10 cooling towers (no. 1) and 25 of the distillation columns (no. 5) are repaired. But when damaged by higher overpressures, these components are replaced by box coolers (no. 36) and a large crude column (no. 35) respectively. For 22 psi, the total estimated replacement effort by the skilled and unskilled repairmen, 44,000 m-h, is about 9% of that estimated for the typical refinery. The ECOU reconstruction effort for refinery damage at 10 psi would be about 13% of that estimated for the typical refinery.

The numbers of component types that require replacement at various incident overpressures are summarized in Table 9. Together with the curves of Figure 7, this tabulation suggests that component repair should not be considered as the preferred action.

In Section 2-1, where the ECOU and its construction are described, a maximum work force of 313 people is estimated for the case where a set of new components is erected on a cleared refinery site. However, a more detailed breakdown of the construction schedule of Figure 3 indicates that a maximum work force of only about 150 people is needed, and the number varies over the 9-week construction period as follows:

Week	Number of Repair Crewmen
1	63
2	135
3	140
4	140
5	140
6	99
7	133
8	140
9	152

If the staff supervision entailed only one 8-hour shift per day, their m-w (man-weeks) of effort over the 9-week period would be reduced to 20 m-w and would require an additional 7 people. Otherwise, the 60 m-w would translate to a staff of 20 supervisors. The average size of the work force is 127 + 7 = 134. The breakdown of the reconstruction effort into tasks that are comparable to the estimates of Table 8 is as follows:

Task	E (m-h)
Mobilization and temporary facilities	1,008
Site clearing	5,040
Replacement	58,128
Staff supervision	3,528
	67,704

The component replacement effort includes that of the team engineers and foremen, and the scheduled effort of 58,100 m-h is to be compared to the 22-psi total effort (Table 8) of 44,000×1.2, or 52,800 m-h. The total scheduled effort with a full complement of staff supervisors would be about 74,800 m-h.

Comparable construction efforts for an ECOU and the S-ECOU on a new site, from the schedules of Figures 4 and 5, are as follows:

Table 8. Estimated direct-labor effort (man-hours) for the repair

the reconstruction of an ECOU (secured condition, original foundat

Component Number	Peak Overpressure (psi)											
	0.5	1	2	3	4	5	6	7	8	9	10	11
1	104	295	834	1533	3568	6255	7500	-	-	-	-	-
5	49	138	184	714	1100	1538	2021	3436	4704	-	-	-
13	32	64	194	320	320	320	320	320	320	320	320	320
14	34	75	164	260	543	877	960	960	960	960	960	960
15	2	6	13	20	39	62	70	70	70	70	70	70
16	10	39	151	335	588	911	1302	2076	3272	4426	6423	8137
17	625	1250	2500	6598	9800	9800	9800	9800	9800	9800	9800	9800
20	10	19	38	58	77	96	115	134	154	173	192	211
23	33	66	132	198	264	330	396	462	610	829	998	1200
24	81	81	81	286	843	960	960	960	960	960	960	960
27	0	0	0	0	6	12	18	24	38	64	108	161
29B	3	6	16	28	41	55	85	126	176	227	260	260
29D	9	20	44	71	98	127	157	187	286	367	479	578
31	6	22	81	242	460	460	460	460	460	460	460	460
32	1	8	49	60	60	60	60	60	60	60	60	60
35	-	-	-	-	-	-	-	-	-	6100	6100	6100
36	-	-	-	-	-	-	-	10900	10900	10900	10900	10900
Total*(m-h/ECOU)	1000	2040	4480	10720	17810	21860	24270	29980	32770	35720	38090	40180

* Refers to column totals; when used in other calculations or in text discussions, the tota

abor effort (man-hours) for the repair or replacement of components in

COU (secured condition, original foundations, H/B > 2 where feasible).

	Peak Overpressure (psi)																
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
5	7500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	2021	3436	4704	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320
7	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960
2	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
1	1302	2076	3272	4426	6423	8137	9891	10780	10780	10780	10780	10780	10780	10780	10780	10780	10780
0	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800	9800
6	115	134	154	173	192	211	230	273	341	402	451	498	588	658	715	767	800
0	396	462	610	829	998	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
0	950	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960
2	18	24	38	64	108	161	225	345	461	593	600	600	600	600	600	600	600
5	85	126	176	227	260	260	260	260	260	260	260	260	260	260	260	260	260
7	157	187	286	367	479	578	669	747	750	750	750	750	750	750	750	750	750
0	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460
0	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
-	-	-	-	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100
-	-	10900	10900	10900	10900	10900	10900	10900	10900	10900	10900	10900	10900	10900	10900	10900	10900
0	24270	29980	32770	35720	38090	40180	42100	43240	43420	43620	43670	43720	43810	43880	43940	43990	44020

tions or in text discussions, the totals should be rounded to 2 or 3 significant numbers.

2

Table 9. Estimated number of component types replaced as a function of peak overpressure in the reconstruction of an ECOU.

Overpressure (psi)	Number of Component Types
1	0
2	0
3	2
4	4
5	5
6	7
7	8
8	8
9	9
10	10
11	11
12	11
13	12
14	13
15	13
16	14
17	14
18	14
19	14
20	14
21	14
22	15

Task	E (m-h)	
	ECOU	S-ECOU
Mobilization and temporary facilities	1,008	504
Site clearing	504	504
Construction	60,984	18,144
Staff supervision	3,528	882
	66,024	20,034

The effort for the construction of an ECOU on a new site is about the same as for its construction on a damaged refinery site; the effort-balancing tasks are the debris clearing for the damaged site (5000 m-h) and the preparation of new foundations at a new site (3500 m-h). The effort of assembling the S-ECOU sections is only about 30% of that for the ECOU, and, as indicated in Figures 4 and 5, it could be constructed in 6 weeks, as compared to 9 weeks for the ECOU.

The numbers of crewmen required over each week of the scheduled construction of the ECOU and S-ECOU at a new site are as follows:

Week	Number of Repair Crewmen	
	ECOU	S-ECOU
1	27	18
2	122	63
3	159	51
4	140	70
5	140	76
6	99	63
7	133	--
8	140	--
9	152	--

The average and maximum numbers of crewmen required per week are 124 and 159 for the ECOU, and 57 and 76 for the S-ECOU.

Rudimentary PERT diagrams for construction of the ECOU for Cases A and B are given in Figures 8 and 9, respectively. These diagrams show that one critical path comprises the replacement or assembly and construction of the pipes, pumps, and exchangers. For the damaged refinery,

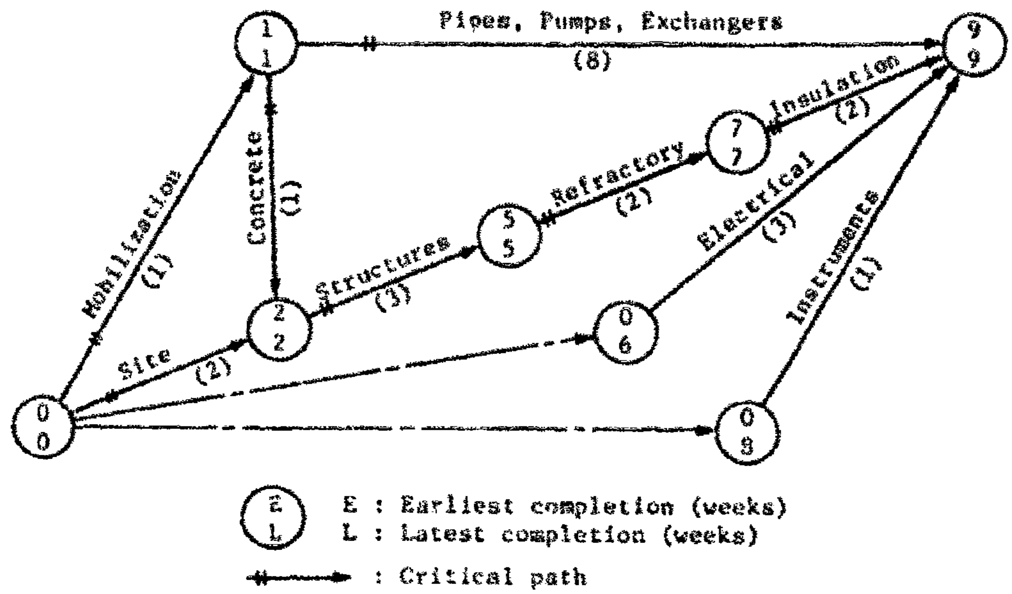


Figure 8. A PERT/CPM for the ECOU constructed on the original refinery foundations (Case A).

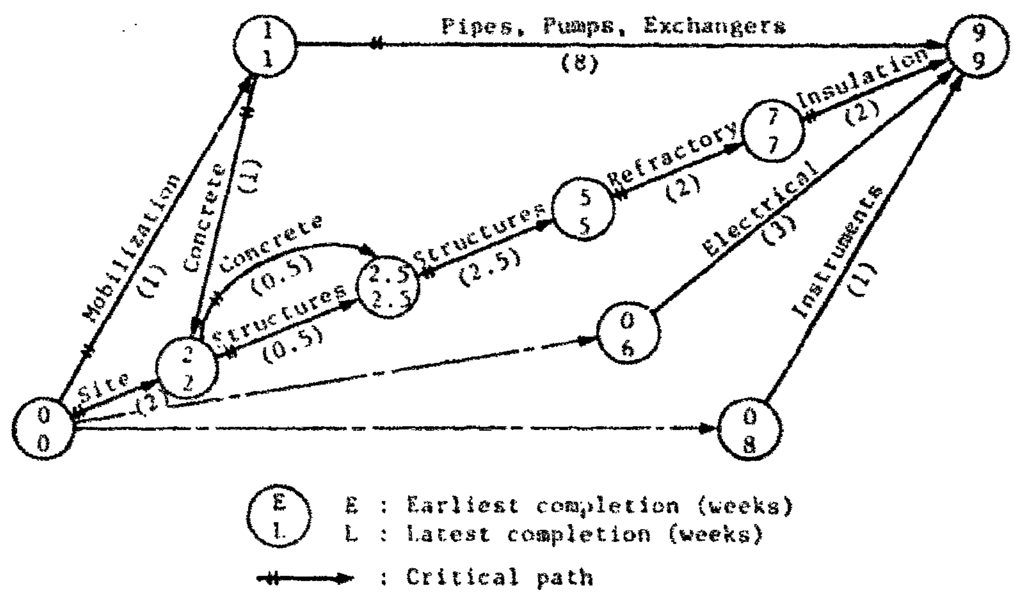


Figure 9. A PERT/CPM for the ECOU constructed on new foundations at a new site (Case B).

It may be noted that the piping is likely to be beyond repair at an incident overpressure of about 8 psi for both the NS and S conditions.

3-4 IMPACT OF PREATTACK PROTECTIVE MEASURES ON REPAIR EFFORTS AND PRODUCTION RECOVERY TIMES

In the previous section, the estimates of repair/replacement effort for restoring the damaged refinery, either to an operating refinery or to an operating ECOU, were noted to reveal significant savings in effort when the refinery was in the S condition at the time of attack, rather than the NS condition. The "hardening" effect of putting up additional bracing and guy wires and filling the columns and tanks with water or other suitable fluids was generally no more than that equivalent to reducing the peak overpressure by about 2 psi in the overpressure range of about 8 to 10 or 11 psi (see Figure 7). However, some benefit of protective measures may be expected over the overpressure range of 2 to 13 psi.

A comparison of reconstruction efforts for the S and NS conditions cannot be used to indicate the relative worth of shutdown procedures, because elimination of the fire hazard for all conditions implies the assumption of a successful preattack shutdown of the refinery. However, it is also generally assumed that if a refinery were not shut down when the attack occurred, a very small overpressure (if not the thermal pulse alone) could ignite fires that would most likely destroy the refinery. Thus, to a first approximation, the direct-labor recovery effort saved by shutting down the whole typical refinery in the S condition can be estimated from:

$$E_s = 479,000 - E_p \qquad (5)$$

in which E_p is the estimated total reconstruction effort in man-hours for any peak overpressure less than 22 psi. Thus for the NS condition, the effect of shutdown on the repair effort if the refinery were damaged by an overpressure of 10 psi would be a saving of 178,900 m-h (37% of the complete replacement effort). The maximum saving or benefit occurs for peripheral exposure of the refinery in the overpressure range of 0.2 to 4 psi, at which a destructive fire could cause as much damage as an overpressure of 22 psi as far as the reconstruction effort is concerned.

The reconstruction effort saved by the blast-damage prevention measures of the S condition, in man-hours and as a percentage of the NS-condition effort, at several levels of the incident overpressure, is summarized in Table 10 for the typical refinery and for the ECOU. The largest savings in repair effort occurs for an incident overpressure of about 10 psi at which point a maximum number of components are being "saved" from failure by one or more of the protective measures. The actual reconstruction time saved by the suggested countermeasures can be estimated from:

$$\Delta t_s = \Delta E_s / (S \times N) \quad \text{(weeks)} \qquad (6)$$

in which S and N are defined as in Equation 4. (If S were in hours per day, Δt_s would be in days.) If N is assumed to be 1000 people (as it was earlier for the reconstruction of a typical refinery), S is 56 hours per week, and ΔE_s is 115,9[illegible]×1.3, or 150,700 m-h (as in Table 10 for the 10-psi level), then Δt_s = [illegible].7 weeks. The protective measures would therefore reduce the estimated reconstruction time for the refinery from 9.7 to 7.[illegible] weeks.

At an incident overpressure of about 4 psi, a work force of 500 would be expected to reconstruct a damaged refinery in the NS condition in about 9.1 weeks, with each person working 56 hours per week; in the S condition, this time would be reduced by about 2.6 weeks to 6.5 weeks. This saving in time, although significant, cannot be evaluated except in terms of the national demand for fuels in a specific postattack setting. It is probably not appropriate in such situations to include a consideration of the effort involved in converting a refinery from the NS condition to the S condition, including the shutdown procedure and the materials used, except in terms of preattack preparation costs. It is clear that most of the repair/replacement tasks in the reconstruction of either the typical refinery or the ECOU could not be effected without preattack stockpiling and other preparations. However, if successful postattack recovery activities hinge on the earliest possible recovery of the production of transport fuels such as diesel fuels, then the described preventative measures would surely be a significant factor in that recovery process on a national scale.

Table 10. Repair effort saved by simple protective measures for typical refinery repair and for construction of ECOU (Case A).[a]

Overpressure (psi)	Typical Refinery ΔE_s (m-h)	Typical Refinery $(\Delta E_s/E) \times 100$	ECOU ΔE_s (m-h)	ECOU $(\Delta E_s/E) \times 100$
1	4,530	20.7	123	5.63
2	66,700	64.2	556	11.4
3	85,600	52.5	1,370	12.2
4	71,400	36.5	1,070	6.70
5	44,900	21.3	1,770	9.80
6	34,300	14.6	3,640	17.1
7	35,700	13.8	5,720	21.8
8	48,400	16.4	7,750	24.8
9	42,700	13.6	6,610	19.5
10	115,900	28.2	9,250	22.8
11	58,300	13.5	2,600	6.19
12	8,060	1.83	908	2.14
13	5,000	1.12	187	0.44
14	4,440	0.98	176	0.41
15	5,780	1.25	231	0.53

[a]The quantity $(\Delta E_s/E) \times 100$ represents the effort saved relative to the effort for the NS condition.

It can be seen from Equation 6 that, for a given size of work force and weekly work period, the production recovery time is directly proportional to the total reconstruction effort in restoring the whole refinery or the ECOU (front-line components) to an operational state. Therefore, the dependence of the production recovery time on the incident overpressure will follow the curves of Figures 6 and 7.

3-5 RESOURCE REQUIREMENTS AND COSTS

In this study, the resource requirements and costs for the reconstruction of the whole typical refinery, except for the manpower effort, were not summarized. Some data for individual components at selected values of the incident overpressure are given in reference 3.

The major resource requirements for construction of the ECOU and assembly of the S-ECOU are summarized in Appendix A and, in more detail, in Appendix B. Present (1980) material and labor costs are estimated as follows:

	Cost ($\$10^6$)		
	ECOU		S-ECOU
Item	Case A	Case B	Case B
Material	3.8	3.9	6.5
Labor	2.9	2.7	2.0
	6.7	6.6	9.5

The cost estimates are based on the 100% availability of the needed labor skills. They include peace-time additions such as contractors' taxes, insurance, fringe benefits, overhead, and profit; many of these items may not apply to labor costs in a post-nuclear war situation. If the skilled labor force were reduced to 25% or so of those needed (but could be made up in numbers from available unskilled labor), the above-estimated costs would increase, on total, by about 60% (about a 15% increase for materials and about a 110% increase for labor). But again, these costs refer to 1980 price scales. However, the differences indicate the estimated drop in efficient use of materials (i.e. their waste) and some increases in construction time with the lesser-skilled work force; they indicate almost a doubling of the effort for a 75% loss of skills in construction work force.

3-6 CRITICAL COMPONENTS

The critical components are defined as those that receive sufficient damage at an incident overpressure of 5 psi to be beyond repair, if not completely destroyed. These components would therefore require replacement with new or otherwise undamaged components when the typical refinery is subjected to overpressures of 5 psi or greater.

In general, all the components listed in Table 2 that are damaged at a given overpressure must be repaired or replaced before the refinery or the ECOU can become operational. Thus, in a sense, no single component is truly "critical"; all are critical, depending on the overpressure and spectrum of products desired from the unit.

By extending the definition given above to include the most vulnerable condition for damage, NS, there are then 11 components of the typical refinery that fall into the critical category; these are listed in Table 11. This list suggests which types of materials and equipment should be considered for stockpiling as components of a refinery. If any of these components are not available, restoration of the refinery or construction of an ECOU may not be possible if the refinery was subjected to incident overpressures in the range of 3 to 5 psi, even though important components that are larger and harder may be readily repaired.

3-7 COMPONENT SUBSTITUTION

Substituting one component for another is a more feasible alternative when an ECOU is constructed on an original refinery site than when the complete refinery is restored. The complete refinery would generally need all components repaired or replaced, whereas the ECOU uses not only far fewer kinds of components, but also a much smaller total number of them than is needed for the refinery.

A list of suggested substitutable components has been provided as Part of Table 2. In the Case A repair option for the ECOU, the original

Table 11. Selected critical components of the typical refinery (for the not secured condition; H/B > 2 where applicable).

Component Number	Component Name	ΔP(dest)[a]
7	Storage tanks, cylindrical	2.6
12	Skid- or frame-mounted equipment, small	5
13	Small panels, racks, and mounted equipment	3
14	Electrical panels and racks	3
15	Large panels and racks	3
16	Pipe arrays and racks	8
17	Box-type furnaces	4
21	Generators, ac, heavy-duty	4
24	Transformers and capacitors, large	4.5
31	Motor control centers	4
32	Prefab buildings (control houses)	5

[a]Denotes the peak (static) overpressure for destruction or component replacement due to damage.

cooling towers and distillation columns are repaired up to the destruction overpressure, at which point they are substituted by simple box coolers and large crude columns, respectively.

More notable, perhaps, is the option of substituting vertical cylindrical furnaces or packaged boiler units for the box-type furnaces, especially since the latter are likely to be damaged beyond repair at an overpressure of about 4 psi, whereas the former two would not be expected to fail until an overpressure of about 8 psi. In addition, the repair effort for the vertical cylindrical furnace or packaged boiler unit, at any overpressure up to and including that for replacement, is less than that required for the box-type furnace.

Other substitutions include the trading possibilities among the different types of columns and vessels, the use of extra columns and vessels as temporary storage tanks, the use of ordinary piping rather than chromium-steel piping for short periods, and other trades that may be possible with some engineering modification.

3-8 STOCKPILING MATERIALS AND EQUIPMENT

Although the stockpiling of materials, parts, and equipment in support of the postattack repair of petroleum refineries (with emphasis on constructing an ECOU for diesel fuel production) was not a consideration in this study, it is discussed briefly to focus attention on the importance of such stockpiling for the construction of an ECOU or S-ECOU, or the restoration of a complete refinery (in the long run, if not in the initial postattack recovery period).

It should be clear from the foregoing discussions that very little repair work or replacement of components in a damaged refinery could be done in the postattack period, early or late, without preattack stockpiling of the needed materials and supplies. Depending on the degree of damage sustained by an existing refinery, the materials costs could be as much as $4 million (1980 value) for an ECOU of 50,000 bpd crude-oil throughput that would produce up to 10,000 bpd of diesel fuel.

Without the plans and means to effect the necessary stockpiling, any civil defense or facility plans for recovery operations to achieve early postattack petroleum-based fuel production could not be carried out.

SECTION 4
CONCLUSIONS

4-1 TIME SCALE OF THE PRODUCTION RECOVERY PROCESS

In the preceding sections, it has been shown that, where the availability of material resources is not a problem during the postattack period of a nuclear war, the time required to restore a petroleum refinery to productive capacity through repair and replacement operations would be inversely proportional to the size of the work force and directly proportional to the amount of effort required. The size and skill composition of the available work force will depend mainly on factors not considered in this study, such as the type or size of the attack, the readiness of the civil defense organization, and the ability of refinery management and other personnel to cope with the situations that arise.

The efforts (direct labor and total labor) required for the construction of facilities such as an ECOU or the reconstruction of a damaged refinery, either to the status of an ECOU or to its original capacity, depend on the level of damage sustained by the refinery. This, of course, depends critically upon the blast-wave overpressure [herein related to the peak (static) overpressure, whether the damage is caused by diffraction or by drag effects of dynamic overpressure]. At incident overpressures greater than about 12 to 15 psi for secured components and about 10 psi for unsecured components, the repair effort and the relative number of refinery components requiring replacement are estimated to be so large as to suggest that all components be replaced (i.e., the refinery or an ECOU should be built new from stockpiled components or undamaged components obtained from other sources).

Examples of calculations of approximate reconstruction times as a function of peak (static) overpressure for the typical refinery (in the S condition at the time of attack) and for a Case-A ECOU are plotted in

Figure 10. For recovery of the typical refinery, a complete complement of unskilled, skilled, and supervisory personnel, totaling 250, is assumed. For the construction of an ECOU on the refinery site, utilizing repaired refinery components and substitutions whenever possible, the total complement of personnel needed (on the average) was assumed to be 130. Although the maximum estimate of repair/replacement effort for the refinery damaged at 22 psi is about 11 times that for construction of the ECOU, the difference in assumed crew sizes reduces that ratio for the reconstruction times to 5.6 (45 weeks versus 8 weeks). Even so, the repair time for the complete refinery, when added to mobilization and site-clearing delay times of 3 to 6 weeks (again, depending on scheduling and crew size) is considerably greater than an ECOU. It would appear that output from a refinery in the S condition that was subjected to blast overpressures of more than about 12 psi could not be expected within the first year after an attack (or even later, if delay times due to fallout radiation hazards were incurred).

For the ECOU, a full complement of unskilled, skilled, and supervisory personnel could complete the restoration of sufficient components for diesel fuel production in about 8 weeks. Mobilization and site clearing are estimated to require an additional week, so that diesel fuel output would be expected in about 2.5 months or less after an attack (neglecting possible additional delays due to the fallout hazard), for incident overpressures on the refinery greater than about 12 psi.

If needed materials and manpower are available in sufficient quantity, rapid restoration of the complete refinery would appear to be a feasible option when the refinery is subjected to overpressures of less than about 4 or 5 psi. At these overpressures, the estimated reconstruction time is 12 to 15 weeks. This option for such relatively low levels of damage may even be a secondary one, since the ECOU, if constructed first, could be producing diesel fuel after only 3 to 4 weeks of repair time.

Except for the delay due to fallout hazards and/or possible political, legal, administrative, or management difficulties in the postattack period, the construction times plus mobilization and site-clearing times

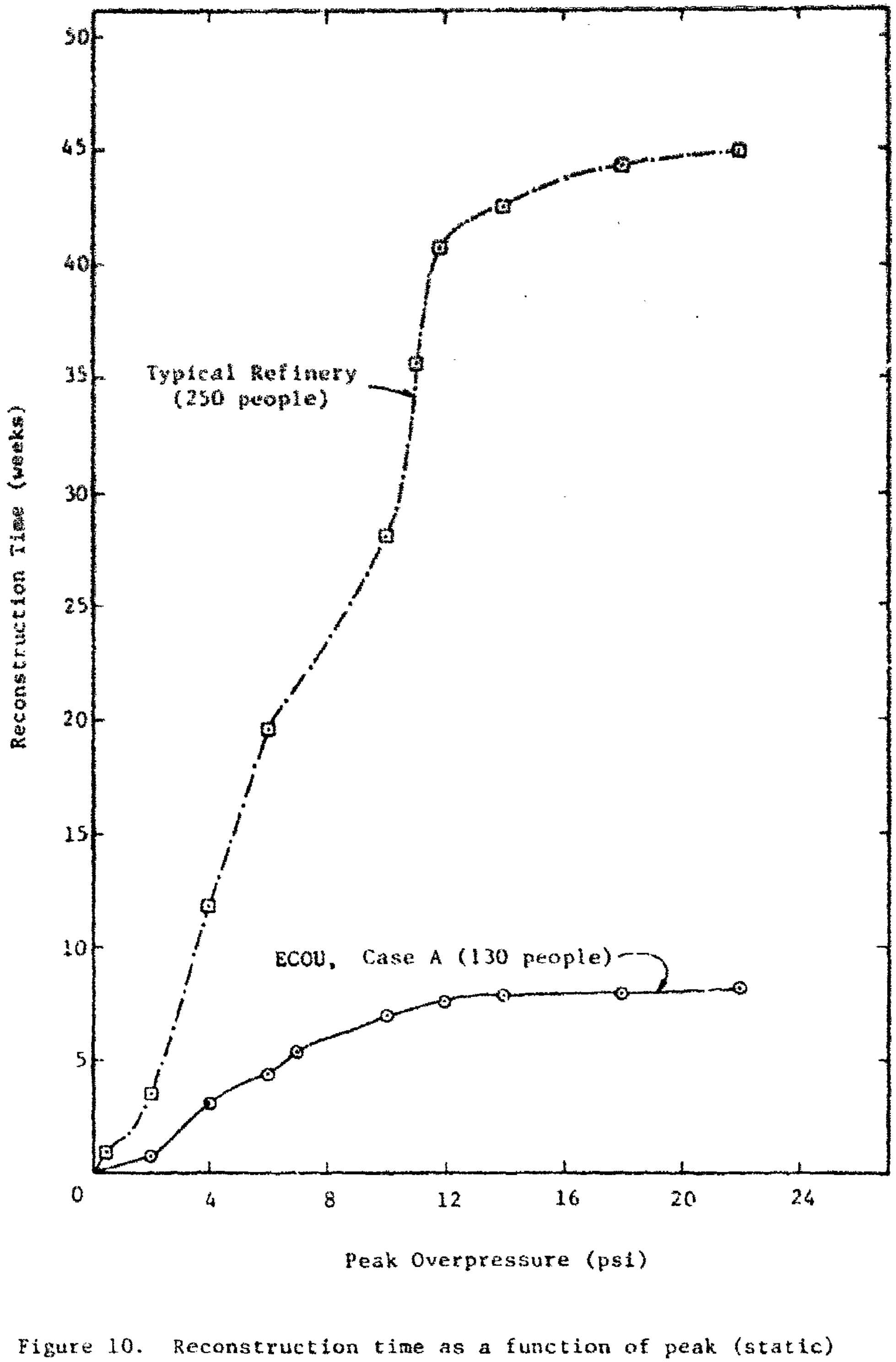


Figure 10. Reconstruction time as a function of peak (static) overpressure for the typical refinery (in secured condition at time of attack) and the ECOU, Case A.

for the Case-B ECOU and S-ECOU should be constant and independent of damage parameters (except where stockpiles are involved). The total time to diesel fuel production is expected to be about 9 weeks for the ECOU and 6 weeks for the S-ECOU. These options should have high priority for those refinery sites that are subjected to overpressures greater than about 12 psi, and also where diesel fuel supplies are insufficient to meet demand beyond 10 or 12 weeks into the postattack period.

4-2 ADVANTAGES OF THE EXPEDIENT CONCEPT AND THE ECOU FOR POSTATTACK RECOVERY OF TRANSPORT FUEL PRODUCTION

It is well known that the high-technology state of U.S. production facilities (computer-controlled systems, many fragile instruments, and the like) has made them highly vulnerable to failure from the blast, thermal, and electromagnetic effects of nuclear explosions. In addition, as in refinery operations, whole conglomerations of processes and equipment may be intricately connected in a variety of series and parallel arrangements to produce a wide spectrum of products from a limited array of inputs. On the other hand, as in the automobile industry, a wide spectrum of inputs may be used to produce a single or a few output products.

The expedience concept applied to the postattack recovery of damaged industrial facilities involves the identification of critical survival items among the output products and the design or redesign of component processes and equipment (or their interconnections) so as to simplify the process and significantly reduce the reconstruction time and effort. For the ECOU described in this report, simple designs of previously used refinery components were used, as well as less efficient forms of a crude-oil distillation unit. When survival itself is in question, the importance of component efficiency as a consideration in the production process decreases greatly. The ECOU design presented as part of this report is probably not as rudimentary as it could be, especially if units with much smaller crude-oil throughput volumes were considered. Furthermore, some high-technology elements (e.g., stainless steel pipe) could be replaced by standard materials, with added maintenance and reduced average throughput. Perhaps in the extreme, usable diesel fuel could be made in a large pot with an elementary condensing-pipe system.

The advantage of the ECOU, as indicated above, is that, for less than one-tenth the effort required to restore a heavily damaged ($\Delta P \geq 12$ psi) refinery to productive status, diesel fuel production could be restored. In addition, the delay time to production after attack would be reduced from about 1 year to about 2.5 months. Finally, the material resources that need to be stockpiled for constructing the ECOU would be much less than those required for reconstructing the whole refinery.

At incident overpressures of less than 10 to 12 psi, early production of diesel fuel could be achieved with the initial repair of the front line of the typical refinery in the form of an ECOU, followed by a staged repair of the complete refinery.

4-3 RELATIONSHIPS AMONG RECONSTRUCTION (REPAIR PLUS REPLACEMENT), OVERPRESSURE (DAMAGE), AND DAMAGE-REDUCING (BLAST-HARDENING) MEASURES

A set of relationships between the reconstruction effort and the peak (static) overpressure for the major components of a typical refinery of 75,000 bpd crude-oil throughput has been presented in Section 2-4 in the form of interpolation equations whose coefficients are based almost completely on previously published information (see Table 3). It has been pointed out, however, that real-world experience and empirical data to support both the damage description (as applicable to both the static and dynamic aspects of the blast wave from a nuclear detonation in the 1- to 10-megaton yield range) and the reconstruction effort are very meager and of unknown accuracy and scope.

In some cases, both types of data appear to be made "conservative" with respect to their use by the offensive side. Perhaps this involves unspecified allowances for targeting and technical "errors" in weapon delivery and actual effects on the target. Such biases could not always be detected in the data that were used; however, the intent, where a selection among sources was made, was to use mid-range values. If bias still remains in the results computed from the interpolation codes, it is more likely to be on the side of predicting more damage, and therefore greater repair efforts for damage at a given overpressure, than the opposite. A rather crude method to account for shock-wave shadowing was included in the computational estimating procedures.

The effort and materials required for building a new refinery (analogous to the replacement of all components of a refinery that was damaged by overpressures of more than 12 to 15 psi) are well known from industrial experience. Also, estimates for the construction of an ECOU from new or undamaged components and for assembly of the S-ECOU should be quite reliable.

The damage-reducing measures, as exemplified by the refinery components in the S condition include: adding guy wires; strengthening frames and supports to keep columns, racks, raised coolers, and other vessels from toppling over at relatively low incident overpressures; and topping off or filling tanks, columns, and vessels with water or other fluids to minimize toppling and to provide added strength to walls and inside parts to minimize denting, buckling, and other forms of damage. And, of course, all the computations apply only to refineries in the shut-down state; otherwise the general assumption would be complete destruction of the facility by fire, regardless of the incident overpressure.

For the typical refinery, the estimates indicate relative large "savings" in reconstruction effort and production recovery times due to the above-described protective measures, in the overpressure range of 2 to 10 psi. They indicate only slightly smaller (relative) savings for the Case-A construction of the ECOU in the overpressure range of 2 to 5 psi, but slightly larger (relative) savings in the range of 6 to 10 psi. Hence it would appear that, where preattack plans include the postattack restoration of facilities for producing either diesel fuel or the whole spectrum of petroleum refinery products, preattack preparations should provide for implementation of the indicated blast-damage-reducing measures.

4-4 RESOURCE REQUIREMENTS

Resource requirements for restoring a complete refinery have not been summarized in this report. However, applicable information for selected damage levels can be obtained from reference 3. The data on resource requirements developed in the present work center on the manpower, supplies, tools, and equipment that would be needed to repair and replace (especially from available parts and materials) components of the designed ECOU, as well as to assemble prefabricated components of the S-ECOU. The information applicable to both Case A (using the original foundations of the damaged refinery) and Case B (using a site away from the damaged refinery, with new foundations for the components) is presented in Appendices A and B. The materials cost for the ECOU is estimated to be about $4 million (1980 value); the cost for the prefabricated S-ECU is estimated to be somewhat over $6 million.

The necessity for stockpiling materials, even prefabricated critical components (those that would be damaged beyond repair at incident overpressures of 5 psi or less), has been discussed. Current refinery management might well consider enlarging their inventories of component parts, equipment, materials, and supplies and storing them in protected locations, at least to the extent of providing for the postattack fabrication of an operating ECOU.

At lower levels of damage to the typical refinery, the ECOU would be constructed in part from undamaged and repaired components of its parent refinery. The S-ECOU, however, which is designed to consist of modularized, prefabricated components mounted on 25 separate skids, would be built in peacetime and would not require the stockpiling of a large number of different materials and parts. Only those required to assemble and connect the modules into a functional unit would be needed.

4-5 SUMMARY OF PROJECT TASK COMPLETION

The Task 1 requirement for detailed component (and process) damage characteristics for a typical refinery is summarized in Table 5 for a rather broad range of selected incident overpressures. This summary is based entirely on previous studies, with only minor modifications to adjust differences in the reported damage descriptors.

For Task 2, the study emphasizes concepts of expedient postattack industrial recovery as applied to the blast-damaged refinery. An ECOU capable of producing diesel fuel and a few other front-line refinery products was designed as an alternative to the reconstruction of a complete refinery. The materials, effort, and time for construction of the ECOU and its skid-mounted companion unit, the S-ECOU, are discussed throughout the report and in the Appendices. Detailed conclusions regarding the clear advantage of these units for the early postattack restoration of production of transport fuels were given earlier in this section.

For Task 3, interpolation equations were derived from reported data relating the skilled and unskilled labor required for repairing individual refinery components to the incident peak (static) overpressure. The overpressure is taken, in part, as a relative measure of the level of damage to a component, as is the level of effort required for its repair. Details of the interpolations are given in Section 2-4, and the deduced values of the empirical coefficients applicable to each of several assumed situations and conditions for each major refinery compnent are summarized in Table 3. Other equations are presented to show the dependence of the unit production-resumption time on the estimated overall repair and replacement effort, the work rate of the repair teams, and the number of skilled and unskilled laborers and supervisory staff. The effect of degradation of the crew's skill composition on the repair effort is noted, and estimates of delay times due to mobilization of crews, preparation of temporary facilities, and site clearing are included.

For Task 4, detailed estimates of the effects of expedient measures for reducing component damage are presented in Section 3. The use of such measures is highly recommended wherever repair operations for the early postattack recovery of production of petroleum-based fuels are contemplated. Major conclusions in this regard were given earlier in this section.

SECTION 5
RECOMMENDATIONS

5-1 PLANNING FOR EARLY POSTATTACK RECOVERY OF PRODUCTION OF PETROLEUM-BASED FUELS

From the results of this study, it is recommended that government agencies with responsibilities for the postattack recovery of industrial production, including petroleum refining outputs, consider the "expedient" approach to industrial recovery. For example, the described ECOU and the S-ECOU could serve as models on which to develop a national plan for developing capabilities for the early postattack restoration of diesel fuel production. Planning studies for such purposes should expand the scope of the estimated resource demands for various necessary materials and supplies to a national scale based on estimates of postattack demands for various types of fuels and the probable damage to existing refineries. Other, supporting studies should consider the time-scale demand by the restoration effort and by the operational unit(s) for resources such as water, steam, gas, electricity, and crude oil. In addition, problems of product storage and transport should be considered as essential factors in recovery planning.

5-2 STOCKPILING

As mentioned several times in this report, the stockpiling of materials and supplies is an absolute necessity for either the reconstruction of refinery components or the construction of an ECOU in the early postattack period, especially if the refinery in question is subjected to overpressures of more than 2 or 3 psi. A brief study of current materials inventories and projected postattack demands is recommended to establish stockpile needs and costs. A determination of safe storage locations could be included in such a study.

5-3 PROTECTIVE MEASURES

Because of the potential savings in recovery time, in repair or replacement effort, and in materials resources from using a few simple, expedient, damage-reducing measures, the study of additional blast-hardening measures is recommended, especially for critical components.

Fire prevention measures, in addition to refinery shutdowns, should be reviewed and updated in view of the ECOU rationale. In addition, reconstruction procedures and schedules should be considered when fallout hazards are taken into account. Delay times, depending on available personnel, shelter facilities, and fallout levels, should be incorporated into the estimating procedures.

5-4 EXTENSION TO OTHER SECTORS

It is recommended that the expediency concept or rationale be extended to other industrial sectors that produce, or are in the production chain of, critical survival items that are expected to be in high demand (and short supply) in the postattack period of a nuclear war involving the United States.

SECTION 6
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APPENDIX A
SUMMARY OF RESOURCES AND LABOR SKILLS REQUIRED FOR CONSTRUCTION AND ASSEMBLY OF THE DESIGNED ECOU AND THE S-ECOU

The summary of resources (construction equipment and materials) and labor skills required for the ECOU (Case A), including detailed descriptions of the activities and components involved in its construction (or replacement) and operating, is given in Table A1. Similar information is summarized for the ECOU (Case B) in Table A2. A gross summary of these requirements for the assembly of the S-ECOU (Case B) is given in Table A3.

These tables were prepared by the Jacobs Engineering Group, Inc., of Concord, California, as a subcontractor, and have not been transcribed by CPR. Note that references in these tables to Exhibits A, B, and C, Appendix B, denote Tables B21, B22, and B23, respectively, of this report. References to the Construction Schedules denote Figures 3, 4, and 5 of this report.

TABLE A1

ITEM NO: General

ITEM: Site Preparation

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION: Site Clear Area: Allow for removal of destroyed refinery in area where new crude oil unit will be built. Structural steel, vessels, columns, electrical conduit, piping, etc., cut and removed to foundation tops. Approximately 150,000 sq. ft. of refinery area to be cleared. New Unit to be built on existing foundation.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) Consumables per Exhibit B, Appendix B b) Approx. 50 cy of concrete and rebar	Electricians	200	2 weeks	*Time required is based on 100% skilled labor available as required. See Construction Schedules for more details and alternates.
		Welders	2000		
		Laborers	2000		
		Oper. Eng.	500		
		Foreman	300		
		Total	5000		

ITEM NO: H-100 A & B

ITEM: Crude Furnaces

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Direct Fired "box-type" furnace, two required, 220 MM BTU/HR total Heat Duty required, each approx. 45'x40'x25' with an 80' high stack mounted on top; fabricated, steel housing with fire-brick and insulating brick, externally insulated, each includes 400 lin. ft. of 5" dia. steel pipe and 8 gas or oil burners.

Resources Required: Constr. Equip.	Resources Required: Materials	Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
See Exhibits A and C, Appendix B	a) 52 tons steel plate	Iron workers	4300	3 weeks	a) Furnaces are sized assuming no crude pre-heaters.
	b) Steel Doors (4 reqd.)	Pipe Fitters	3200		
	c) 2-tons C.Iron pipe or chrome Supports	Welders	1800		b) Two units rather than one unit were selected for flexibility of operations and reducing construction time.
	d) 16 gas or oil burners				
	e) 10,000 sq.ft. red brick				
	f) 10,000 sq.ft. fire brick	Laborers	200		
	g) 3600 sq.ft. floor insulat	Brick Layer	1100		
	h) 800 ft. of 5" dia. steel piping	Operating Eng.	200		
	i) 1200 sq.ft. insul. fire brick	Insulators	200		
	j) 160' of 36" dia. 5/8" thick steel pipe for stacks	Foreman	600		
	k) Consumables per Exhibit B, Appendix B	Total	10,300		

ITEM NO: C-100

ITEM: Crude Column

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Crude Distillation column, 20-25 ft. diameter by 60-65 ft. long (Tangent to tangent) with 20-22 bubble cap sieve or weir type distillation trays on 2 ft. spacing, 5/8" thick C. Steel shell with S. Steel internals preferred, 25,000 lbs. Dry wt., externally insulated, with nozzles, relief valves and internal piping.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) 8-8ft. high pre-rolled 5/8" thick C. Steel plates 20-25 ft. Diam.	Cement Masons	250	3 weeks	a) C. Steel or C. Iron trays and internals may be substituted for S. Steel.
	b) 2-ASME dished heads 25' Dia.				
	c) 22 Distillation trays S. Steel Preferred				b) Column may be substituted with smaller dia. columns providing total cross-sectional area remains approx. the same.
	d) Tray supports - S. Steel	Ironworkers	1650		
	e) 5700 sq. ft. of 3" thick insulation	Pipefitters	1650		c) Column "packing" of scrap steel may be substituted for Dist. trays. Eff. will decrease appreciably.
		Welders	1650		
	f) Misc. piping, etc.	Insulators	250		
	g) Consumables per Exhibit B, Appendix B	Operating Eng.	1250		
		Foreman	700		
		Total	7900		

ITEM NO: C-101, C-102 and V-100

ITEM: Strippers and overhead Accumulator

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

C-101 and C-102 - Distillation towers; each approx. 4'-6" dia. by 17' high (t-T), C. Steel shell with dished heads and 6 S. Steel bubble cap, weir or sieve type trays, 15,000 lbs. dry wt. V-100 Horiz. Pressure vessel, 7' dia. x 20' long (T.T) 1/2" Thick-C, Steel material.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Schedule B	a) 5-8 Ft. high prerolled 5/8" thk. C. Steel plates, 4'6" Dia.			3 weeks	a) C. Steel or C. Iron trays and internals may be substituted.
	b) 3-8 ft. long pre-rolled 1/2" thick C. Steel plates 7' door.	Laborers	100		b) Column "packing" or scrap steel may be substituted for Dist. trays, Eff. will decrease appreciably.
	c) 12 S. Steel distillation trays.				
	d) 6-ASME dished heads	Ironworkers	200		
	e) Tray supports	Pipefitters	150		
	f) 400 Sq.ft. insulation	Welders	200		
	g) Consumables per Sch. "B."	Insulators	100		
		Operating Eng.	50		
		Foremen	100		
		Total	900		

ITEM NO: P-100, P-101-P-102, P-103

ITEM: Pumps

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Centrifugal pumps from 150gpm up to 1400 gpm with motor drivers. Motor sizes are from 15 hp up to 400 hp. C. Steel or C. Iron construction for pumps.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) Pumps and Motors as defined on Dwg. 3774-KE-1. b) Consumables per Exhibit B, Appendix 5	Pipefitters Machinists Laborers Foremen Total	200 200 150 100 650	4 weeks	a) Reciprocating pumps may be substituted. Steam turbine drivers may be substituted for motor drivers. Additional steam will be required.

ITEM NO: E-101 & E-106

ITEM: Box Coolers

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Box Coolers, Two required; one to be 65'x20'and10' high concrete construction with 5000 ft. of 3" dia. steel pipe inside, 112mm BTU HR Duty required one to be 55'x20'x10' high concrete construction with 4000 ft. of 3" dia. steel pipe inside, 78.4 mm BTU/HR. Duty required.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C. Appendix B	a) 9000 ft. of 3" dia. Steel pipe b) Misc. Struct. Steel, platforms etc. c) Consumables per Exhibit B, Appendix B	Laborers	250	3 weeks	a) Box Coolers, to be field erected. b) Shell and tube exchangers can be substituted in place of Box Coolers. However, another 12 exchangers would be required. Air cooled exchangers may also be used.
		Ironworkers	3000		
		Pipefitters	3000		
		Welders	4500		
		Oper. Eng.	400		
		Foreman	200		
		Total	11,350		

ITEM NO: E-100's, E-102, E-103's

ITEM: Shell and Tube Exchangers

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Shell and tube heat exchangers, 8 required for maximum thermal efficiency, 20" to 37" dia.x20" long C-Steel construction with steel tubes.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) Heat exchanger shells, flanges, gaskets, etc. of various dia. from 20" dia. to 37" dia., 8 required length 20' long.	Pipefitter	150	6 weeks	a) Man-hours required is based on exchanger units having been pre-fabricated.
		Welder	150		
	b) 7600 C. Steel heat exchanger tubes, 3/4" dia. by 16' long	Boiler maker	200		b) Units can be field fabricated providing materials listed and additional manpower (approx. 15,000 mn hrs. is available)
		Foreman	100		
	c) Consumables per Exhibit B, Appendix B	Operating Eng.	50		
		Total	650		

ITEM NO: General

ITEM: Electrical and Instrumentation
(See Drawing 3774-KE-1)

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Electrical and Instrumentation installation to provide power to motors, lighting, controls etc. as required.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) Control instruments of various sizes per 3774-KE-1	Electricians	4400	3 weeks	
	b) Conduit, wires etc. as follows:	Operating Eng.	600		
3/4" cond. 3500'	#14 Awg -4000'				
1" cond. 5000'	#12 Awg -9000'	Foremen	600		
1¼" cond. 5000'	#10 Awg -7000'				
1½" cond. 1000'	# 8 Awg -1000'	Total	5600		
2" cond. 400'	# 6 Awg -1200'				
3" cond. 1000'	1/0 Awg -3400'				
4" cond. 1500'	2/0 Awg - 200'				
	4/0 Awg -1200'				
	350 mcm -2400'				
	500 mcm -2300'				
	15kv cable -2000'				
	c) 5 floodlights				
	d) 5 Sect. Motor control Center				
	3 30KVA Trans.				

ITEM NO: General

ITEM: Pipeways and Piping

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Approximately 2800 lin. ft. of double deck pipeway with approx. 6250 lin. ft. of C-Steel pipe from 2" dia. to 24" diam.

Resources Required: Constr. Equip.	Resources Required: Materials	Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
See Exhibits A and C, Appendix B	a) Pipe, Sch. 40 butt welded C-steel of following sizes:	Pipefitters	7000	8 weeks	a) To improve reliability of the crude unit approx. 100 ft. of 12" dia. and 350 ft. of 20" dia. of C-Steel piping should be installed with S-Steel or Chrome piping for C-101 column and H-100A & B furnaces.
	600' of 2" dia.	Welders	4200		
	3300' of 4" dia.	Laborers	2500		
	1000' of 6" dia.				
	500' of 8" dia.	Carpenters	800		
	250' of 10" dia.				
	200' of 12" dia.	Operating Eng.	800		
	400' of 20" dia.				
	100' of 24" dia.				
	b) Bolts, gaskets, valves, flanges of various sizes to match above.	Insulators	1000		
		Foreman	1700		
	c) Consumable supplies per Exhibit B, Appendix B	Total	18,000		
	d) Structural steel, concrete etc. to build pipeway.				
	e) Insulation, various sizes.				

ITEM NO: General

ITEM: Staff Supervision

EXPEDIENT CRUDE OIL UNIT (CASE A)

DESCRIPTION:

Supervisory staff required to construct the crude oil unit.

Resources Required		Labor Skills	Man-Hrs.	Time	Comments
Constr. Equip.	Materials	Required	Req'd.	Req'd.	
See Exhibits A and C, Appendix B		Gen. Supt.	600	9 weeks	
		Craft Suprvs.	1360		
		Mech. Field Eng	680		
		Elect. Field Eng	680		
		Elect. Designer	680		
		Piping Designer	1360		
		Instr. Designer	680		
		Structr. Designer	680		
		Civil/Struct. Eng	100		
		Process Eng.	300		
			7120		

TABLE A2

ITEM NO: General

ITEM: Site Preparation

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION:

Site preparation - clean and lovel fairly level site for new crude oil unit, remove burden, trees, excavate to construct foundations.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) Consumables per Exhibit B, Appendix B	Laborers	1000	1 week	a) Foundation work for each major type of equipment is listed with the equipment item.
		Operating Eng.	250		b) Time required is based on 100% skilled labor available as required. See Construction Schedules for more details and alternates.
		Foremen	250		
		Total	1500		

ITEM NO: H-100 A & B

ITEM: Crude Furnaces

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION:

Direct Fired "box-type" furnace, two required, 220 MM BTU/HR total Heat Duty required, each approx. 45'x40'x25' with an 80' high stack mounted on top; fabricated, steel housing with fire-brick and insulating brick, externally insulated, each includes 400 lin. ft. of 5" dia. steel pipe and 8 gas or oil burners.

Resources Required		Labor Skills	Man-Hrs.	Time	Comments
Constr. Equip.	Materials	Required	Req'd.	Req'd.	
See Exhibits A and C, Appendix B	a) 52 tons steel plate	Iron workers	4300	4 weeks	a) Furnaces are sized assuming no crude pre-heaters.
	b) Steel Doors (4 reqd.)	Pipe Fitters	3200		b) Two units rather than one unit were selected for flexibility of operations and reducing construction time.
	c) 2-tons C.Iron pipe or Chrome supports	Welders	1800		
	d) 16 gas or oil burners	Carpenters	200		
	e) 10,000 sq.ft. red brick	Cement Masons	800		
	f) 10,000 sq.ft. fire brick	Laborers	600		
	g) 3500 sq.ft. floor insulat.	Brick Layer	1100		
	h) 800 ft. of 5" dia. steel piping	Operating Eng.	200		
	i) 1200 sq.ft. insul. fire brick	Insulators	200		
	j) 160' of 36" dia. 5/8" thick steel pipe for stacks	Foremen	600		
	k) 120 $yd.^3$ concrete rebar for foundation	Total	13,000		
	l) Consumables per Exhibit B, Appendix B				

ITEM NO: C-100

ITEM: Crude Column

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: Crude Distillation column, 20-25 ft. diameter by 60-65 ft. long (tangent to tangent) with 20-22 bubble cap sieve or weir type distillation trays on 2 ft. spacing, 5/8" thick C. Steel shell with S. Steel internals preferred, 25,000 lbs. Dry wt., externally insulated, with nozzles, relief valves and internal piping.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) 8-8ft. high pre-rolled 5/8" thick C. Steel plates 20-25 ft. Diam.	Cement Masons	250	4 weeks	a) C. Steel or C. Iron trays and internals may be substituted for S. Steel.
	b) 2-ASME dished heads 25' Dia.	Laborers	250		b) Column may be substituted with smaller dia. columns providing total cross-sectional area remains approx. the same.
	c) 22 Distillation trays S. Steel Preferred	Carpenters	250		
	d) Tray supports - S. Steel	Ironworkers	1650		c) Column "packing" of scrap steel may be substituted for Dist. trays. Eff. will decrease appreciably.
	e) 5700 sq. ft. of 3" thick insulation	Pipefitters	1650		
	f) $30cy^3$ of concrete and rebar $4d^3$	Welders	1650		
	g) Misc. piping, etc.	Insulators	250		
	h) Consumables per Exhibit B, Appendix B	Operating Eng.	1250		
		Foreman	700		
		Total	8400		

ITEM NO: C-101, C-102 and V-100

ITEM: Strippers and overhead Accumulator

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: C-101 and C-102 - Distillation towers; each approx. 4'-6" dia. by 17' high (t-T), C. Steel shell with dished heads and 6 S. Steel bubble cap, weir or sieve type trays, 15,000 lbs. dry wt. V-100 Horiz. Pressure vessel, 7' dia. x 20' long (T.T) 1/2" thick-C, Steel material

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) 5-8 Ft. high pre-rolled 5/8" thk. C. Steel plates, 4'6" Dia.	Cement Masons	100	4 weeks	a) C. Steel or C. Iron trays and internals may be substituted.
	b) 3-8ft. long pre-rolled 1/2" thick C.Steel plates 7'door.	Laborers	100		b) Column "packing" or scrap steel may be substituted for Dist. trays, Eff. will decrease appreciably.
	c) 12 S.Steel distillation trays.	Carpenters	100		
	d) 6-ASME dished heads	Ironworkers	200		
	e) Tray supports	Pipefitters	150		
	f) 400 Sq.ft. insulation	Welders	200		
	g) 10 cy concrete and rebar	Insulators	100		
	h) Consumables per Exhibit B, Appendix B	Operating Eng.	50		
		Foremen	100		
		Total	1100		

ITEM NO: P-100, P-101-P-102,P-103

ITEM: Pumps

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: Centrifugal pumps from 150gpm up to [illegible]00 [illegible]pm with motor drivers. Motor sizes are from 15 hp up to 400 hp. C.Steel or C. Iron construction for pumps.

Resources Required		Labor Skills	Man-Hrs.	Time	Comments
Constr. Equip.	Materials	Required	Req'd.	Req'd.	
See Exhibits A and C, Appendix B	a) Pumps and Motors as defined on Dwg. 3774-KE-1.	Carpenters	150	5 weeks	a) Reciprocating pumps may be substituted;
	b) Consumables per Exhibit B, Appendix B.	Pipefitters	200		b) Steam turbine drivers may be substituted for motor drivers. Additional steam will be required.
		Machinists	200		
		Laborers	150		
		Cement Masons	200		
		Foremen	100		
		Total	1000		

ITEM NO: E-101 & E-104

ITEM: Box Coolers

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: Box Coolers. two required; one to be 65'x20'x10' high concrete construction with 5000 ft. of 3" dia. steel pipe inside, 112mm BTU HR Duty required, one to be 55'x20'x10' high concrete construction with 4000 ft. of 3" dia. steel pipe inside, 78.4 mm BTU/HR. Duty required.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B	a) 90 cy Concrete & rebar	Cement Masons	300	5 weeks	a) Box Coolers, to be field erected.
	b) 9000 ft. of 3" dia. steel pipe	Laborers	750		b) Shell and tube exchangers can be substituted in place of Box Coolers. However, another 12 exchangers would be required. Air cooled exchangers may also be used.
	c) Misc. Struct. Steel, platforms etc.	Ironworkers	3000		
	d) Consumables per Exhibit B, Appendix B	Pipefitters	3000		
		Welders	4500		
		Carpenters	500		
		Oper. Eng.	400		
		Foreman	200		
		Total	12,650		

ITEM NO: E-100's, E-102, E-103's

ITEM: Shell and Tube Exchangers
(See Dwg. 3774-KE-1)

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: Shell and tube heat exchangers, 8 required for maximum thermal efficiency, 20" to 37" dia. x 20' long C-Steel consturction with steel tubes.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibit A and C, Appendix B	a) Heat exchanger shells, flanges, gaskets, etc. of various dia. from 20" dia. to 37" dia., 8 required, 20' long. Refer to 3774-KE-1	Pipefitters	150	7 weeks	a) Man-hours required is based on exchanger units having been prefabricated and available in warehouses.
		Welders	150		b) Units can be field fabricated providing additional materials and additional manpower are available.
		Boiler makers	200		
	b) 7600 C.Steel heat exchanger tubes, 3/4" dia. by 16' long for above shells.	Carpenters	150		
		Concrete Masons	100		
	c) Concrete, 6cy.	Foreman	100		
	d) Consumables per Exhibit B, Appendix B	Operating Eng.	50		
		Total	900		

TABLE A3

SKID-MOUNTED EXPEDIENT CRUDE OIL UNIT (CASE B)

ITEM NO: General

ITEM: Construct Skid Mounted Crude Unit

DESCRIPTION: Install pre-fabricated, skid-mounted Crude Unit of nom. 35,000 - 50,000 BPD capacity, approx 25 skids required, skids are pre-piped, wired, etc. Time and man-hours listed are to receive and unload skids, fabricate and install interconnecting piping and electrical, connect power supply, pressure test systems, calibrate instruments and insulate. Approximate total weight is 375 tons.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and B, Appendix B	a) 100 cy of concrete and rebar.	Pipefitter	4000	6 weeks	Time required is based on 100% skilled labor available as required. See Construction Schedule for more details and alternates.
	b) 30 tons of pipe supports.	Welder	8000		
	c) 2500 lin. ft. of piping.	Laborer	2000		
	d) Insulation, etc.	Carpenter	2000		
	e) Consumable supplies per Exhibit B, Appendix B.	Operating Eng.	2000		
		Cement Mason	1000		
		Electrician	2000		
		Foreman	1000		
		Total	22,000		

ITEM NO: General

ITEM: Staff Supervision

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: Supervisory staff required to construct the crude oil unit.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A and C, Appendix B		Gen. Supt.	600	9 weeks	
		Craft Suprvs.	1360		
		Mech. Field Eng.	680		
		Elect. Field Eng	680		
		Elect. Designer	680		
		Piping Designer	1360		
		Instr. Designer	680		
		Structr. Designer	680		
		Civil/Strct. Eng	100		
		Process Eng.	300		
			7120		

ITEM NO: General

ITEM: Pipeways and Piping

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: Approximately 2800 lin. ft. of double deck pipeway with approx (250 [illegible] ft. of C-Steel pipe from 2" dia. to 24" diam.

Resources Required: Constr. Equip.	Resources Required: Materials	Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
See Exhibits A & C, Appendix B	a) Pipe, Sch. 40 butt welded C-steel of following sizes: 600' of 2" dia. 3300' of 4" dia. 1000' of 6" dia. 500' of 8" dia. 250' of 10" dia. 200' of 12" dia. 400' of 20" dia. 100' of 24: dia. b) Bolts, gaskets, valves, flanges of various sizes to match above. c) Consumable supplies per Exhibit B, Appendix B. d) Structural steel, concrete etc. to build pipeway. e) Insulation, various sizes	Pipefitters Welders Laborers Carpenters Operating Eng. Insulators Foreman	7000 4200 2500 800 800 1000 1700 18,000	8 weeks	a) To improve reliability of the crude unit approx. 100 ft. of 12" dia. and 250 ft. of 20" dia. [illegible] C-Steel piping should be installed with S-Steel or Chrome piping for C-101 column and H-100A , B furnaces.

ITEM NO: General

ITEM: Electrical and Instrumentation (See Drawing 3774-KE-1)

EXPEDIENT CRUDE OIL UNIT (CASE B)

DESCRIPTION: Electrical and Instrumentation installation to provide power to motors, lighting, controls etc. as required.

Resources Required		Labor Skills Required	Man-Hrs. Req'd.	Time Req'd.	Comments
Constr. Equip.	Materials				
See Exhibits A & C, Appendix B	a) Control instruments of various sizes per 3774-KE-1	Electricians	4400	3 weeks	
3/4" cond. 3500' 1" cond. 5000' 1¼" cond. 5000' 1½" cond. 1000' 2" cond. 400' 3" cond. 1000 4" cond. 1500	b) Conduit, wires etc. as follows: #14 Awg -4000' #12 Awg -9000' #10 Awg -7000' #8 Awg -1000' #6 Awg -1200' 1/0 Awg -3400' 2/0 Awg -200' 4/0 Awg -12[illegible]' 350 mcm -2400' 500 mcm -2300' 15kv cable -2000'	Operating Eng. Foreman Total	600 600 5600		
	c) 5 floodlights				
	d) 5 Sect. Motor control Ce[illegible]				
	3 30KVA Trans.				

APPENDIX B
SUMMARY OF DETAILED CALCULATIONS OF RESOURCES REQUIRED FOR CONSTRUCTION OF THE DESIGNED ECOU

The estimated materials and effort required in various construction tasks for the ECOU are listed in Tables B1 through B18. The estimated major materials and effort required for the tasks in the assembly of the S-ECOU are given in Table B19. The estimated quantities of materials required for the ECOU are given in Table B20 by type of material. The construction equipment required (Exhibit A) is listed in Table B21; the major consumable supplies needed (Exhibit B) are listed in Table B22; and the types of small tools needed (Exhibit C) are listed in Table B23.

These tables were prepared by the Jacobs Engineering Group, Inc., of Concord, California, as a subcontractor. Tables B1 through B19 have not been transcribed by CPR; Tables B20 through B23 have been.

Table B1
ECOU (Case A)
Site Clearing

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
Site Clearing Area = Allow for Removal of destroyed crude oil unit equipment, piping conduit and Structural steel (flame cut) to foundation tops - with no steam-out. Assume replacement equipment and materials will be installed on existing foundations	150000	SF			
Furnaces (cut up-drag off)	2			310	620
Crude Column	1			220	220
Heat Exchangers	10			24	240
Accumulator	1			60	60
Kerosene Stripper	1			80	80
Transfer Pumps	10			24	240
Structural Steel	100	Tons		10-	1000
Piping	30000	LF		0.05	1500
Electrical	LS			-	500
Misc. items, instruments, shelters, etc.	Allow	10%		-	540
TOTAL THIS PAGE					5000

Table B2
ECOU (Case B)
Site Clearing

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
Clearing & Grubbing Leveling existing Open Land Area	150000	SF			500
		TOTAL THIS PAGE			500

Table B3
ECOU (Case A)
Concrete Work

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
Allow for patching Repair and additions to existing foundations in unit area					400
TOTAL THIS PAGE	Allow				400

Table B4
ECOU (Cases A and B)
Change Pump and Furnaces

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
PUMP P-100					
A. Install pump 8 x 13, 400 HP, vertical	1	Ea			200
B. Foundation & suction well	2	Cy		30	60
C. Structural steel - pump mtg frame & trash screen	1000	Lbs			40
FURNACE H-100 A&B CABIN TYPE 45' x 40' long Ea	2	Ea			
A. Fabricate steel housings	52	Tons		35	1820
Steel flues stacks & guys	2	Ea		120	240
Cast iron doors (install)	4	Ea		8	32
Cast Tube Supports (install)	2	Tons		50	100
Transit Roofing	56	Sq		15	840
B. Foundations (45x40x1)x2 *	130	Cy		10	1300
Common red brick	10400	SF		005	57.0
Firebrick	10000	"		"	500
Lt. Wt. Insul firebrick	4000	"		"	200
Lt. Wt. suspended wall	8000	"		"	400
Floor insulation	3600	"		"	180
Loose insulation	Allow	"		-	170
C. Crossover piping (5" 0)	400	LF		2.5	1000
Burners (set-in & support)	4	Ea		8	32
Tube installation-butt W. (5"0)	7700	LF		025	1925
Tube fittings-stress relief	800	Ea		4-0	3200
Test - Calibrate	65			Allow	160

Note: Unless otherwise noted Manhour estimates include receiving, uncrating and transporting equip. to installation location within 200 feet of receiving point. Also included are testing and alignment of pumps and drivers.

TOTAL THIS PAGE 12925

* for Case B only

Table B5
ECOU (Cases A and B)
Crude Oil Column

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
* CRUDE COLUMN C-100	1	Ea			
25' Ø x co2' T-T 1 21 dist. trays on 2' spacing wall thickness 5/8" C.S. internals S-STL. 125,000 lbs dry					
* Assume shop fabricated & stored rolled plates, dished heads, support rings & trays are available for field welding, assy, erection.					
Concrete foundation allow* 323000#/A @ 100#/CF =	30	Cy		10	300
Support skirt w/base ring & manway (1600 in weld)	1	Ea			320
Shell Assy & heads	Allow LS				3960
Insulation supports	Allow				160
Tray Supports & Tray last	21	Ea			2620
Nozzles (10 Ea)	Allow				300
Manways (2)	Allow				80
Insulation	5700	SF			580
Testing					80
TOTAL THIS PAGE	1	Ea			8400

* for Case B only

ECOU Table B6
(Cases A and B)
Vessels

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
KEROSENE & DIESEL STRIPPER *	1	Ea		Allow	450
C-101 & C-102 4'-6 Ø x 17' T-T (Field Fab.) C. S. Shell, 5/8" Thk 15000 lbs.					
CONCRETE FOUNDATION ** 15000/4 @ 100#/CF	2	Cy		20	40
Insulation	375	SF			40
Testing	Allow				20
V-100 OVERHEAD ACCUMULATOR	1	Ea			
7' 0 x 20' T-T Horizontal, 300° F, 29 PSI C.S., 1/2" Wall, 15000 Lbs					365
Nozzles	Allow				135
CONCRETE FOUNDATION **	2	Cy			40
TOTAL THIS PAGE	2	Ea			1090

* Assume Rolled Plates & heads are shop Fab'd and stored for field assy.

** for Case B only

Table B7
ECOU (Cases A and B)
Heat Exchangers

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
E-100A KEROSENE/CRUDE HEAT EXCHANGER	1	Ea			80
Shell & tube, 20"Ø x 20' Long, C.S. 3/4"Ø x 16' long tubes, 325 1020 S.F.					
CONCRETE FOUNDATION*	1	Cy			40
E-100B DIESEL/CRUDE HEAT EXCH.	1	Ea			80
Shell & tube, 29"Ø x 20' long, 750 tubes, C.S., 2350 S.F.					
CONCRETE FOUNDATION*	1	Cy			40
E-100C[B] RESID./CRUDE HEAT EXCH.	3	Ea		80	240
Shell & tube, 37"Ø x 20' long, S/S 1270 Tubes, 3985 S.F.					
CONCRETE FOUNDATION*	1	Cy			40
TOTAL THIS PAGE	5	Ea			520

* for Case B only

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
E-101 OVERHEAD CONDENSER					
Box cooler, 112 MM BTU/Hr 65' x 20' x 10' High, C.S.					
Fabricate & install platework	1	Ea			2250
Pipe coils	5000	LF			4500
Foundation for E-101*	48	Cy		10	480
E-104 RESID. COOLER					
Box cooler, 78.4 MM BTU/Hr 55' x 20' x 10' High, C.S.					
Fabricate & install	1	Ea			2000
Pipe coils	4000	LF			3000
Foundation for E-104*	40	Cy		10	400
E-102 KEROSENE COOLER	1	Ea			80
Shell & tube, 29"Ø x 20' long C.S., 875 tubes, 2750 S.F.					
Foundation for E-102*	1	Cy			40
TOTAL THIS PAGE	3	Ea			12750

* for Case B only

Table B8.
ECOU (Cases A and B)
Heat Exchangers and Pumps

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
E-103'S DIESEL COOLER					
Shell & tube, 31"Ø x tubes = 3/4" x 16' long, C.S., 875 tubes, 2750 S.F.	2	Ea		80	160
Foundation for E-103'S*	1	Cy			40
P-101 COLUMN REFLUX PUMP	1	Ea			140
6 x 9, 1520 GPM, 100 HP 65 ΔP, 3000 lbs.					
Foundation for P-101*	1	Cy			40
P-102 GASOLINE PUMP	1	Ea			140
6 x 9, 1520 GPM, 100 HP 65 ΔP, 3000 Lbs.					
Foundation for P-102*	1	Cy			40
P-103 KEROSENE PUMP	1	Ea			30
2 x 9, 150 GPM, 15 HP 90 ΔP, 1000 lbs.					
Foundation for P-103*	.5	Cy			30
TOTAL THIS PAGE	5	Ea			620

* for Case B only

Table B9.
ECOU (Cases A and B)
Pumps

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
P-104 DIESEL PUMP					
3 x 9, 300 GPM, 50 HP Matl - S/S, 145 ΔP, 2000 Lbs.	1	Ea			50
Foundation for P-104*	1	Cy			40
P-105 RESID. BOTTOMS PUMP	1	Ea			150
4 x 13, 830 GPM, 150 HP 5 Ch../S/S, 165 ΔP, 2400 Lbs					
Foundation for P-105*	1	Cy			40
TOTAL THIS PAGE	2	Ea			280

* for Case B only

Table B10.
ECOU (Cases A and B)
Pipeway Supports

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
PIPEWAYS					
31 Bents - double deck 8" pipe @ 90'/bent	2800	LF			740
Pipeway Foundations*					
18"Ø x 4' = 7 CF Ea x 62 =	20	Cy		8	160
TOTAL THIS PAGE	31	Ea		29	900

* for Case B only

Table B11.
ECOU (Cases A and B)
Piping

DESCRIPTION		QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
FIELD FABRICATED PIPE Including Fittings, Flanges, Valves, Specialties, Field Supts, Testing						
Pipe, C.S. Sch. 40, BW.	2"	530	LF		1.0	530
" " "	4"	1310	"		2.0	2620
" " "	6"	1000	"		2.5	2500
" " "	8"	460	"		2.8	1288
" " "	10"	230	"		3.2	736
" " "	12"	80	"		4.5	360
" " Std. Wt. "	24"	100	"		6.0	600
Pipe - 5 chrome Smls	12"	100	LF		8.0	800
" "	20"	340	LF		8.0	2720
Utility Piping						
Assume 50% process piping Average line size 4"Ø		2100	LF		2 *	4200
Avg 6" diameter						
TOTAL THIS PAGE		6250	LF		2.62	16354

Table B12.
ECOU (Cases A and B)
Instruments

DESCRIPTION		QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
INSTRUMENTATION						
Control Valves	2"	2	Ea		8.0	16
" "	4"	2	"		12.0	24
" "	6"	5	"		18.0	90
" "	8"	1	"		20.0	20
" "	10"	1	"		24.0	24
FRC - 4"		3	Ea		16.0	48
6"		2	"		16.0	32
LIC		5	"		16.0	80
TRC		2	"		16.0	32
PC		1	"		16.0	16
PI - 3/4"		6	Ea		4.0	24
TI - 1"		5	Ea		4.0	20
Tubing Mounting Hardware						180
Testing						40
TOTAL THIS PAGE		LS				646

Table B13.
ECOU (Cases A and B)
Electrical

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
Allowance for MCC's Power Lighting & Grounding On Site					
10% of 56685 MH					5670
#14 AWG	4000	LF			30
#12 AWG	9000	LF			90
#10 AWG	7000	LF			84
# 8 AWG	1000	LF			15
# 6 AWG	800	LF			15
# 4 AWG	1200	LF			27
1/0 AWG	3400	LF			120
2/0 AWG	200	LF			10
4/0 AWG	1200	LF			61
350 MCM	2400	LF			160
500 MCM	2300	LF			224
I/C - #2 15 KV Shld Cable	2000	LF			85
42 Circuit 120/208V PNL	1	Ea			24
Pushbuttons Exp. Prod f.	6	Ea			4
Supports - Misc. steel	4000	Lbs			
1 MVA Trans. 12.47 KV/480V, 3Ø	1	Ea			250
5 Sect. MCC with 1200A Main	1	Ea			100
30KVA Trans. 480/120-208	1	Ea			18
Floodlites	25	Ea			75
400 H.P. Motor	1	Ea			8
150 H.P. Motor	1	Ea			6

Table B13 cont.

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
100 H.P. Motor	1	Ea			4
100 H.P. Motor	1	Ea			4
50 H.P. Motor	1	Ea			3
15 H.P. Motor	1	Ea			2
3/4" C	3500	FT			200
1" C	5000	FT			320
1¼" C	500	FT			52
1½" C	1000	FT			120
2" C	400	FT			57
3" C	1000	FT			220
4" C	1500	FT			450
Misc. Conduit Fittings, Pull Boxes, Terminal Blocks	Lot	Ea			

Table B14.
ECOU (Cases A and B)
Insulation

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
INSULATION					
2" Thk F. G. Block W/Alum Jacket Equipment (Misc.)	6000	SF			300
Piping - Avg. Size 6" Incl. Fittings, Flgs, Valves 1-1/2" Thk F.G. w/Alum Jacket SS Bands	1200	LF			400
TOTAL THIS PAGE					700

Table B15.
ECOU (Cases A and B)
Construction Equipment

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
CONSTRUCTION EQUIPMENT					
Forklift (10 ton)	2	Ea			
Flatbed Truck	1	Ea			
Backhoe	1	Ea			
Crane 30 Ton Truck	1	Ea			
Scaffolding (Allow)	5000	SF			
Chain Hoists (5 Ton)	4	Ea			
Electric Weld Machines	6	Ea			
Gas Powered Welding Mach	4	Ea			
Table Saws	2	Ea			
Pipe Cutters, Threaders	4	Ea			
Acetylene Torch Rigs	4	Ea			
Power Grinders, Drills	12	Ea			
Air Compressors, Hoses	2	Ea			
Power Generator (Diesel)	2	Ea			
Gas powered concrete Mixer	4	Ea			
Placing Equipment, Tools Wheelbarrows, Hose, etc.	Lot				

Table B16.
ECOU (Cases A and B)
Field Staff

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS	WKS
Supervision - Staff						
General Superintendant	1	Ea		168/WK	1512	9
Craft Supervisors	2	Ea		"	3024	9
Field Engineer (Mech)	1	Ea		"	1344	8
Field Engineer (Elec)	1	Ea		"	672	4
Designer Elec.	1	Ea		112/WK	672	6
" Piping-Mech	2	Ea		"	1008	9
" Instrument	1	Ea		"	448	4
" Structural	1	Ea		"	560	5
Process Engineer	1	Ea		"	672	6
Civil Engr (Survey)	1	Ea		"	224	2
TOTAL THIS PAGE					10136	

Table B17.
ECOU (Cases A and B)
Temporary Facilities

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
Temporary Office Trailer or Shack	Allow				40
Desks	2	Ea			10
Drafting Tables, Machines					10
Plan Files					2
Temporary Electrical					60
Temporary Water					60
Chemical Toilet Fac.					10
Welding Bays	4	Mo			88
Storage & Warehousing Materials					700
Misc. Office Supplies	Allow				100
TOTAL THIS PAGE					1080

Table B18
ECOU (Cases A and B)
Composition of Crew, Including Craft Labor

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	100% TOTAL MAN-HOURS	25% SKILLED LABOR[a] PERCENT ADDED MAN-HOURS
Piping-Pump-H. Exch/Installation						
Foreman	10	%			3781	7.4
Pipefitter	40	%			15124	60.0
Welder	25	%			9453	38.0
Laborer	10	%			3781	7.4
Carpenter	5	%			1891	3.7
Operating Engineer	10	%			3781	7.4
S/T	100	%			37811	123.9
Vessels, Box Coolers, Furnaces, Structural Steel						
Foreman	10	%			948	2.3
Ironworker - Welder	60	%			5690	23.0
Laborer	10	%			948	2.3
Operating Engineer	20	%			1896	4.6
S/T	100	%			9482	32.2
Foundations, Concrete Work						
Foreman (Carpenter)	10	%			317	0.76
Cement Mason	60	%			1902	7.60
Laborer	10	%			317	0.76
Operating Engineer	20	%			634	1.50
S/T	100	%			3170	10.62
Electrical						
Foreman	10	%			567	1.8
Electrician	80	%			4536	18.0
Operating Engineer	10	%			567	1.8
S/T	100	%			5670	21.6
Instrumentation						
Foreman	10	%			65	.23
Pipefitter	90	%			581	2.30
S/T	100	%			646	2.53

[a]For a crew with only 25 percent of desired skills for the repair teams (total = 2.08 E, where E is effort for crews with 100% of needed skills) and the remainder of the crew is made up of nonconstruction personnel.

Table B18 Cont.

DESCRIPTION		QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	100% TOTAL MAN-HOURS	25% OF SKILLED LABOR MAN-HOURS
Refractory Brick							
Foreman		10	%			162	0.36
Bricklayer		55	%			891	3.60
Laborer		15	%			243	0.54
Carpenter		10	%			162	0.36
Operating Engineer		10	%			162	0.36
	S/T	100	%			1620	5.22
Insulation							
Foreman		10	%			252	0.80
Insulation Worker		80	%			2012	8.00
Laborer		5	%			126	0.40
Operating Engineer		5	%			126	0.40
	S/T	100	%			2516	9.60
Temporary Facilities							
Foreman		10	%			96	0.096
Laborer		80	%			768	0.770
Operating Engineer		5	%			48	0.048
Carpenter		5	%			48	0.048
	S/T	100	%			960	0.962
Site Clearing							
Foreman		10	%			48	.096
Operating Engr.		50	%			240	.960
Laborer		40	%			192	.380
	S/T	100	%			480	1.436
TOTAL						62355	207.7

Table B19. S-ECOU (Case B) all tasks.

DESCRIPTION	QUANTITY	UNIT	MATERIALS $/UNIT	MAN-HRS. OR $/UNIT	TOTAL MAN-HOURS
o Mobilize & Temp Facility	1	Ea			500
o Receiving Skid Mounted equipment - Removing flange protectors & protective coverings	25	Ea			1000
o Concrete Foundations	100	Cy			2000
o Set Skids on existing clear site 200 ft from receiving	25	Ea			2500
o Pipe & Conduit Supports	30	Tons			1000
o Fabricate interconnecting piping & install	2500	LF			6000
o Install Pump P-100	1	Ea			300
o Install electrical service to each skid	Allow				2000
o Pressure test systems	Allow	Ea			1000
o Calibrate instruments & Run-in Systems	Allow				1500
o Insulation of Piping (off skids)	Allow				700
Subtotal					18500
Supervision	Allow				2500
Temporary Facilities	Allow				500
TOTAL THIS PAGE	25	Ea			21500

Table B20. ECOU (Cases A and B): estimated material quantity requirements.

A. Yard Piping Carbon Steel A-53

Size	Sch	Pipe LF	Fittings 90	T	Un	FC	Flanges		BNG	Plug or Gate Va		Check		Joints SocW. or Scrd.
1/2	80	200	40	10	10	20	150# scrd	2	4	600#	10	600#	5	Scrd.
3/4	"	1000	200	50	50	100	" "	10	20	"	40	"	20	"
1	"	1000	200	50	50	100	" "	10	20	"	40	"	20	"
1-1/2	40	1000	200	50	50	100	" "	10	20	"	40	"	20	"
					45	1/2C	150# and			150# or		150# or		Flanged
2	"	600	120	30	30	60	300#RFWN	50	100	300#	25	300#	15	& Butt W.
3	"	500	100	20	20	20	"	40	80	"	20	"	10	"
4	"	1300	175	50	50	50	"	105	210	"	55	"	25	"
6	"	1000	135	35	35	35	"	80	160	"	40	"	20	"
8	"	500	70	20	20	20	"	40	80	"	20	"	10	"
10	"	300	40	10	10	10	"	25	50	"	15	"	10	"
12	STD	100	15	5	5	5	"	10	20	"	5	"	3	"
14	"	40	4	2	2	2	"	5	10	"	2	"	1	"
16	"	40	4	2	2	2	"	5	10	"	2	"	1	"
18	"	40	4	2	2	2	"	5	10	"	2	"	1	"
20	"	400	40	10	10	10	"	35	70	"	15	"	10	"
24	"	100	10	2	2	2	"	10	20	"	5	"	3	"
Total		8120	2591					442	884		336		174	

B. Alloy Piping - 1-1/4 Cr. 1/2 Moly A-217, WC-6

Size	Sch	Pipe LF	90°	T	45°	RED	180°	FLG	BNG	Plug	Check	Joints Butt W Flanged 600 lb RTJ
5"	80	10000	500	50	20	20	200	100	100	10	5	
6"	"	100	20	5	5	5	10	10	10	5	2	"
12"	60	100	20	2	2	2	-	10	10	5	2	"
20"	30	400	40	4	4	4	-	20	20	10	4	"
Total		10600	570	61	31	31	210	140	140	30	13	

Table B20 cont.

C. Structural Steel Incl Furnace & Box Coolers

Shapes	WFL	Channel	Angle	T	Total Weight
<20#	5000	2000	2000	1000	10000 #
20-40	8000	5000	2000		15000 #
>40#	10000				10000 #
	1/8"	1/4"	1/2"	3/4"	
Plate	66000#	8000#	1000#	1000#	76000 #
Ladder	(100 LF)				1500 #
Platform Grating (1000 SF)					10000 #
Bolts, Nuts, Clips (Allow)					9500 #
Pipe Support Bents (8" Ø Pipe)					80000 #
Total					106 Tons

D. Concrete Materials*	Quantity
Formwork Back-up 2800 BF., Ply	2800 SF
Concrete (7 sack/Cy, 90^{66}/Sack)	2000 Sacks
Sand	70 CY
Gravel Aggregate	140 CY
Reinf Steel, WWF = Tie Wire	14000 Lbs
Anchor Bolts 1/2 thru 1"x16" Lg	1400 Lbs
Grout (Allow)	100 CF
Total CY in-place	284 CY

E. Rings, Trays

(1) Crude Column	
5/8" thk x 12'-6" Radius Rolled Plate	5700 SF
5/8" thk x 25"-0" Dia Dished Head	2 Ea
1/4" thk x 2" W x 12'-6 Radius Bar	1650 LF
304 SS Dist. Trays	21 Ea
(2) Kerosene/Diesel Stripper	
1/2" thk x 2'-3" Radius Rolled Plate	400 SF
1/2" thk x 4'-6" Dia. Elliptical Head	3 Ea
(3) Overhead Accumulator	
1/2" thk x 3'-6" Radius Rolled Plate	700 SF
1/2" thk x 7'-0" Dia. Elliptical Head	2 Ea

* for Case B only

Table B20 (cont.)

F. Furnace Refractory Brick	$/Unit	Area, Length or Volume
Common Red Brick	4.00	10400 SF
Firebrick	9.00	10000 SF
Light Wt Insul Firebrick	15.00	16000 SF
High Temp Mortar	10.00	2300 CF

G. Insulation		
2" Thick Fiberglass Panels		12000 SF
1-1/2" Thick Fiberglass 6" Pipe Insul		1000 LF
2" Thick Fiberglass 20" Pipe Insul		500 LF
Wire (Galv Steel)		1000 LF
Aluminum Sheet Jacket Mtg		17000 SF
S.S. Bands & Clamps		2000 LF
Mastic		100 Gals

H. Instrumentation

Pressure Gages - 6   Flow Indicators - 10

Temperature Gages - 5   Press Safety Valves - 10

Press. Controller w/control Va - 1 Set

Flow Recorder/Controller w/Orifice Flgs & Control Va - 3 Sets

Flow Recorder w/Orifice Flgs - 2 Sets

Temp. Recorder/Controller w/T.W. & Control Va - 2 Sets

Level Indicating Controller - w/Control Va - 5 sets

Temp Controllers & Va's for Steam - 4 Sets

Press Regulator Air - 4 Sets

Flow Ind. Controllers Water - 8 Sets

Table B21. Construction equipment required.

Item	Quantity
10-ton forklift	2
Flatbed truck	1
Backhoe	1
30-ton truck crane	1
5-ton chain hoist	4
Scaffolding	5000 SF
Electric welding machine	6
Gas-powered welding machine	4
Table saw	2
Pipe cutter, threader	4
Acetylene torch rig	4
Power grinder, power drill	12
Air compressor, hoses, etc.	2
Diesel power generator	2
Gas-powered concrete mixer	4
Miscellaneous wheelbarrows, hoses	1 lot
Tools, placing equipment, etc.	1 lot

Table B22. Consumable supplies.

This list is intended to define the character of consumable supplies, but is not to be interpreted as a complete list of all such items.

Abrasives: paper, powerder
Abrasive wheels
Acid
Adapter, hose
Adhesive
Alcohol
Anchor, cinch
Antifreeze

Babbitt
Badges
Bags: paper, burlap
Banding: material, clips
Bands, elastic, helmet
Barrels: water, trash
Batteries, flashlight
Belt dressing
Belts, safety
Bits, drill, all types
Blades, all types
Boots, construction, rubber
Brads
Breaker points
Bricks, rubbing
Brooms
Brushes, all types
Buckets
Bulb, light
Burlap

Cables
Carbide
Carborundum blocks, stone
Cartridge, stud gun
Chalk, marking
Chalk line
Chamois
Chisels
Cleaners, tips
Cleaning compounds and fluids
Clips: wire, rope
Cloth: emery, straining
Clothing
Coal and coke
Connectors, hose
Coolers, water
Cords, extension
Corks
Cotter pins
Couplings, hose
Crayons, marking
Creosote
Cups, water
Cutters, glass, wheel
Cutting oil

Demolition points
Dies: bolt, conduit, pipe, Whitney Punch
Dippers
Discs: cutting, grinding
Disinfectants
Drills: masonry, shank, twist, star, bits
Drinking water
Drivers, sheeting
Drums: gas, oil
Dunnage

Emery cloth
Expansion shields: tube, roll, mandrel
Explosives
Extractors, screw

Face shields
Fasteners
Faucets
Files
First aid supplies
Filters: respirators, oil
Fittings: alemite, hose
Flashlights and batteries
Flares
Flints, Lighter
Float, wood
Flux
Fly spray
Form oil
Friction tape
Funnels

Gads
Gaskets, hose
Glasses: goggles, hoo[illegible]hes, lantern, light, fl[illegible]lig[illegible], lamp
Gloves, all types
Glue
Glycerin
Graphite
Grease
Grinding compounds, wheels

Hacksaw blades
Handles, all types
Hasps
Hats, safety
Hinges
Holders, electrode
Hoods, welding
Hooks
Hose: presto soldering, steam, water, air, fire, welding

Ice

Kerosene
Keys: chuck, lock
Knives, putty

Lamps
Lashing, wire rope
Latches
Lens: goggles, helmet, hood
Lightbulbs
Lighters: flint, torch
Line: chalk, mason
LPG
Lubricants, lube oil
Lumber, scaffold
Lugs: solder, solderless

Mandrels
Masks, gas
Measurers
Menders, hose
Mirrors
Mops

Nails
Nuts: wire, die
Nozzles: hose, sandblast

Oil: lubricating, cutting
Oakum

Packing: water, steam
Packing material
Padlocks
Pails
Paint, identification
Paper: sand, emery, toilet, writing, etc.
Paste, solder
Patterns
Pencils
Pipe compound
Pipe tools: cutter wheel, dies, rollers, pins
Preservatives
Pulleys
Putty
Pins

Rags, wiping
Raincoats
Reamers, hole
Receptacles
Respirators
Rivet sets
Rope: sisal or manila
Rubber boots
Rubbing stones
Ruler, folding, pocket
Runways

Safety equipment: first aid, goggles, hats
Salt tablets, dispensers
Sandblasting nozzles
Sandpaper
Saw blades, all types
Screens, sand
Screws
Segments: pipe, die
Shackles
Shellac
Shims
Shields, face
Signs
Slings: rope, wire, nylon
Soap
Soapstone
Solder and flux
Spray, insect
Stakes
Steel wool
Stencils, painting
Supplies, restroom
Survey stakes
Sweeping compound

Tacks
Tags
Tape: friction, linen, rubber, scotch, etc.
Taps, bolt
Tarpaulins
Tempstix
Thermometers
Thimbles, wire rope
Thread dope
Tips: cutting, presto soldering, welding, torch
Towels paper, cloth

Washers: flat, lock
Wastes, wiping
Wedges
Wheels: cutting, grinding, emery
Wicks, lantern
Wire: soft hack, tie, rope
Wire brushes

Table B23. Small tools.

This list is intended to define the character of small tools, but is not to be interpreted as a complete list of all such items.

Adapters, impact wrench
Adzes
Anvils, blacksmith
Arbors
Augers

Bars: nails, crow, pinch, wrecking, hickey, bricking-up, claw, rivet
Benders, tubing, hand
Banding machine
Blocks: rope, wire, snatch, tackle, cable, flaring
Bobs, plumb
Bolt cutters
Boxes: instrument, tool
Braces: carpenter, drill
Brands
Bull points
Burner, melting pot

Cable: wire, welding
Calipers: tube, inside, outside, micrometer
Cans: safety, gas, oil, spray
Carts, oxygen cylinder
Caulking gun
Cement jointing tools
Chain, boomer
Chainfalls
Chisel, caulking
Clamps: "C," form, line-up
Concrete floats
Conduit floats
Conduit hickeys
Cutters: bolt, wire, pipe, tube, tin snip, gasket

Diggers, pot hole, hand portable
Drills: electric, breast

Flaring tools
Flatters
Floats, hand
Forge
Frames, hacksaw

Gauges: drilling, feelers, wire, center, arc air
Grinders, bench
Grips
Guns: alemite, point stud, grease

Hacksaws
Hammers: sledge, hand, slag
Handle, ratchet
Heads, universal die
Hickeys, conduit
Hods, brick-mortar
Hoes
Hoists: chain, lever type
Hooks: timber-cant, packing
Horn, signal
Horses, mason
Hydrometer battery

Impact: drive, air, electric (max. 1/2")
Indicators, dial
Irons: caulking, soldering

Jack: reel, hydraulic, porta-power, pipe, ratchet

Ladders: step, extension, wood, aluminium
Ladles, melting
Lanterns
Lead pots
Letters, steel (A to Z)
Levels, hand

Machinist straightedge
Mallets
Mattocks
Mauls
Micrometers
Mixers

Nitrogen regulator

Ohmmeters
Oiler: line, bench, air-line
Oven, rod

Table B23, cont.

Picks, R.R.
Pipe rollers
Planers
Pliers: vice-grip, channel-lock, side cutter, etc.
Plugs, plumbers
Plumb bobs
Poles, range
Porta-power
Post-hole diggers, hand
Pots: melting, fire, lead
Puller, nail
Pulleys: flange, jacks, well, wheel
Pumps: small head, barrel, hand
Punches: gaskets, knockout, whitney

Rakes: asphalt, yard
Ratchet, all types
Reamers, pipe
Regulator: presto, soldering, acetylene, oxygen
Retainer, pipe
Rivet sets
Rods: level, line
Roller: pipe, tube

Sanders, electric
Saws: hood, hand, hacksaw frames power, sabre, skil
Scoop, hand
Scrapers
Screwdrivers, step, all types
Shackles, all types
Sheaves, steel
Shears
Sheetmetal rolls
Shovels, hand, all types
Side cutter
Snips, metal
Sockets, all types
Spades
Spikes, marlin
Spray can: concrete, form oil
Spreader: chain, flange
Squares: combination, framing steel
Stamp steel
Straightedge, all types

Tachometer
Tampers, hand
Tankers: fuel, oil
Tapes: fish-electric, steel measuring
Telephone, handset
Testers, battery
Threaders: pipe, bolt (hand-operated)
Tongs: rivet, brick, chain, pipe heater, etc.
Tool box, hand-carried
Tools: flaring, banding
Torches: welding, blow, gas
Trowels: power-operated
Trucks, hand, warehouse

Universal, impact

Vises: portable, hand, tripod-pipe, machinist
Voltmeters

Wheelbarrows
Wrecking bars
Wrenches, all types, hand
Walkie-talkie telephones

APPENDIX C

COMPLETE LIST OF SKID-MOUNTED REFINERIES MANUFACTURED BY HOWE-BAKER ENGINEERS, INC.

1,800 BPSD 34.0° API	Mobil Oil of Libya; Amal Field, Libya Producing 600 B/D of Diesel Fuel
1,800 BPSD 33.0° API	Amoseas Petroleum Limited; Nafoora Field, Libya Producing 600 B/D of Diesel Fuel
5,400 BPSD 21.0° API	Sinclair Venezuelan Oil Company; Barinas, Venezuela Producing 805 B/D LVN, 100 B/D HVN, 540 B/D Kerosine, 975 B/D of Diesel Fuel
1,000 BPSD 47.0° API	Texaco Petroleum Company; Orito Field, Colombia Producing 305 B/D Gasoline; 275 B/D Kerosine (JP-1A), 295 B/D Diesel Fuel
2,800 BPSD 27.4° API	Cabinda Gulf Oil Company;Luanda, Angola Producing 163 B/D LVN, 135 B/D HVN, 700 B/D Diesel Fuel
1,800 BPSD 44.0° API	Occidental Oil of Libya; Intisar Field, Libya Producing 600 B/D of Diesel Fuel and 100 B/D Jet Fuel
4,800 BPSD 28.2° API	Atlantic Richfield Oil Company; North Slope, Alaska Producing 493 B/D Distillate and 1,000 B/D Diesel Fuel
1,000 BPSD 29.0° API	Texaco Petroleum Company; Ecuador Producing 305 B/D Gasoline, 240 B/D Kerosine (JP-1A), 295 B/D Diesel Fuel
1,200 BPSD 12.6° API	Tenneco Oil Company; Bakersfield, California Producing Resid (Upgrades 12.6° API Sandy Crude)
600 BPSD 34.0° API	Sonatrach; El Borma Field, Algeria Producing 200 B/D Diesel Fuel
16,000 BPSD 28.0° API	Falconbridge; Dominican Republic Producing 6,000 B/D Naphtha
10,000 BPSD 32.1° API	Petrola Hellas; Athens, Greece To Produce 2,570 B/D Naphtha, 960 B/D Kerosine, 1,970 B/D Diesel Fuel, 4,500 B/D Fuel Oil
10,000 BPSD 32.1° API	Petrola Hellas; Athens, Greece To Produce 2,570 B/D Naphtha, 960 B/D Kerosine, 1,970 B/D Diesel Fuel, 4,500 B/D Fuel Oil
375 BPSD 40.0° API	Socea/Gress; Algeria To Produce 120 B/D Turbine Fuel

Source: **Howe-Baker Engineers, Inc. P.O. Box 956 Tyler, Texas 75710**

1,175 BPSD 40.7° API	Abu Dhabi Petroleum Company; Abu Dhabi, Trucial States To Produce 458 B/D Turbine Fuel
10,000 BPSD 36° API	Government of Iraq; Iraq To Produce 1,850 B/D Kerosine, 1,350 B/D Diesel Fuel including Kerosine Mercapfiner® Treating Facilities
10,000 BPSD 36° API	Government of Iraq; Iraq To Produce 1,850 B/D Kerosine, 1,350 B/D Diesel Fuel including Kerosine Mercapfiner® Treating Facilities
5,000 BPSD 34° API	Bay Refining (Dow Chemical); Bay City, Michigan To Produce 1,750 B/D Naphtha, 3,250 B/D Fuel Oil
20,000 BPSD 25/36° API	Petrol Hellas; Athens, Greece To Produce 4400 B/D Naphtha, 3600 B/D Kerosine, 4400 B/D Diesel, 7600 B/D Fuel Oil
20,000 BPSD 25/36° API	Petrola Hellas; Athens, Greece To Produce 4400 B/D Naphtha, 3600 B/D Kerosine, 4400 B/D Diesel, 7600 B/D Fuel Oil
20.000 BPSD 25/36° API	Petrola Hellas; Athens, Greece To Produce 4400 B/D Naphtha, 3600 B/D Kerosine, 4400 B/D Diesel, 7600 B/D Fuel Oil
20,000 BPSD 25/36° API	Petrola Hellas; Athens, Greece To Produce 4400 B/D Naphtha, 3600 B/D Kerosine, 4400 B/D Diesel, 7600 B/D Fuel Oil
10,000 BPSD 36/43° API	Government of Iraq; Baghdad, Iraq To Produce 1760 B/D Light Naphtha, 250 B/D Heavy Naphtha, 1850 B/D Kerosine, 1350 B/D Light Atm. Gas Oil, 1925 B/D Heavy Atm. Gas Oil, 12,825 B/D Fuel Oil
10,000 BPSD 36/43° API	Government of Iraq; Kirkuk, Iraq To Produce 1760 B/D Light Naphtha, 250 B/D Heavy Naphtha, 1850 B/D Kerosine, 1350 B/D Light Atm. Gas Oil, 1925 B/D Heavy Atm. Gas Oil, 12,825 B/D Fuel Oil
10,000 BPSD 36/43° API	Government of Iraq; Beije, Iraq To Produce 1760 B/D Light Naphtha, 250 B/D Heavy Naphtha, 1850 B/D Kerosine, 1350 B/D Light Atm. Gas Oil, 1925 B/D Heavy Atm. Gas Oil, 12,825 B/D Fuel Oil
10,000 BPSD 36/43° API	Government of Iraq; Samawah, Iraq To Produce 1760 B/D Light Naphtha, 250 B/D Heavy Naphtha, 1850 B/D Kerosine, 1350 B/D Light Atm. Gas Oil, 1925 B/D Heavy Atm. Gas Oil, 12,825 B/D Fuel Oil

10,000 BPSD 36/43°-API	Government of Iraq; Beije, Iraq To Produce 1760 B/D Light Naphtha, 250 B/D Heavy Naphtha, 1850 B/D Kerosine, 1350 B/D Light Atm. Gas Oil, 1925 B/D Heavy Atm. Gas Oil, 12,825 B/D Fuel Oil
10,000 BPSD 36/43° API	Government of Iraq; Samawah, Iraq To Produce 1760 B/D Light Naphtha, 250 B/D Heavy Naphtha, 1850 B/D Kerosine, 1350 B/D Light Atm. Gas Oil, 1925 B/D Heavy Atm. Gas Oil, 12,825 B/D Fuel Oil
2,600 BPSD 44.8° API	Sonatrach; Haoud el Hamra To Produce 905 B/D Turbine Fuel
25,000 BPSD 27.8° API	Energy Company of Alaska, North Pole, Alaska To Produce 1495 B/D Light Naphtha, 1967 Heavy Naphtha, 4733 B/D Kerosine, 1350 B/D Light Atm. Gas Oil, 1925 B/D Heavy Atm. Gas Oil, 12,825 B/D Fuel Oil
5,000 BPSD 49° API	Pitt Oil Company, Indianola, Pennsylvania To Produce 3,000 B/D Gasoline, 2,000 B/D No. 2 Oil
10,000 BPSD 36/43° API	Government of Iraq; Iraq To Produce 1750 B/D Light Naphtha, 250 B/D Heavy Naphtha, 1850 B/D Kerosine, 1350 B/D Diesel Fuel including Naphtha and Kerosine Merox® Treating Facilities (UNDER CONSTRUCTION)
10,000 BPSD 36/43° API	Government of Iraq; Iraq To Produce 1750 B/D Light Naphtha, 250 B/D Heavy Naphtha 1850 B/D Kerosine, 1350 B/D Diesel Fuel including Naphtha and Kerosine Merox® Treating Facilities (UNDER CONSTRUCTION)
5,000 BPSD 44° API	Attock Refinery Limited; Rawalpindi, Pakistan To Produce 2,125 B/D Stabilized Naphtha, 1,000 B/D Kerosine, 1,050 B/D Diesel, 250 B/D Atm. Gas Oil, 500 B/D Fuel Oil (UNDER CONSTRUCTION)
20,000 BPSD 44° API	Attock Refinery Limited; Rawalpindi, Pakistan To Produce 8,500 B/D Stabilized Naphtha, 4,000 B/D Kerosine, 4,200 B/D Diesel, 1,000 B/D Atm. Gas Oil, 2,000 B/D Fuel Oil (UNDER CONSTRUCTION)
2,000 BPSD 39° API	Mobil Libya; Libya To Produce 655 B/D Naphtha, 610 B/D Diesel, 725 B/D Fuel Oil (ENGINEERING)
30,000 BPSD 33.1° API	Riverside Oil & Refinery Company; Westwego, Louisiana To Produce 1,630 B/D Light Naphtha, 3,600 B/D Heavy Naphtha, 4,500 B/D Kerosine, 4,200 B/D Diesel, 2,100 B/D Atm. Gas Oil, 13,200 B/D Residue

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