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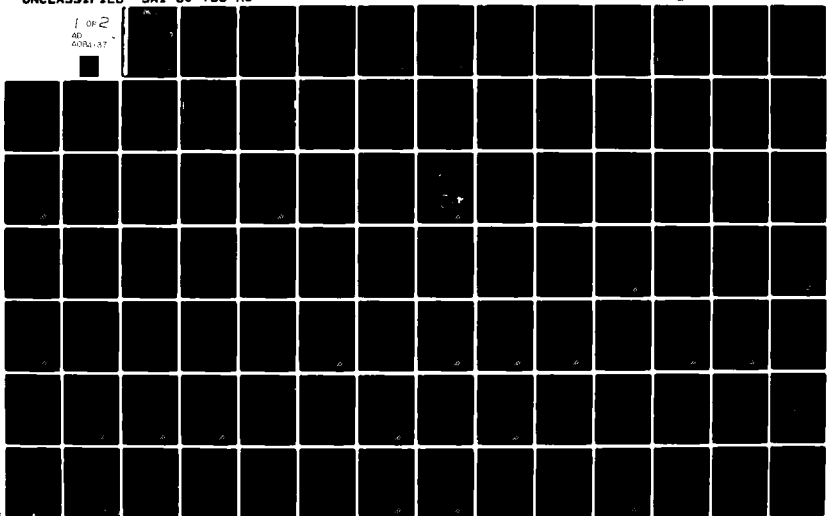
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**CRITICAL INDUSTRY REPAIR AND RECLAMATION  
STUDY: U.S. RUBBER INDUSTRY**

**FINAL REPORT**

Prepared by:

Ellery Block, Herbert Lewis, Ralph Sievers and Timothy White

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MAY 8 1980**

Prepared for:

Ballistic Missile Defense Systems Command  
P. O. Box 1500  
Huntsville, Alabama 35807

Federal Emergency Management Agency  
Washington, D. C. 20472

Under:

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CRITICAL INDUSTRY REPAIR AND RECLAMATION STUDY:  
U.S. RUBBER INDUSTRY

by

Ellery Block  
Herbert Lewis  
Ralph Sievers  
Timothy White

SUMMARY REPORT

30 November 1979

Prepared for:

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## EXECUTIVE SUMMARY

### 1. Type of Study

This research identifies products produced by the rubber industry that are expected to be in great demand in the U.S. after a full-scale nuclear war. This research then discusses the vulnerability to nuclear effects of facilities and equipment needed to produce those products and defines measures to both reduce and restore post-war production quickly.

### 2. Objectives

The major objectives of the study were:

- a. Identify the rubber industry products essential to post-war survival and recovery.
- b. Estimate early post-war demand for these essential rubber industry products, as a function of current usage and production capacity.
- c. Identify bottlenecks in the production processes for these essential products, and define for each bottleneck process its:
  - vulnerability to nuclear effects
  - activities to reduce vulnerability or restore production

### 3. Procedure

SAI initially determined essential post-war rubber industry products (based on previous analyses of essential post-war activities and products needed to support those activities) and examined required inputs and resources for their production processes. This information was used in compiling a "strawman" describing essential post-war products, their potential demand, their vulnerabilities during an attack, and measures to restore post-war production. The strawman was presented to personnel of the B. F. Goodrich Company (subcontractor to SAI in this study), a major producer of rubber and rubber products. The

strawman, its critique, and the ensuing discussions between B. F. Goodrich and SAI personnel permitted the strawman to be refined to reflect a realistic appraisal of industrial protection needs for the U.S. rubber industry. These discussions were complemented with visits to selected, representative rubber production facilities.

#### 4. Findings

The U.S. Rubber Industry is vital to national survival and recovery in a post-war environment. Thus, selected types of the rubber industry's production facilities should be protected against a nuclear attack. Civil defense or passive measures (hardening/jury-rigging/substitution) can be used in protecting these production facilities. Passive measures may have to be complemented with ballistic missile defense, in situations where direct targeting of vital facilities is likely, such as the larger production facilities for synthetic rubber.

Findings are presented next in two parts: (A) essential post-war rubber products and their demand, and (B) industrial protection/rebuilding for process bottlenecks.

- A. Demand. An extensive list of post-war rubber product requirements was defined and priorities established. As a result of this activity, the demand analysis was limited to three rubber product groups: tires (medium and large truck, off-the-road, agricultural), hoses, and belts. Medium and large trucks will provide most all transportation during early post-war survival and recovery phases. Their demand will dominate the demand for rubber products, because of (1) high failure rates attributable to poor road conditions coupled with truck overloading and continual operating efforts, and (2) tires use significantly more rubber than do the other products. Off-the-road tires will be in great demand to support debris removal and construction. Agricultural tire demand will be equal to peacetime demand.\* Hose demand will be greatest during the recovery and mature phases as industry rebuilds. Belt demand will be considerable during survival and recovery phases to support coal mining, mechanical power transmission, and industrial rebuilding.

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\*Or may be a linear function with surviving population.

Recapping is not the solution to the availability of medium and large truck tires. The principal expected failure mode is sidewall damage due to early post-war operating conditions--not tread wearout. Bias ply tires can be patched, but would require inner tubes--we were told that cracked sidewalls of bias ply truck tires are sometimes repaired in South America with a rubber boot bolted in place. However, the trend in U.S. tire production is toward production of radial truck tires, with bias ply equipment being discarded. Radial tire sidewalls cannot be patched because they are designed to flex. Further, they are more susceptible to damage than the sidewalls of bias ply tires. Finally, if supplies of synthetic or natural rubber run out, recapping is not a valid option. Thus, recapping cannot be expected to extend the lifetime of most large truck tires in post-war use.

SAI's analysis of demand for essential rubber industry products during early post-war phases is as follows.

Essential Product	Years to depletion if no production is resumed after a war*	Percent of Current production required shortly after a war to prevent depletion
Tires		
Medium and Large Truck	1½ to 2½	20
Farm	9**	60
Off-the-road	1½	55
Hose	1½ to 2	30
Belts	1 - 2¾	60

The requirement for styrene butadiene rubber (SBR) was estimated as a function of capacity for producing the above essential post-war rubber products, assuming natural rubber, which is imported, is not available. The

\*Assuming fuel is not a limit factor.

\*\*But farm production will decrease by about 11% per year until production of farm tires is resumed.

requirement for SBR has to be matched to the physical capability to produce needed end products, or to the demand for those products, whichever is less. If all production capacity for essential post-war rubber products survives, 40% of current SBR production capacity is required. However, if 70% of essential product capacity survives, 30% of current SBR production capacity is required. Austere early demand would require about 15% of SBR capacity.

The strategic stockpile includes sufficient natural rubber for 2/3 of rubber needs during the first year after a war. Moreover, most of the stockpile is in five locations that are likely targets. Thus, the stockpile may not be available.

Further study is required to assess the most beneficial combination of active and passive defense for (1) insuring that most of the essential end product facilities survive an attack, and (2) insuring that about 40% of SBR production, and its essential inputs, survives.

- B. Two forms of nuclear damage were considered: destruction of the facility and its equipment by a direct hit or by collateral damage such as collapse of the building housing the production process. The production facility would be destroyed by a direct hit. Production could be regained only by complete rebuilding. With collateral damage, the production facilities would be damaged, but equipment might be repairable. Certain passive measures could be used to protect the facilities and their equipment against fire and pressure effects from collateral damage; for example, removing all flammables from the production site; building sandbag and cribbing enclosures around production equipment and associated instrumentation. Passive protective measures would not be useful against a direct hit, but would increase the number of weapons the Soviets must use to target a given amount of industry if the target set were spread over an area, as opposed to being point targets. Important point targets require active defenses.

A number of materials associated with rubber product production are flammable; such as fuel, styrene butadiene rubber, solvents, butadiene and styrene. Fire, caused by sparks from debris, would occur at lower pressure levels than damage from pressure effects at these facilities.

As a generalization, protective measures for passively hardening rubber production facilities (including filling process lines and tanks with water, building sandbag and cribbing enclosures around production equipment and controls, removing flammables from the premises) would increase the pressure levels which could be sustained by

the facilities and equipment. Properly installed sandbag and cribbing enclosures can achieve hardness levels for equipment to at least 40 psi overpressure. External equipment and tanks (e.g., fractional distillation columns, storage tanks, process piping) could be hardened to achieve an approximate doubling of dynamic pressure levels the items could tolerate before severe damage or destruction were experienced.

Steam is the major essential utility required by the rubber industry and its allied input industries, especially the petrochemical ones. On-site steam boilers are very soft; about 2 psi overpressure would severely damage or destroy them. Hardening of most boilers is not practical. Only the newer, more efficient, more compact boilers could possibly be hardened by building enclosures around them. A more efficient measure is to harden the manufacturers of boilers. Electricity is second in importance as a utility required by the rubber industry; it is used as a power source for the motors driving heavy, rotating production equipment. Heavy-duty, large horsepower electrical motors, if severely damaged or destroyed, have the longest replacement lead times under peacetime conditions--typically 28-32 months. These motors should be protected, even though they may survive collateral damage. Their control systems are vulnerable and also have long delivery leadtimes.

Process piping would be extensively damaged or destroyed since it is normally not tied down in order to permit expansion and contraction. Protective measures for piping include using shear bolts in bolted pipe sections to predetermine failure modes, and fastening the pipes (once cooled down) to their supports. The need for considering piping is evident in the Neches Butane Products Company that we visited, where over 3300 miles of piping are to be found. This plant supplies butadiene for production of styrene butadiene rubber. Similar petrochemical companies supplying the synthetic rubber industry have comparable runs of piping. The longest leadtime to build or repair one of these facilities would involve the fabrication and joining of piping.

The major inputs for synthetic rubber production are derived from petroleum and petrochemicals. Substitution of most items with non-petroleum-derived materials is not possible.

In processing of rubber and producing rubber products, certain pieces of equipment are unique and essential; these include:

- Mixers - used to blend additives into rubber stock.
- Mills - used to prepare rubber stock for processing.

- Calenders - used to imbed cords or fabrics into sheet rubber.
- Extruders - used to form special shapes such as tire tread.
- Tire building machines - used to build up tires.
- Curing ovens - used to mold and vulcanize rubber.

These pieces of equipment are hard to collateral damage, but can be damaged by debris caused by collapse of the production buildings.

Instrumentation and controls (including fluidic and electrical signal lines) would be extensively damaged or destroyed by collateral damage. Centralized control rooms that house instrumentation and control equipment, would be reduced to flying debris which would destroy the instrumentation and equipment. Although the majority of instrumentation is standard, "off-the-shelf" equipment, replacements probably would not be readily available in the post-war environment, so protection of the instrumentation and controls is required.

#### 5. Recommendations for Future Study

Steam is essential in this and many other industries. Steam boilers and piping will be easily destroyed by collateral damage from nuclear attack and replacements would not be readily available. Boiler manufacture and installation processes should be studied to determine their protection potential.

Process piping used in the rubber industry would be severely damaged or destroyed. This piping, if severely damaged or destroyed, could not readily be replaced since minimal stocks of piping are maintained in inventory. The manufacture of steel piping should be studied to determine protection or jury-rigging potential.

Studies should be performed on the degree to which industry is becoming independent of electricity supplied by municipal or other utilities; also on the degree to which industry is becoming able to use alternate fuels in generating its own power. Means of expedited power restoration to rubber industry production facilities (and others) should be examined.

Tire production hinges on one major peacetime bottleneck: the availability of resorcinol formaldehyde (used to coat tire cords and plies to assure maximum adhesion of the rubber to those materials). There is only one U.S. manufacturer of resorcinol, needed to make the adhesive. The facilities

required for resorcinol production are capital intensive and facilities for additional production do not exist. Since there are no substitutes for resorcinol adhesives, a study of how the necessary resorcinol supply is to be maintained in the post-war environment should be conducted.

Fire-induced collateral damage to facilities producing synthetic rubber dominates pressure-related damage. Industries supplying basic inputs to the rubber industry (e.g., butadiene producers, styrene producers) have flammable end products. These products, when stored in quantity on the premises, represent grave fire hazards capable of destroying the entire facility. Solvents used in the production of rubber products, including gasoline and other flammables, present serious fire hazards in the facilities. Additional studies to determine the extent to which fires caused by collateral damage dominate pressure-induced damage in other industries should be conducted. Results of these studies may indicate that fire, rather than pressure, is the dominant mode of collateral damage in certain industries. Hardening measures need to be designed to cope with fire hazards.

Demand for inputs to the rubber end products, defined in this study as essential for post-war recovery, should be analyzed. Then the entire process should be modeled to provide a tool for post-war management decisions.

These demand estimates should also be used to determine the most beneficial combinations of active and passive defense.

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- Mr. David Flanders, Manager, Corporate Purchasing
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## SECTION 1. INTRODUCTION

### 1.1 GENERAL

Science Applications, Inc. (SAI), is under contract to the Ballistic Missile Defense Systems Command (BMDSC) and the Federal Emergency Management Agency (FEMA) to study the U.S. Rubber Industry. This study is concerned only with essential post-war products manufactured by the rubber industry; in particular, the demand for them, their production vulnerabilities, and measures to both reduce and restore post-war production quickly.

### 1.2 APPROACH

SAI initially determined essential post-war rubber industry products\*, and examined required inputs and resources for their production processes. This information was used in compiling a "strawman" describing essential post-war products, their potential demand, their vulnerabilities during an attack, and measures to restore post-war production. The strawman was presented to personnel of the B. F. Goodrich Company\*\*, a major producer of rubber and rubber products. The strawman, its critique, and the ensuing discussions between B. F. Goodrich and SAI personnel permitted the strawman to be refined to reflect a realistic appraisal of industrial protection needs for the U.S. rubber industry. These discussions were complemented with visits to selected, representative rubber production facilities: the B. F. Goodrich Chemical Company in Port Neches, Texas (producer of styrene butadiene rubber), the Neches Butane Products Company in Port Neches, Texas (producer of butadiene), the B. F. Goodrich Tire plant in Miami, Oklahoma (producer of truck, off-the-road, agricultural and passenger car tires), the B. F. Goodrich belt plant in Akron, Ohio (producer of conveyor belts), the B. F. Goodrich Hose plant in Akron, Ohio (producer of fire and other specialty hoses), and the B. F. Goodrich Hose plant in Marion, Ohio (producer of various general purpose industrial hoses). The production and

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\*Based on an analysis of essential post-war activities and products needed to support those activities (Reference 1).

\*\*B. F. Goodrich was a subcontractor to SAI in this study.

engineering personnel at these facilities were interviewed to obtain information concerning their production processes bottlenecks, resource limitations, also replacement requirements and lead times for essential capital equipment. Additionally, proposed hardening concepts for specific equipment and facilities were discussed with these people.

### 1.3 ASSUMPTIONS AND LIMITATIONS

During the course of this study, several assumptions were made which should be considered in the interpretation of the study results. First, it was assumed that the U.S. was damaged, but did not lose the war. Another assumption was that essential portions of the U.S. economy were successfully defended (e.g., fuel was available for transportation and production, shipments of raw and processed materials were still practical, etc.). SAI also assumed that essential rubber items in the post-war environment would be in demand and sufficient production capacity must be available to fill that demand. Next, technical and managerial personnel in the essential rubber industries (and their support industries) would be successfully evacuated (with their families) and be available again for work when post-war conditions required resumption of production. Another assumption was that hardening recommendations, if implemented, should not interfere greatly with normal production processes.

Industry disruption from a nuclear attack was assumed to occur in either of two ways: (1) direct nuclear hit and (2) collateral damage from a nearby nuclear blast. The former would destroy the entire production facility. In the latter, the facility would experience fire or collapse of all buildings and external equipment from pressure effects.

Budget and time constraints permitted only a moderately detailed study of the rubber industry, and a summary level study of those industries providing necessary inputs to the rubber industry. Therefore, only one typical production facility for each essential rubber industry product was visited. Except for butadiene production, industry facilities producing necessary inputs were not visited.

## SECTION 2. SUMMARY

### 2.1 GENERAL

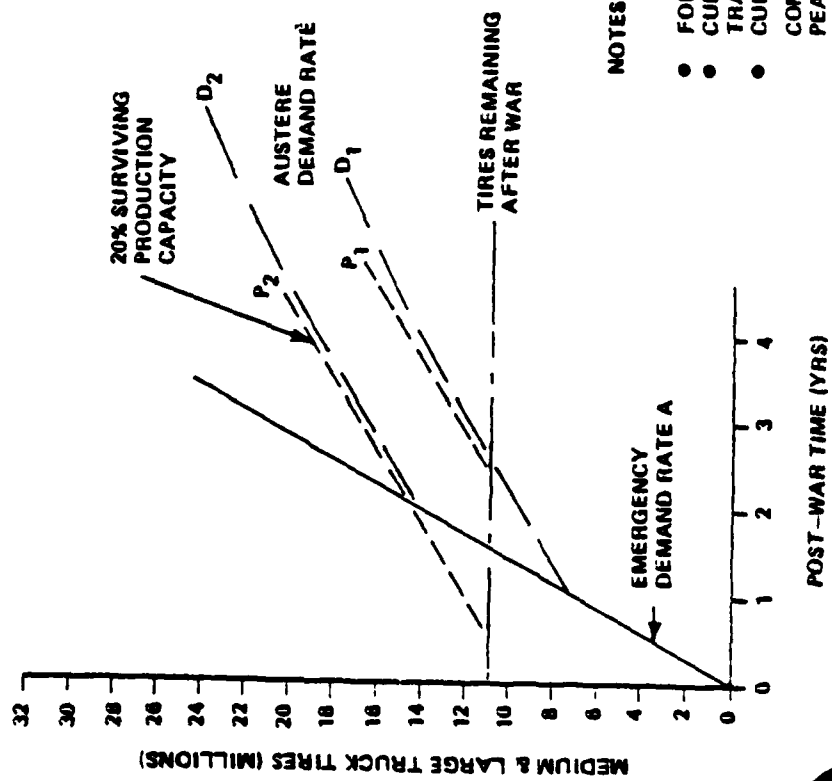
The U.S. Rubber Industry is vital to national survival and recovery in a post-war environment. Thus, selected types of the rubber industry's production facilities should be protected against a nuclear attack. Civil defense or passive measures (hardening/jury-rigging/substitution) can be used in protecting these production facilities. Passive measures may have to be complemented with ballistic missile defense, in situations where direct targeting of vital facilities is likely, such as the larger production facilities for synthetic rubber. Study findings are summarized in the following paragraphs. Essential rubber products and estimates of their post-war demand are first presented. Then, industrial protection of the manufacturing processes for these essential products is discussed.

### 2.2 DEMAND

An extensive list of post-war rubber product requirements was defined and reviewed with B. F. Goodrich to establish priorities. As a result of this activity, the demand analysis was limited to three rubber product groups: tires (truck, off-the-road, agricultural), hoses, and belts. Large trucks will provide most all transportation during early post-war survival and recovery phases. Their demand will dominate the demand for rubber products, because of high failure rates attributable to poor road conditions coupled with truck overloading and continual operating efforts. Off-the-road tires will be in great demand to support debris removal and construction. Agricultural tire demand will be equal to peacetime demand.\* Hose demand will be greatest during the recovery and mature phases as industry rebuilds. Belt demand will be considerable during survival and recovery phases to support coal mining, mechanical power transmission, and industrial rebuilding.

Two demand rates were established for truck tires (as shown in Figure 2-1): Curve A - assumed full utilization of all surviving large trucks for transporting emergency supplies, and Curves  $D_1$  and  $D_2$  - a time phased large

\*Or may be a linear function with surviving population.



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**NOTES:**

- FOR TRUCKS > 33,000 LBS
- CURVE A ASSUMES TRUCKS ARE DOMINANT FORM OF EMERGENCY TRANSPORTATION OPERATING ON 24 HOUR BASIS
- CURVES D<sub>1</sub> AND D<sub>2</sub> ASSUME TRUCKS ARE DELIVERING ESSENTIAL COMMODITIES FOR AUSTERE POST-WAR NEEDS, BASED ON THE PEACETIME TRUCKING ROLE. THEY BEGIN 1 OR 2 YEARS AFTER WAR TERMINATION.
- CURVES P<sub>1</sub> AND P<sub>2</sub> SHOW 20% OF CURRENT PRODUCTION INITIATED AT 1/2 OR 2 1/2 YEARS AFTER WAR TERMINATION TO MATCH DEMANDS D<sub>1</sub> OR D<sub>2</sub>.

Figure 2-1. Post-War Truck Tire Availability



truck tire demand based on specific commodity transportation requirements beyond early post-war phases. In accordance with Curve A, depletion of the post-war large truck tire availability could occur after  $1\frac{1}{2}$  years if emergency transportation requirements persist and production of tires is not resumed. However, if emergency transportation requirements subside after one year (a likely situation), and specific commodity transportation requirements begin to dominate (Curve  $D_1$ ), tire depletion could be extended to about  $2\frac{1}{2}$  years if no tire production occurred. A 20% production rate, at  $2\frac{1}{2}$  years after the war ends, would appear sufficient to meet likely tire demand as shown in Curves  $P_1$  and  $D_1$ . In the less likely situation where emergency transportation requirements dominate truck usage for 2 years after a war (Curve  $D_2$ ), production must begin earlier and reach the 20% rate at 2 years after the war is over (Curve  $P_2$ ). Thus, as shown in Figure 2-1 and assuming fuel is not a factor, production of medium and large truck tires should resume in time to be at 20% of current production by about 2 to  $2\frac{1}{2}$  years after the war is over.

Recapping is not the solution to the availability of large truck tires. The principal expected failure mode is sidewall damage due to early post-war operating conditions--not tread wearout that can be fixed by recapping. Bias ply tires can be patched, but would require inner tubes--we were told that cracked sidewalls of bias ply truck tires are sometimes repaired in South America with a rubber boot bolted in place. However, the trend in U.S. tire production is toward production of radial truck tires, with bias ply equipment being discarded. Radial tire sidewalls cannot be patched because they are designed to flex. Further, they are more susceptible to damage than the sidewalls of bias ply tires.

For those tires that could be recapped, either a hot or a cold process might be used. Although hot recapping is still used for recapping some truck tires, most equipment in the U.S. for the hot recapping process has been discarded because of the greater economy of cold processing. Only five facilities in the U.S. have the special equipment to produce treads needed in the cold process. However, either the hot or the cold recapping processes require virgin rubber--reclaimed rubber will not perform in a high temperature and friction environment. When supplies of synthetic or natural rubber run out, recapping is not a valid option. Thus, recapping cannot be expected to extend the lifetime of most large truck tires in post-war use.

A post-war demand rate for farm tires could not be derived as a function of current use, since peacetime demand exhibits a closer relation to farm income than to years of service. Therefore, post-war demand was assumed to be equal to peacetime demand based on 1978 data, but might vary linearly with surviving population. A more conservative estimate of demand might be higher if farm equipment were pressed into service for debris removal, construction, road building, etc. However, we assumed farm equipment would be used principally for agriculture. Depletion of farm tires is estimated to occur in 9 years after a war. However, unless production is resumed at about 60% of the peacetime rate, farm output may drop by about 11% per year because of reduced farm equipment availability.

Off-the-road tires include those used on earth movers, loaders-dozers, road builders, compactors, and mining-loggers. A post-war demand rate, based on usage factors such as miles/tire or years/tire could not be defined. Therefore, it was assumed that post-war demand equals peacetime replacement demand, based on the consideration that the increased demand resulting from increased usage of this equipment would be offset by a potential lower demand resulting from longer retention of tires. Depletion will occur in approximately 1½ years unless production is resumed to approximately 55% of peacetime.

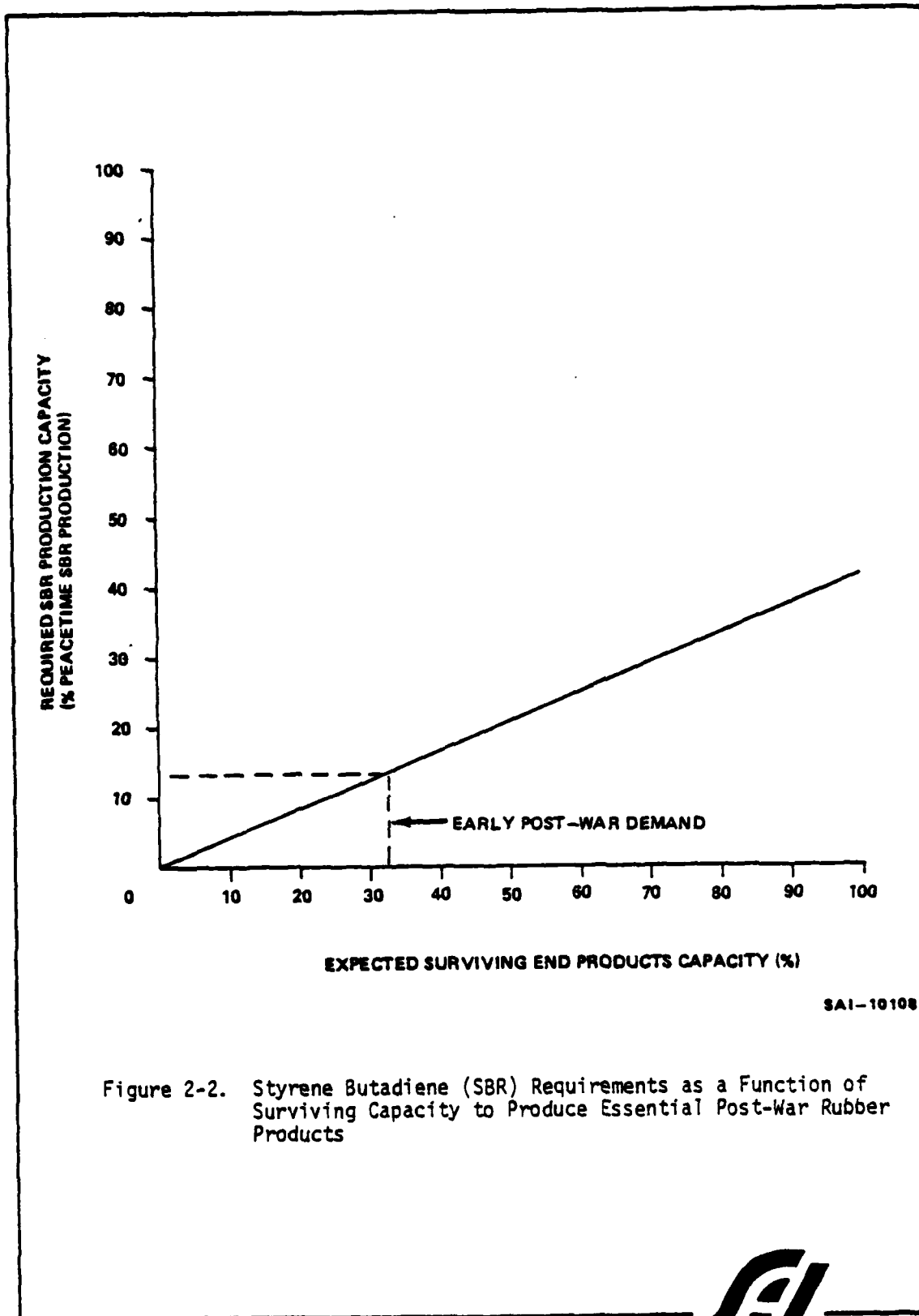
The major categories of rubber hose include high pressure and low pressure hoses. High pressure hoses are those rated for use at pressures about 1000 psi. These include hydraulic hoses used for industry and automotive systems, and non-hydraulic hoses used for petroleum production, mining and construction. Low pressure hoses are rated for use at pressures below 500 psi. These include: (1) long length hoses used for welding, heater systems, air systems, aviation, gasoline and hydraulics; and (2) shortlength, hand-made hoses used for chemical processing and transportation, petroleum production, hot water or steam systems, and fire fighting. About six months inventory exists in the U.S. at any one time, but only about 50% of this inventory might survive an attack. In a post-war environment, demand for high pressure hoses might reach 29 million feet per year in the survival phase and increase to 86 million feet per year during the transition phase. The demand rate for low pressure hose might reach 116 million feet per year in the survival phase and 335 million feet per year in the transition phase. The greatest demand is likely to be for short length, high pressure hydraulic hoses and for low pressure, long length hoses.

Depletion of high pressure hose is estimated to occur in  $1\frac{1}{2}$  to  $3\frac{1}{4}$  years after a war unless production is restored by those times to about 30% of the peacetime rate. Depletion of low pressure hose is estimated to occur in two or three years after a war unless production is restored by those times to about 25% of the peacetime rate.

Two major categories of rubber belts are: flat conveyor belts and mechanical power transmission belts. Flat belts are used to transport or handle bulk materials such as coal, hard rock ore, and agricultural produce. Mechanical power transmission belts are used to transfer power from a central source to auxiliary components. The market distribution of belts and the rationale establishing demand factors in the post-war environment led to demand estimates for each category of belts. The demand for flat belts might reach 11 million pounds per year in the survival phase and increase to 60 million pounds per year in the transition phase. Power belt demand may reach 31 million belts per year in the survival phase and increase to 76 million belts per year in the transition phase. Assuming no post-war production of belts, the cumulative demand for flat belts may exceed estimated inventories of 28 million pounds after three years, and demand for power belts may exceed the inventory of 33.4 million belts in about 15 months.

Depletion of rubber flat belting is estimated to occur in one or two years after a war unless production is restored by those times to about 50% of the peacetime rate. Depletion of rubber power belts is estimated to occur in one year after a war unless production is restored by that time to about 60% of the peacetime rate.

The requirement for styrene butadiene rubber (SBR) was estimated as a function of capacity for producing the above essential post-war rubber products, assuming natural rubber, which is imported, is not available, and that SBR is the dominant type of synthetic rubber in use shortly after a war. The requirement for SBR has to be matched to the physical capability to produce needed end products, or to the demand for those products, whichever is less. Figure 2-2 shows that, if the minimum production capacity for early demand of essential post-war rubber products survives, 15% of current SBR production capacity is required. Eventually, as all essential product capacity is brought on line, 40% of current SBR production capacity is required. The strategic stockpile includes sufficient natural rubber for  $\frac{1}{2}$  of rubber needs during the first year after a war. Moreover, most of the stockpile is in five locations that are likely targets. Thus, the stockpile may not be available.



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Figure 2-2. Styrene Butadiene (SBR) Requirements as a Function of Surviving Capacity to Produce Essential Post-War Rubber Products



Based on the foregoing demand analyses, from 20% to 60% of production capacity for the above-named rubber products is required after a war. A more detailed study of the existing dispersion of those facilities is required to identify beneficial combinations of active and passive defense for end product facilities. However, only small amounts of SBR production need to survive. Further study is required to assess the most beneficial combination of active and passive defense for (1) insuring that most of the essential end product facilities survive an attack, and (2) insuring that about 40% of SBR production, and its essential inputs, survives.

### 2.3 INDUSTRIAL PROTECTION

The presentation in this part is divided into two groups. The first group is applicable to the total rubber industry producing essential products. The second discusses aspects peculiar to the industry producing specific essential rubber products.

#### 2.3.1 General Comments

As noted earlier, two forms of nuclear damage were considered: destruction of the facility and its equipment by a direct hit or by collateral damage. The production facility would be destroyed by a direct hit. Production could be regained only by complete rebuilding. With collateral damage, the production facilities would be damaged, but equipment might be repairable. Certain passive measures could be used to protect the facilities and their equipment against fire and pressure effects from collateral damage; for example, removing all flammables from the production site; building sandbag and cribbing enclosures around production equipment and associated instrumentation. Passive protective measures would not be useful against a direct hit, but would increase the number of weapons the Soviets must use to target a given amount of industry if the target set were spread over an area, as opposed to being point targets. Important point targets require active defenses.

A number of materials associated with rubber product production are flammable; such as fuel, styrene butadiene rubber, solvents, butadiene and styrene. Fire, caused by sparks from debris, would occur at lower pressure levels than damage from pressure effects at these facilities.

As a generalization, protective measures for passively hardening rubber production facilities (including filling process lines and tanks with

water, building sandbag and cribbing enclosures around production equipment and controls, removing flammables from the premises) would increase the pressure levels which could be sustained by the facilities and equipment. Properly installed sandbag and cribbing enclosures can achieve hardness levels for equipment to at least 40 psi overpressure. External equipment and tanks (e.g., fractional distillation columns, storage tanks, process piping) could be hardened to achieve an approximate doubling of dynamic pressure levels the items could tolerate before severe damage or destruction were experienced.

Except for older versions of steam boilers and the problem of fire in storage containers containing hazardous materials that cannot be dispersed in a timely and safe manner, the process and production equipment for synthetic rubber production and essential rubber product production facilities can be passively hardened to withstand overpressures in excess of 15 psi. If nearby preferred targets are directly targeted and pressure effects of collateral damage do not exceed 15 psi overpressure at the synthetic rubber facilities, then the latter facilities would survive, except for their boilers. If the production of synthetic rubber and its essential products were also thought to be "essential" by the Soviet Union, then these facilities would have to be directly targeted for their destruction. An example is the B. F. Goodrich styrene butadiene production facility in Port Neches, Texas, around which there are several preferred targets. The circle seen in Figure 2-3 encompasses the area within which a 1 Mt nuclear blast at the B. F. Goodrich facility would produce overpressures of at least 2 psi. That facility is far enough away from other targets (see the four radial lines in Figure 2-3) that the expected overpressures would be less than 15 psi. Consequently, even though several preferred targets are in the immediate area, collateral damage cannot be expected to produce assured destruction of the B. F. Goodrich facility when those preferred targets are hit; rather, the B. F. Goodrich facility would have to be directly targeted.

Steam is the major essential utility required by the rubber industry and its allied input industries, especially the petrochemical ones. On-site steam boilers are very soft; about 2 psi overpressure would severely damage or destroy them. Hardening of most boilers is not practical. Only the newer, more efficient, more compact boilers could possibly be hardened by building enclosures around them. A more effective measure is to harden the manufacturers of



boilers. It is unlikely that undamaged boilers would be substituted at sites where primary boilers are destroyed. The only boilers of capacities comparable to those used in the rubber industries would be boilers in other basic industries or in electrical-generating facilities supplying power to cities. Moreover, manpower and transportation to dismantle intact boilers and re-erect them where needed would not generally be available. In the instances where docks are available, large ships could be docked nearby industrial facilities, to supply steam, electricity, and compressed air. Electricity is second in importance as a utility required by the rubber industry; it is used as a power source for the motors driving heavy, rotating production equipment.

Heavy-duty, large horsepower electrical motors, if severely damaged or destroyed, have the longest replacement lead times under peacetime conditions--typically 28-32 months. These motors should be protected, even though they may survive collateral damage. Open motors are more susceptible to damage (water damage from rain or flooding, mechanical damage from flying debris) than their hermetically-sealed counterparts. Motor controls are vulnerable and have long delivery lead times.

Process piping would be extensively damaged or destroyed since it is normally not tied down in order to permit expansion and contraction. Protective measures for piping include using shear bolts in bolted pipe sections to pre-determine failure modes and fastening the pipes (once cooled down) to their supports. The need for considering piping is evident in the Neches Butane Products Company that we visited, where over 3300 miles of piping are to be found. This plant supplies butadiene for production of styrene butadiene rubber. Similar petrochemical companies supplying the synthetic rubber industry have comparable runs of piping. The longest lead time to build or repair one of these facilities would involve the fabrication and joining of piping.

Butadiene production facilities, which supply styrene butadiene rubber producers, are especially vulnerable to fire since butadiene is extremely flammable. Moreover, butadiene burns intensely and radiates sufficient energy to destroy surrounding facilities. The Neches Butane Products Company has a butadiene tank farm of approximately ten tanks holding 6,000 and ten tanks holding 12,000 barrels of butadiene each.\* Fire originating in the tank farm would destroy the

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\*These tanks are not always full.

entire production facility. The fire could be started by a single piece of debris rupturing one tank. Since the quantity stored is so great at this facility, the butadiene cannot be disposed of quickly. Butadiene gas being heavier than air prevents venting of the butadiene directly to the air for safe dispersion; the butadiene vapors would merely hug the ground and present a severe fire hazard over an area larger than the plant. Normal butadiene consumption at the nearby styrene butadiene rubber production facilities consumes average butadiene reserves in about one week, but just transfers the hazard to the user.

The major inputs for synthetic rubber production are derived from petroleum and petrochemicals. Substitution of most items with non-petroleum-derived materials is not possible.

In processing of rubber and producing rubber products, certain pieces of equipment are unique and essential; these include:

- Mixers - used to blend additives into rubber stock.
- Mills - used to prepare rubber stock for processing.
- Calenders - used to imbed cords or fabrics into sheet rubber.
- Curing ovens and presses - used to mold and vulcanize rubber.

These pieces of equipment are hard to collateral damage, but can be damaged by debris caused by collapse of the production buildings. Detailed hardening measures for these and other pieces of equipment are presented later.

Instrumentation and controls (including fluidic and electrical signal lines) would be extensively damaged or destroyed by collateral damage. Centralized control rooms that house instrumentation and control equipment, would be reduced to flying debris which would destroy the instrumentation and equipment. Although the majority of instrumentation is standard, "off-the-shelf" equipment replacements probably would not be readily available in the post-war environment, so protection of the instrumentation and controls is required.

### 2.3.2 Production of Large Truck Tires

Styrene butadiene rubber is the primary synthetic rubber used in tire production. Since all other synthetic rubbers are derived from petrochemicals, they are not meaningful substitution candidates for styrene butadiene rubber in the post-war environment.

Natural rubber is also used in tire production. Since all of the natural rubber used in the U.S. is imported (primarily from Malaysia and Indonesia), that supply would be tenuous in the post-war period. However, tires can be made of 100% styrene butadiene rubber (if available) at some compromise of tire life or service.

Production of large truck tires is tending to shift from bias ply tires towards radial tires. Radial tires are more susceptible to sidewall damage because they have thinner sidewalls than bias ply tires. Sidewall damage is expected to be the dominant form of damage in the post-war environment because of the anticipated poor conditions of roads and the overloading of trucks.

In peacetime use, both radials and bias ply tires are retreaded. However, on the rough roads envisioned for the post-war environment, bias tire carcasses are expected to suffer less sidewall damage than radial tire carcasses. Thus, a higher proportion of bias tires will be suitable for retreading than radial tires. Since the percentage of radial tires is increasing (about half of large truck tires produced today are radials), the ability for retreading truck tires after a war is decreasing. Also, if tires are used beyond their estimated recapping life, they cannot be retreaded. In the post-war period, it is unlikely that tires will be taken out of use in time to insure retreading.

The tire building equipment for radial tires is different than that used for bias ply tires. As bias ply tires are being replaced in the marketplace by radials, bias ply tire building machines are being sold to companies in other countries or are being scrapped.

Reclaimed rubber is not a realistic substitute for virgin styrene butadiene or natural rubber in tire production; truck tires of reclaimed rubber would not last long, perhaps only 2-5% of the miles obtained from new tires. Since present-day truck tires contain about one-third natural rubber, almost total use of reclaimed rubber is not practical. However, as much as 10% of reclaimed rubber can be used as an extender in production of degraded tires. Much smaller percentages (about 1%) of reclaimed rubber are routinely used in peacetime tire production.

Carbon black is an essential additive to reinforce the physical characteristics of both synthetic and natural rubber. Carbon black for tires is obtained from petroleum. The petroleum-derived oil furnace black is used to reinforce and fill SBR for tire applications. Natural gas-derived thermal black is used in other essential rubber products such as hoses.

Resorcinol, from which the resinified resorcinol adhesive for fabric and tire cord dipping operations is derived, is manufactured by only one U.S. firm, Koppers Manufacturing; the process is quite capital-intensive. Further, substitutes are not apparent. Phenol resins can be used, but with poor bonding of coated tire cords to the tire rubbers.

Vinyl pyridine is an essential monomer in the preparation of latex for cord treatment to ensure good adhesion. Reith Chemical is the only U.S. manufacturer of vinyl pyridine. Substitutes are available, but production facilities are insufficient for large scale requirements.

Certain types of equipment are essential for the production of tires. These equipment are:

- Mills and mixers - used to process rubber stock
- Calenders - used to press cords into the rubber sheeting
- Extruders - used to form tread
- Tire building machines - used to build up tires
- Curing presses - used to mold and vulcanize tires

One method of extending tire life in the post-war environment is to keep major roads in good repair. Asphalt could be used to repair the roadbeds, if available from petroleum refineries. Sidewall damage caused by pot holes is the major expected unrepairable cause of radial tire failure in the post-war environment.

For use as tire cords (excluding metals), there are several materials which are not derived from petrochemicals. These are cotton, fiberglass and rayon. Rayon is derived from cellulose and should be reasonably available in the post-war period. Further, rayon is a better choice for tire cord than is cotton, which is no longer used in tires. Fiberglass is derived from silica and is presently used in tire production. The normal truck tire cords used in the peacetime economy are nylon and steel; aramid is still experimental.

In radial truck tires, fiberglass can be used for belts, but not in the carcass. In bias ply truck tires, rayon can be used for both. For truck

tires using rayon or fiberglass, these tires should be used at reduced speeds and loads to prevent excessive heat buildup (tires typically run about 200°F).

Nylon cords are preferred for regular service during peacetime in off-the-road tires. Rayon can be used, but tire life would be somewhat degraded. Since abrasion is the major cause of off-the-road tire failure, tread thickness can be increased and the sidewall can be reinforced with either additional rubber or with a steel plate similar to that in current off-the-road experiments being conducted by the tire industry.

Since agricultural tires are not exposed to the heat buildup or abrasion of the truck or off-the-road tires, either fiberglass or rayon can be used in those tires to produce acceptable products.

### 2.3.3 Hose Production

Hoses can be made from various synthetic rubbers, all of which are derived from petroleum refining operations; hence, they are not post-war substitutes for one another. However, water hoses can be made from 100% reclaimed rubber. Oil resistant hoses can be made from a high percentage of oil resistant rubber reclaim with some natural rubber as a binder.

Filament reinforcements used in hoses include cotton, polyester, nylon, and rayon. Nylon and polyester are petroleum-derived and probably would not be available in the post-war environment. Rayon, derived from cellulose (i.e., wood fibers) and cotton could be used as a substitute for the nylon and polyester fibers. Brass plated and stainless steel wire is also used as a reinforcing medium in hoses; other materials can be used as substitutes with reduced performance.

Woven fabrics, such as canvas, are used as an abrasion cover for some hoses. These fabrics include both synthetic and natural fibers. Synthetic fibers are derived from petrochemicals, preferred targets for nuclear attack. The natural fibers would be more available in the post-war environment.

Hose couplings are made from brass, aluminum, plastic, or steel. Since the uses of hoses dictate the type and material composition of the couplings, substitution is not as practical as might be expected. However, some substitutions still can be made--for example, low pressure, general purpose hoses can have plastic or aluminum couplings. In the post-war environment, jury-rigging hose connections may be possible by using hose clamps in lieu of couplings for low pressure applications.

The forms (mandrels) upon which hoses are built, are subject to collateral damage from flying debris. Although of a specialized nature, mandrels can be repaired or replaced in the field.

Certain types of equipment are essential in the production of hoses. These equipment are:

- Mills, internal mixers and calenders - used to process rubber stock,
- Extrusion machines - used to extrude the hose tube,.
- Braiding/wrapping/weaving machines - used to place reinforcement onto the tube,
- Vulcanizing sheath-wrapping machines - used to wrap a layer onto the hose for containment of the hose during the vulcanization process, or lead-extruding machines - used to coat a lead sheath onto a hose for vulcanization,
- Curing ovens - used to vulcanize the uncured hoses, and
- Vulcanizing-sheath removal machines - used to remove the sheath required for vulcanization from the vulcanized hose.

These pieces of equipment can be protected against collateral damage by building sandbag and cribbing enclosures around the equipment. The curing ovens, being hard to damage, can also be used to store materials inside (e.g., mandrels, nylon wrapping materials, weaving bobbins).

#### 2.3.4 Belt Production

Synthetic rubbers, commonly used in belt production, are all derived from petrochemicals, so these rubbers are not substitutions for one another. Most of the reinforcing cords used in belting are derived from petrochemicals; therefore, they may be in limited supply during the post-war environment. Of the remaining cords (i.e., rayon, fiberglass, steel), rayon would be suitable for post-war use, as it is derived from wood products and would be available in the post-war period.

Conveyor belting, if cleanly severed, can be repaired in the field by either of two methods: (1) lacing the broken ends together and (2) splicing the broken ends together by means of portable vulcanizing units.

Certain types of equipment are essential for the production of belts. These equipment are:

- Mills, internal mixers, calenders, and extruders - used to process rubber stock,
- Building machines - used to install top and bottom covers on the belt carcass,
- Curing presses - used to vulcanize the assembled belt and covers.

Most of this equipment can be hardened by building enclosures of sandbags and cribbing around the equipment and their associated controls. The building machines are soft and portions of their operation can be jury-rigged (e.g., materials-handling conveyors, supply and take-up reels for belting). The curing presses are harder than building machines.

#### 2.4 RECOMMENDATIONS FOR FUTURE STUDY

Steam is the most essential utility in this and many other industries. Steam boilers and piping will be easily destroyed by collateral damage from nuclear attack and replacements would not be readily available. Boiler manufacture and installation processes should be studied to determine their protection potential.

Process piping used in the rubber industry would be severely damaged or destroyed. In certain petrochemical facilities supporting the rubber industry, large amounts of piping are used. The Neches Butane Products Company has approximately 3300 miles of piping. This piping, if severely damaged or destroyed, could not readily be replaced since minimal stocks of piping are maintained in inventory. The manufacture of steel piping should be studied to determine protection or jury-rigging potential.

Electrical power is required in the rubber industry to drive heavy, rotating equipment. Although restoration of electrical service is easier than restoration of steam (if small to medium power generation utilities survive), electrical power still represents a bottleneck to production. Studies should be performed on the degree to which industry is becoming independent of electricity supplied by municipal or other utilities; also on the degree to which industry is becoming able to use alternate fuels in generating its own power. Means of expedited power restoration to rubber industry production facilities (and others) should be examined.

Tire production hinges on one major peacetime bottleneck: the availability of resorcinol formaldehyde (used to coat tire cords and plies to assure maximum adhesion of the rubber to those materials). There is only one U.S.

manufacturer of resorcinol, needed to make the adhesive, Koppers Manufacturing. Koppers also supplies much of the overseas demand for resorcinol. The facilities required for resorcinol production are capital intensive and facilities for additional production do not exist. Since there are no substitutes for resorcinol adhesives, a study of how the necessary resorcinol supply is to be maintained in the post-war environment should be conducted.

Fire-induced collateral damage to facilities producing synthetic rubber dominates pressure-related damage. Industries supplying basic inputs to the rubber industry (e.g., butadiene producers, styrene producers) have flammable end products. These products, when stored in quantity on the premises, represent grave fire hazards capable of destroying the entire facility. For example, the butadiene storage tank farm at the Neches Butane Products Company contains enough butadiene (20 spherical tanks holding between 6,000 and 12,000 barrels each) to destroy the facility in the event of fire caused by sparks from flying debris. Other facilities having large quantities of styrene butadiene rubber stored as inputs (e.g., hose production) or as outputs (e.g., finished tires) present a lesser fire hazard. The styrene butadiene rubber is hard to ignite, but, when ignited, is very difficult to extinguish. Solvents used in the production of rubber products, including gasoline and other flammables, present serious fire hazards in the facilities. Additional studies to determine the extent to which fires caused by collateral damage dominate pressure-induced damage in other industries should be conducted. Results of these studies may indicate that fire, rather than pressure, is the dominant mode of collateral damage in certain industries. Hardening measures need to be designed to cope with fire hazards.

Demand for inputs to the rubber end products, defined in this study as essential for post-war recovery, should be analyzed. Then, the entire process should be modeled to provide a tool for post-war management decisions.

These demand estimates should also be used to determine the most beneficial combinations of active and passive defense.

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### SECTION 3. ESSENTIAL POST-WAR PRODUCTS FROM THE U.S. RUBBER INDUSTRY

This section presents results of SAI's analysis to identify post-war rubber products, then estimates of their demand requirements.

#### 3.1 ESSENTIAL RUBBER PRODUCTS

This section presents results of SAI's analysis to identify post-war rubber product requirements. The inclusive list of rubber products was extracted from the Rubber Red Book (Reference 2). These rubber products were then ranked in terms of essential and non-essential products required for post-war recovery. A comprehensive list was established for the initial ranking of rubber products into the essential and non-essential categories. As shown in Table 3-1, the criteria relating essential products included those items supporting essential activities, such as transportation of food, energy, and health care products; high rate consumables; non-reusable items; and items in potentially high destruction areas. Criteria for judging non-essential rubber product items included those items that could be cannibalized, reusable items, low rate consumption items, and other items that are likely to survive in sufficient quantity for early post-war needs. These criteria were used to establish the initial ranking of rubber products for post-war recovery and then were reviewed with personnel of the B. F. Goodrich Company. Results of the ranking of the post-war rubber product requirements are listed in Table 3-2. The items listed under the category Essential, are interpreted to include those items which are the most needed rubber products in the post-war environment.

The results of ranking essential rubber products for the post-war environment emphasized selected types of tires (large truck, off-the-road, and farm), conveyor and power (mechanical power transmission) belts, and hoses. The remaining essential rubber products are listed in order of their importance, based on the rankings from the SAI/B. F. Goodrich discussions.

The rankings in Table 3-2 reflect considerable attention toward the survival and transition phases of the post-war environment, rather than to the subsequent basic recovery and mature economic recovery phases. It is in these two early phases that consumption is likely to be high and not supported by

Table 3-1. Criteria to Establish Post-War Rubber Product Requirements

CATEGORY	CRITERIA	DEFENSE CONSIDERATION
Essential	<ul style="list-style-type: none"> <li>● Supports Essential Activities, i.e., Transportation of Food, Energy, and Health needs</li> <li>● High Rate Consumption Item</li> <li>● Non-Reusable Item</li> <li>● Supports Repair and Refurbishment</li> <li>● High Destruction Level</li> <li>● Short Life Items</li> </ul>	Defend Manufacturers (Combinations of active and passive defense)
Non-Essential	<ul style="list-style-type: none"> <li>● Cannibalization Potential</li> <li>● Reusable Items</li> <li>● Low Rate Consumption</li> <li>● Low Destruction Level</li> <li>● Luxury Item</li> <li>● Substitution Potential</li> <li>● Long Life Item</li> </ul>	No Defense



Table 3-2. Post-War Rubber Product Requirements

ESSENTIAL	NON-ESSENTIAL
<p>Tires</p> <p>Truck</p> <p>Off-the-Road, Construction, Agricultural, Industrial</p> <p>Hoses</p> <p>High Pressure</p> <p>Low Pressure</p> <p>General Purpose</p> <p>Power Belts</p> <p>Power Transmission</p> <p>Conveyor</p> <p>Inner Tubes</p> <p>Tire Repair</p> <p>Cement Kits</p> <p>Repair Putty</p> <p>Tread Rubber</p> <p>Seals, Gaskets and Bushings</p> <p>Transmissions, Pumps</p> <p>Refrigeration</p> <p>Medical and Lab</p> <p>Tubing, Surgical, Blood Bags, Drugs, X-Ray Protection, Gloves</p> <p>Electrical Tape</p> <p>Rubber Rollers</p> <p>Can and Drum Closures</p> <p>Industrial Protective Clothing</p> <p>Adhesives and Cements</p> <p>Portable Storage Tanks</p> <p>Military (Special Purpose Sensor Domes)</p>	<p>Bathing Accessories</p> <p>Toys</p> <p>Cellular Goods</p> <p>Stationery Goods</p> <p>Latex Foam</p> <p>Polyurethane Foam</p> <p>Vinyl Foam</p> <p>Flooring</p> <p>Latex Products</p> <p>Household Goods</p> <p>Dental Goods</p> <p>Footware</p> <p>Mountings</p> <p>Hard Rubber</p> <p>Pipes and Fittings</p> <p>Electrical</p> <p>Tank Linings</p> <p>Insulated Wire and Cable</p> <p>Welding Cable</p> <p>Oil Well Cable</p> <p>Power and Lighting</p> <p>Heels and Soles</p> <p>Plumber Specialty</p> <p>Mechanical</p> <p>Brakes</p> <p>Clothing</p> <p>Coat, Rainwear</p> <p>Sporting Goods</p> <p>Automobile Tires</p> <p>Tape (Friction and Thermoplastic)</p>



production of essential rubber items. During a survival phase, there is major emphasis on restoring order, equitably redistributing life-support consumables, and producing more life-support consumables. The transition phase is defined as one in which basic industry and services are repaired through cannibalization and consolidation, production and distribution of life-support needs are improved, and military capability begins to be rebuilt. In the recovery phases, priorities and controls are refined, basic industry and services are beginning to operate for volume requirements, consumer products are provided to improve productivity, and the military continues to be rebuilt.

Medium and large truck tires\* appear to be the most essential rubber product during the survival and transition phases, because large trucks will provide most all the early post-war transportation, as was shown in an earlier analysis by SAI on defense requirements for the transportation industry (Reference 3). The early demand for small truck tires would be low because of the large number of these vehicles when compared to the potential fuel supply. It is also expected that the demand for automobile tires would be low because automobile usage would be limited due to fuel shortages, thus passenger tires would not be an essential item. However, off-the-road tires are considered to be essential because it is expected that a large requirement would exist for the removal of debris and the reconstruction of damaged facilities. Farm tires are also considered essential because demand for farm tires is likely to be equal to peacetime demand. Industrial hoses represent an essential need because they would be extensively damaged during an attack. Hydraulic hoses for trucks and off-the-road equipment would be in demand during survival and recovery phases due to normal wear-out rates. Power belts and conveyor belts represent an essential rubber product requirement during both the survival and recovery phases where conveyor belts would be needed to support mining of new energy sources, such as coal; also conveyor and mechanical power transmission belts would be needed to replace those easily damaged during an attack.

The demand for essential rubber product items such as tire repair parts, seals, gaskets, rollers, can and drum enclosures, adhesives, and cements were not addressed in detail because their production problems are trivial compared to the problems of producing tires, hoses and belts. Also, medical and

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\*Designations for trucks and tires are not the same. Large trucks use medium and large truck tires.

laboratory products, while essential to the survival and recovery phases, include many products that can be re-used rather than discarded, thus, can have longer life times than during peacetime. Therefore, the demand for production of medical and laboratory products is less likely to be great during the survival and recovery phases.

The following paragraphs present estimates of post-war demand for the tires used by large trucks, off-the-road and farm vehicles, for industrial hoses, and industrial belts, and for synthetic rubber.

### 3.2 POST-WAR TIRE DEMAND

This section presents estimates of the post-war demand for tires as a function of time after a nuclear war. Emphasis is directed to truck tires for support of basic commodity transportation, agricultural tires which support farming operations, and off-the-road tires which support debris removal and construction. Each is discussed in turn. An underlying assumption in presenting demand for tires is the availability of fuel.

#### 3.2.1 Medium and Large Truck Tire Demand

This subsection discusses the demand estimates for *medium and large* truck tires used on large combination trucks needed for long haul transportation. Large, over-the-road trucks, with carrying capacities greater than 30,000 lbs., are expected to provide most all of the transportation during early survival and recovery phases. These trucks are a key transportation mode for several reasons. Large inventories are widely distributed over the U.S. and a majority are expected to survive. Trucks are extremely flexible, with the ability to traverse unimproved roads and open terrain. An infrastructure will exist to support truck operations in a crisis environment. Large trucks comprise about 7% of the U.S. truck inventory. These large trucks are efficient in terms of fuel consumption and manpower requirements per amount of commodities transported when compared to other trucks on a ton/mile basis. Thus, we assumed significant numbers of other trucks would not be used due to fuel shortages, and tires would be scavenged for them (Reference 3).

The results for large truck tire demand were derived for two different perceived usages. These usages would be approximately in series with each other after a war.

### Usage Number 1: Full Truck Utilization

This case assumes full utilization of all the surviving large trucks on a 24 hour basis, particularly during the early post-war phase. Estimating details of the emergency demand is impossible because of the large differences between peacetime operations and early post-war operations. In addition to casual relationships, transportation during emergency situations has a history of confused scheduling.

### Usage Number 2: Time Phased Commodity Demand

This demand was derived by assessing the basic essential commodities to be transported in each of the post-war phases, after usage Number 1 slowed.

The basic assumptions supporting estimates of post-war rubber product demand for medium and large truck tires include the following:

- The primary mode is large combination trucks (Class VIII vehicles) with 33,000 to 80,000 pounds capacity.
- Average load estimated to be 50,000 pounds.
- Average speed of 35 mph.
- Truck operation for 16 hours per day.
- Average one-way haul distance of 500 miles per day.
- Tire performance of 50,000 miles per tire (no recapping) during the survival phase, 150,000 miles per tire (with recapping) in the recovery phase, and 200,000 miles per tire (with recapping) in the mature economy phase.
- Post-war population levels estimated at 80% and 90% peacetime population (assumes an active and successful civil defense program).

The analytical model used to estimate the yearly requirement for truck tires was based on estimates of daily mileage requirements for large transport trucks and tire performance. The model is appropriate for demand calculations for both Usage 1 and Usage 2 demand conditions. The model accounts for the total number of trucks required per day, based on the number of loads to be hauled and the number of trucks required to maintain a delivery rate of one truckload per day. The daily mileage of all trucks is calculated using an average trip distance of 500 miles. Daily mileage was then transformed to an estimate of the number of tires required, based on the assumed tire performance in each post-war phase.

An inventory estimate of medium and large truck tires was established for comparison of the demand for truck tires in a post-war phase. The inventory was based on 1977 estimates of large trucks assumed to be in the inventory at the time of the attack. The resulting estimate of medium and large truck tire inventory was 10 million tires. This accounted for 30% survival of the 2.6 million truck tires in the 1977 wholesale inventory, plus 30% of the 1977 retail inventory (.6 million), plus 90% survival of large trucks in the Class VIII category with 14 or 18 (an average of 16) tires each truck (9.2 million).

Results of post-war truck tire availability as a function of post-war time is shown in Figure 3-1. Two demand rates were established for truck tires (as shown in Figure 3-1): Curve A - assumed full utilization of all surviving large trucks for transporting emergency supplies, and Curves  $D_1$  and  $D_2$  - a time phased medium and large truck tire demand based on specific commodity transportation requirements beyond early post-war phases. In accordance with Curve A, depletion of the post-war medium and large truck tire availability could occur after  $1\frac{1}{2}$  years if emergency transportation requirements persist and production of tires is not resumed. However, if emergency transportation requirements subside after one year (a likely situation), and specific commodity transportation requirements begin to dominate (Curve  $D_1$ ), tire depletion could be extended to about  $2\frac{1}{2}$  years if no tire production occurred. A 20% production rate at  $2\frac{1}{2}$  years after the war ends, would appear sufficient to meet likely tire demand as shown in Curves  $P_1$  and  $D_1$ . In the less likely situation where emergency transportation requirements dominate truck usage for two years after a war (Curve  $D_2$ ), production must begin earlier and reach the 20% rate at two years after the war is over (Curve  $P_2$ ). Thus, production of medium and large truck tires should resume in time to be at 20% of current production by about 2 to  $2\frac{1}{2}$  years after the war is over.

### 3.2.2 Farm Tire Demand

This section presents estimates of post-war demand for farm tires and interprets the demand in terms of the percent exhaustion of the inventory assuming no post-war production capacity for farm tires. Farm tires include tires for such vehicles as tractors, grain combines, corn pickers, pickup balers and field storage harvesters. Post-war farm activity was assumed to be

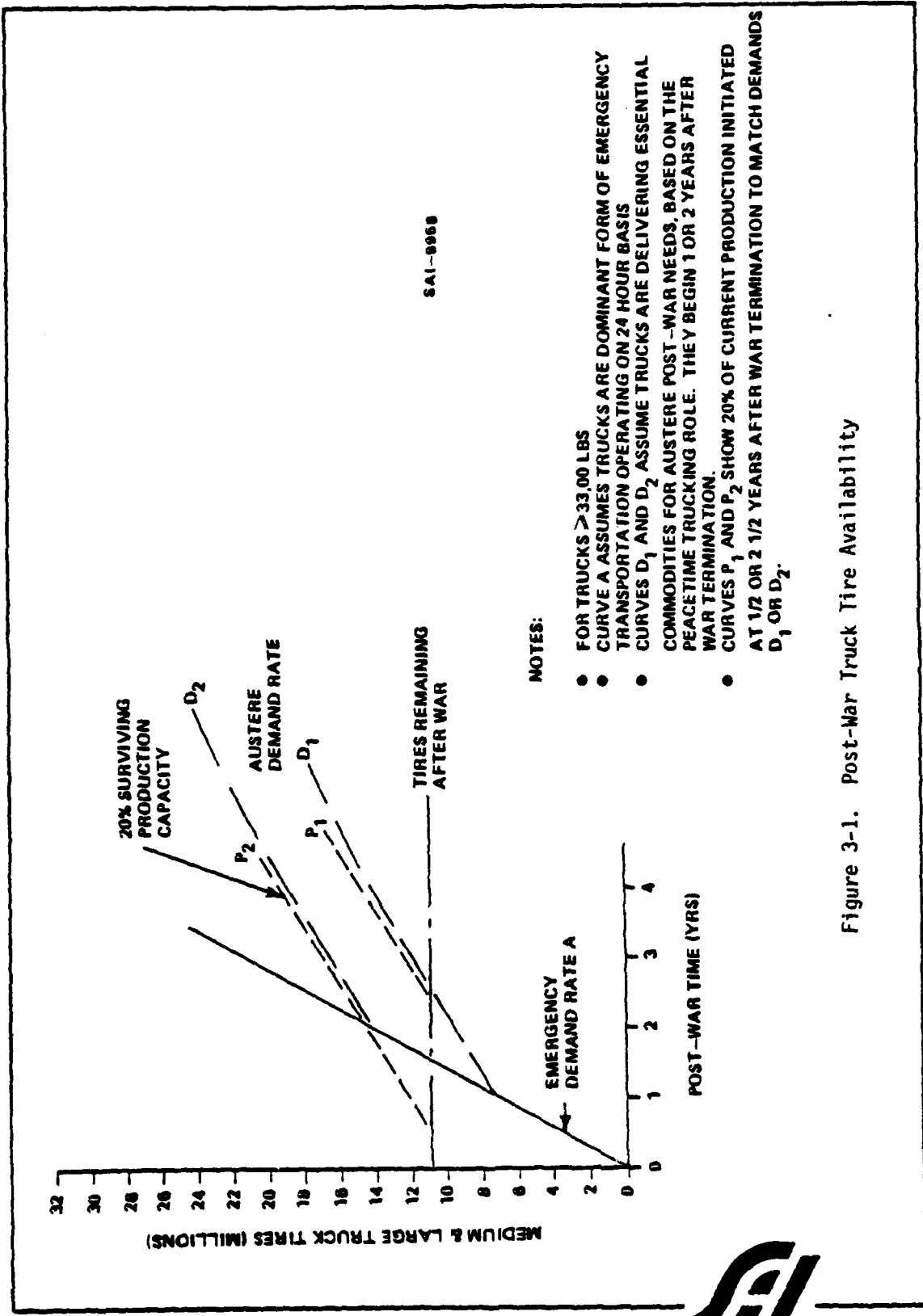


Figure 3-1. Post-War Truck Tire Availability



equal to that of peacetime farm activity. Therefore, the post-war demand for farm tires was assumed to equal the replacement rate of farm tires averaged for the years 1973 to 1975. Farm tire production and sales histories do not correlate with any tire life period. Long term replacement or demand, historically, correlates with farm income; therefore, tire performance is not used as a factor in establishing the post-war demand for farm tires. The farm tire demand is assumed to be linear in early post-war phases, recognizing the demand may be higher if farm vehicles are pressed into greater service such as for use in construction and debris removal.

The post-war demand for farm tires was based on historical production of replacement farm tires and did not include production for original equipment. This demand rate was then compared to the estimated level of the post-war farm tire inventory, which represented tires surviving on vehicles and the wholesale inventory surviving an attack. (The 1978 farm tire inventory was assumed to represent the farm tire inventory at the time of a future nuclear attack.) The demand rate is interpreted in terms of the percent of the inventory exhausted as a function of the post-war period. The farm tire inventory assumed a 90% vehicle survival rate since most of the vehicles are in rural areas. The number of surviving farm vehicles was thus estimated to be 5.9 million. The 1978 wholesale and retail inventory of farm tires is estimated to be 3 million tires. Assuming a 50% survival rate, since wholesale inventory stocks are stored in central distribution areas in industrial locations, the resulting wholesale inventory would be approximately 0.5 million tires and the retail inventory of about 0.6 million tires. Adding these to the estimated number of vehicles with four tires (some have more) gives a total estimated inventory of farm tires of 24.6 million tires. This level of surviving farm tire inventory represents a conservative estimate of the inventory at the time of an attack in the 1985-1990 time period. This assumes that the new products produced between 1978 and 1985 are offset by depreciated or scrapped vehicles.

Assuming that post-war farm tire demand is equal to the 1978 peacetime replacement demand (excluding demand for new equipment) of 2.7 million farm tires per year\*, and that no post-war production capability exists (see

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\*This assumption was made, recognizing that (1) peacetime demand for farm tires is a function of both usage and farm income, and (2) debris clearing would not be an added requirement beyond peacetime farm usage.

Figure 3-2. We will run out of farm tires in about nine years. However, since farm output is assumed to be a linear function of austere farm tire demand, output will decrease each year by about 11%. To maintain farm output, farm tire production should average at least 60% of current peacetime production, which is the equivalent of the peacetime farm tire replacement market.

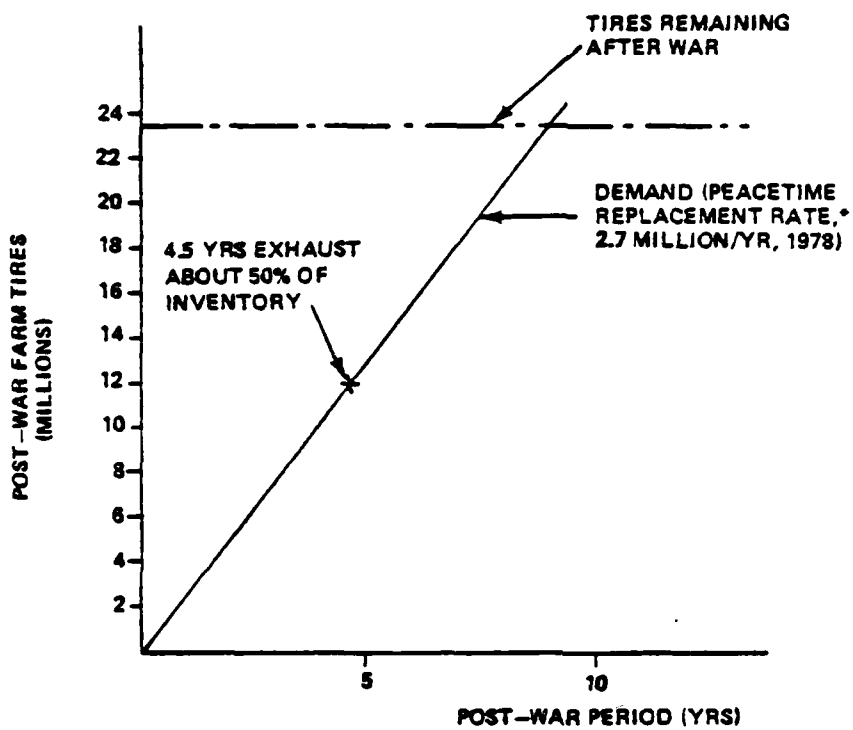
### 3.2.3 Off-the-Road Tire Demand

This portion presents estimates of post-war demand for off-the-road tires and interprets the demand in terms of potential shortages relative to likely surviving inventories. Off-the-road tires are used by such vehicles as earth movers, loader-dozers, road builders, compactors, and mining loggers. Peacetime demand is highly variable. It is a function of accidental abuse--not mileage or time. It is assumed that the post-war demand for off-the-road tires equals the peacetime replacement demand. The increased post-war usage of this type equipment would create a higher demand, but we are unable to predict that demand. Off-the-road tire inventories were projected from estimates of the number of vehicles in 1965. (Using the 1965 inventory of vehicles, including coal mining machinery, earth moving equipment, construction equipment, road graders, and road scraper vehicles.) A factor of two increase in the total inventory was assumed for the 14-year period to derive 1979 estimates of off-the-road vehicles. The number of tires were derived assuming four tires per vehicle.

The estimated post-war demand for off-the-road tires, as a function of years, is presented in Figure 3-3, based on a replacement rate of 0.4 million tires per year. Unless production is resumed to about 55% of the peacetime rate, off-the-road tires will be depleted by 1½ years after the war. Normal off-the-road tire service life is 1.5 to 2.5 years per tire. The service life could be shorter due to the more intensive use of off-the-road vehicles for debris removal and construction.

### 3.3 POST-WAR HOSE DEMAND

This section presents estimates of the demand for rubber hose in a post-war environment.



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\* EXCLUDES TIRE DEMAND FOR ORIGINAL EQUIPMENT PRODUCTION.

Figure 3-2. Farm Tire Availability in Post-War Environment



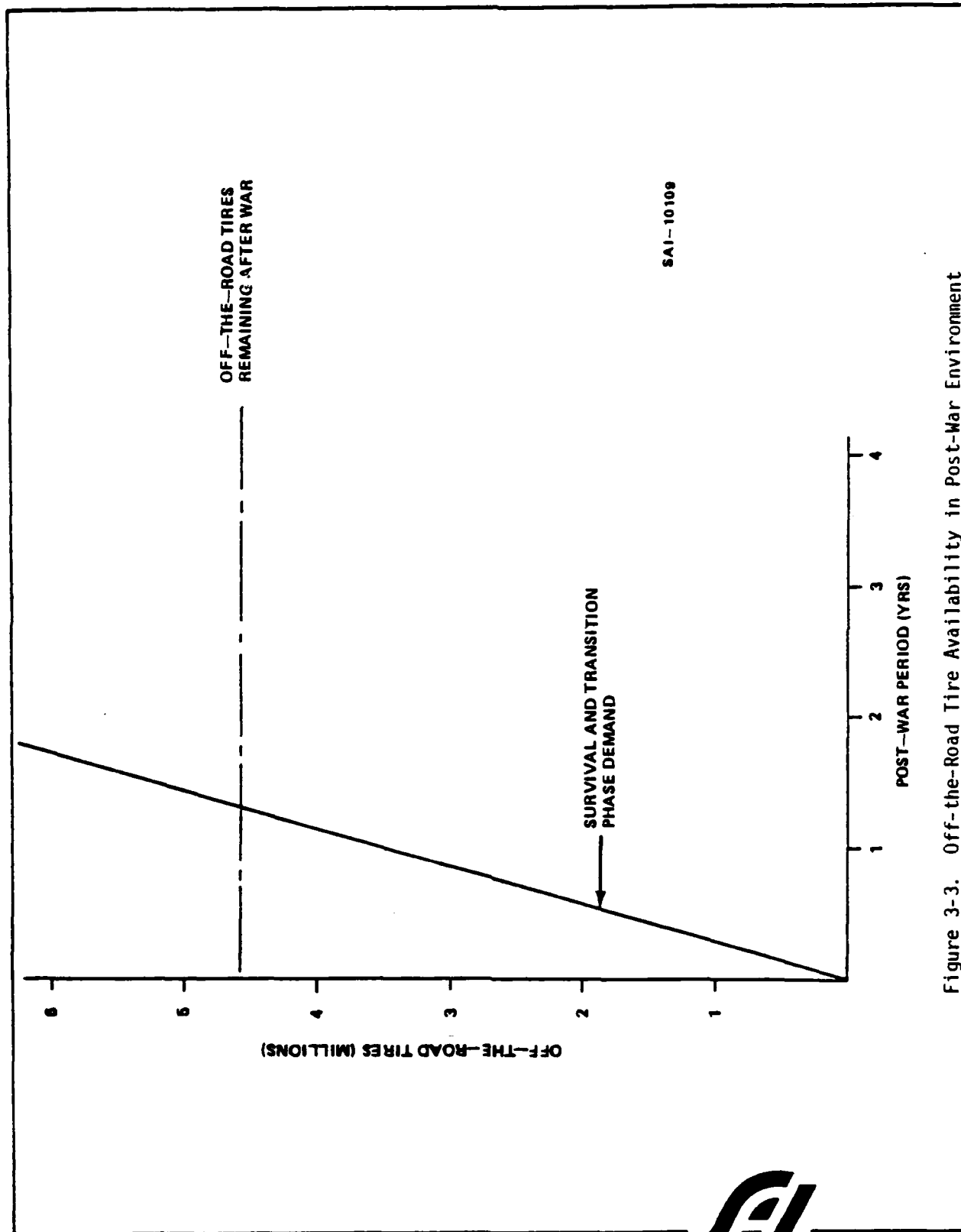


Figure 3-3. Off-the-Road Tire Availability in Post-War Environment



The major categories of rubber hose include high pressure, low pressure, and general purpose hoses. High pressure hose, rated at greater than 1000 psi, includes hydraulic hoses for industry and automotive applications and non-hydraulic hoses used for petroleum production, mining and construction. Hydraulic hoses are usually less than 1.0 inch in diameter, while non-hydraulic high pressure hoses have diameters between  $\frac{1}{2}$  and 5 inches. Low pressure hoses, rated at pressures less than 500 psi, include long length hoses for welding, heating systems, air systems, aviation, gasoline and hydraulic applications; also handmade hoses used in chemical processing and transportation, petroleum production, gasoline distribution systems, steam and hot water systems, agricultural production, and material handling; and fire hoses. Low pressure hoses usually have diameters of  $\frac{1}{4}$  to 8 inches and lengths greater than 25 feet. Hand-made hoses have diameters greater than two inches and lengths less than 100 feet. General purpose hoses are used in light industry and domestic applications. The greatest portion of general purpose hose production is plastic rather than rubber. Therefore, demand estimates for rubber hoses concentrates on high pressure and low pressure hoses.

The following paragraphs present the basic factors, statistical data, and approach used to establish the demand estimates. Demand is presented as a rate, in terms of units per year.

Statistical data such as replacement rates and inventories were estimated by B. F. Goodrich personnel, since those data were not readily available. It was assumed that (1) post-war demand would be less than peacetime demand, (2) 1978 shipments of rubber hoses served as a base for calculating demand for each type of hose, and (3) these shipment quantities were applicable to future times. The factor used to relate reduced demand is derived below. Also, shipments were interpreted as production rates, which could represent demand for replacement hoses rather than hoses for new equipment. Replacement hose was used for demand estimates since in the survival and transition phases, emphasized in this analysis, little requirement would exist for new motor vehicles and new manufacturing equipment.

Peacetime shipments for rubber hoses are presented in Table 3-3 for the years 1977 and 1978. Between these years, shipments tended to increase by less than 25% for high pressure hydraulic hoses and low pressure, long length

Table 3-3. Peacetime Shipments of Rubber Hoses

TYPES OF RUBBER HOSES	SHIPMENTS (MILLION FEET)	
	1977	1978
High Pressure		
Hydraulic	224.930	278.984
Non-Hydraulic	8.343	10.709
Low Pressure		
Long Length	1,113.252	1,276.923
Hand Made	183.46	152.10
Fire Hose (Circular Woven)	24.941	94.974
General Purpose		
Garden (Plastic)	241.485	239.879

hoses. Fire hose shipments remained about the same while shipment of low pressure man-made hoses decreased. B. F. Goodrich estimated that of these shipments, replacement hoses represented about 50% of the total for high pressure and 40% for low pressure hoses. Also, B. F. Goodrich estimated performance life to be 2 to 10 years for high pressure hoses; and 1 to 10 years for low pressure hoses. Physical abuse is the main factor contributing to short hose life; however, other factors include application, environment, and frequency of use.

B. F. Goodrich estimates that approximately six months of hose inventory might exist at any time in the plant warehouse and distribution network. Perhaps only about 50% of this inventory would survive attack on the major industrial areas. Assuming that the remaining three months inventory represents 25% of the 1978 hose shipments, approximately 73 million feet (0.25 x 290 million feet) of high pressure hose would survive in inventory. Considering low pressure hose, if a three month inventory survives, then approximately 381 million feet (0.25 x 1524 million feet) might be available in inventory following an attack.

The approach for estimating demand accounted for the proportion of replacement hoses and factors for reduced demand representing phased demand over a 10-year period. A constant demand rate factor was assumed for both the survival and transition phases. The rubber hose shipments for 1978 (see Table 3-3) served as the basis for demand estimates. These were multiplied by the replacement and phased demand factors to derive estimates of yearly post-war demand. The replacement factor was 0.5 for high pressure rubber hoses and 0.4 for low pressure hoses.

The post-war demand factor is a multiplier used to calculate the change in demand between the survival and transition phases for each classification of rubber hose. The rationale for assigning the relative values to the demand factors follows below.

High pressure hydraulic hose demand is expected to be small (0.2 of peacetime demand) in the survival phase because the major requirement is only for trucks and some light industry. However, in the transition phase, an increase in manufacturing and transportation might increase demand to about 0.6 of peacetime demand. Non-hydraulic, high pressure hose demand is also expected

to be low (0.1 of peacetime production) in the survival phase, since mining and petroleum production would be low, but in the transition phase, as the activities increased along with construction, the demand might increase to 0.4 times that of peacetime demand.

Low pressure, long length hose demand is expected to be low (0.2) in the survival phase since there is likely to be little need for replacing hoses used in welding, air and aviation during survival activities. However, demand might increase to 0.6 that of peacetime demand in the transition phase as industry rebuilds. Likewise, low pressure hand-made hose demand is expected to be low (0.2) in the survival phase since little requirement exists for chemical processing and transportation, and gasoline distribution. The major demand is likely to be generated from agricultural activity. Demand might increase to 0.4 in the transition phase as petroleum production, gasoline distribution and manufacturing increase. Demand for fire hose is expected to be low (0.2) and about equal (0.2) during the survival and recovery phases mainly because its lifetime is long (10 years) and only replacement of some destroyed urban equipment may be required.

A summary of the demand factors assigned to each classification of rubber hose is presented in Table 3-4 along with the replacement factor. The multiplication of these factors yields the demand rates for the post-war survival and transition phases.

The resulting demand rates for each classification of hose reflect expected changes between the survival and transition phases of a post-war environment. Table 3-4 shows that demand for high pressure hoses might reach a rate of 29 million feet per year during the survival phase and increase to 86 million feet per year during the transition phase. The demand rate for low pressure hose might reach 116 million feet per year in the survival phase and 333 million feet per year in the transition phase. The most important demand is likely to be for the high pressure, hydraulic hoses, and the low pressure, long length hoses, since these support requirements are most likely to arise for truck transportation, manufacturing, energy processing and distribution. Also, these hoses tend to have a shorter performance life.

Table 3-4. Post-War Rubber Hose Demand Rates

CLASSIFICATION	1978 SHIPMENTS (MILLION FEET)*	ESTIMATED PORTION FOR REPLACEMENT **	POST-WAR DEMAND FACTOR		POST-WAR DEMAND (MILLION FEET/YEAR)	
			SURVIVAL	TRANSITION	SURVIVAL	TRANSITION
High Pressure						
Hydraulic	279.0	.5	.2	.6	28.0	84.0
Non-Hydraulic	10.7	.5	.1	.4	0.54	2.2
	—				—	—
	289.7				28.54	86.2
Low Pressure						
Long Length	1277.0	.4	.2	.6	102.0	307.0
Hand Made	152.0	.4	.2	.4	12.0	24.0
Fire Hose	95.0	.4	.2	.2	2.0	2.0
	—				—	—
	1524.0				116.0	333.0

\*Rubber Manufacturers Association, 1979; provided by B. F. Goodrich.

\*\*B. F. Goodrich



The cumulative post-war demand for high pressure hose, presented in Figure 3-4, reveals that an estimated post-war remaining inventory of about 73 million feet is sufficient for 1½ to 2¾ years, based upon whether the survival phase ends one, two or three years after the war. Therefore, production at about 30% of peacetime should be attained by these times to prevent shortage.

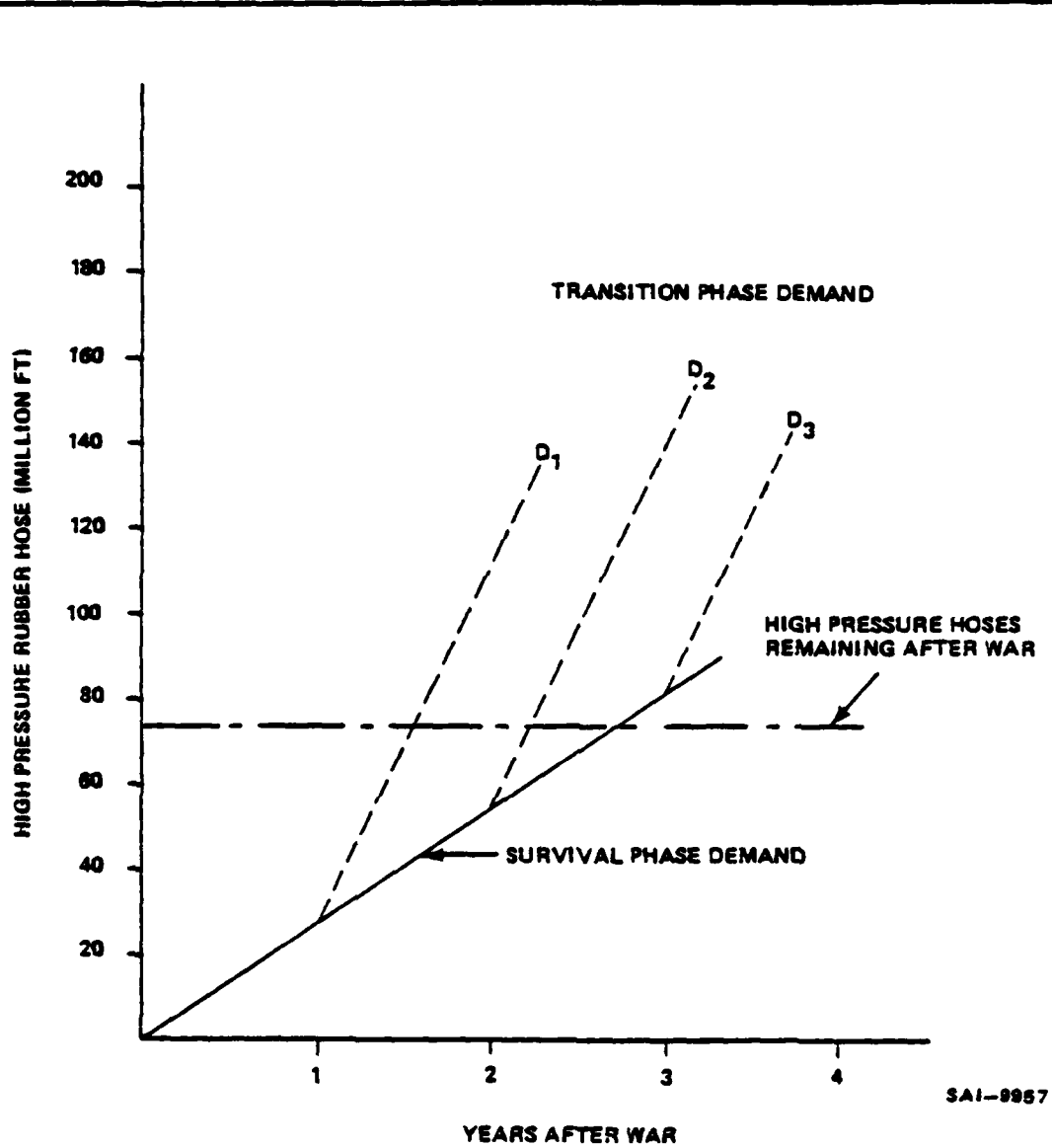
The cumulative post-war demand for low pressure hose is shown in Figure 3-5. Assuming a remaining inventory of 365 million feet reveals that the estimated demand may exhaust inventories in two to three years following a war. This estimate assumes a transition phase demand beginning one, two, or three years after the war ends. To prevent shortages, production should resume in time to meet about 25% of the peacetime rate at these times.

#### 3.4 POST-WAR RUBBER BELT DEMAND

This section presents estimates of the demand for rubber belts in a post-war environment. Two major categories of belts are considered: flat conveyor belts and power transmission belts. Flat belts are used to transport heavy materials such as coal, hard rock ore, and agricultural produce. Coal burning plants are major users of flat belts. Power belts, or V-belts, as they are commonly called, are used to transfer power from a central source to auxillary components such as used on automobiles, agricultural implements and industrial equipment. Basic statistical data are presented in the following subsections, along with the approach used to estimate post-war demand for rubber belts.

Belt production in the U.S. is performed by a small number of manufacturers. Because of this, a limited and insufficient data base on peacetime shipments and production is available in the open literature, due to the fact that such disclosures would reveal the market share of the few companies.

A summary of the estimates for current shipments of flat and power belts is presented in Table 3-5. The 1977 shipments for power belts were calculated based on 1972 shipments. A multiplying factor was derived from flat belt shipments between 1972 and 1977 for which data was available. About 14 companies shipped 113 million pounds of flat belting in 1977; and about six to nine companies manufactured and shipped an estimated 133 million power belts in 1977.

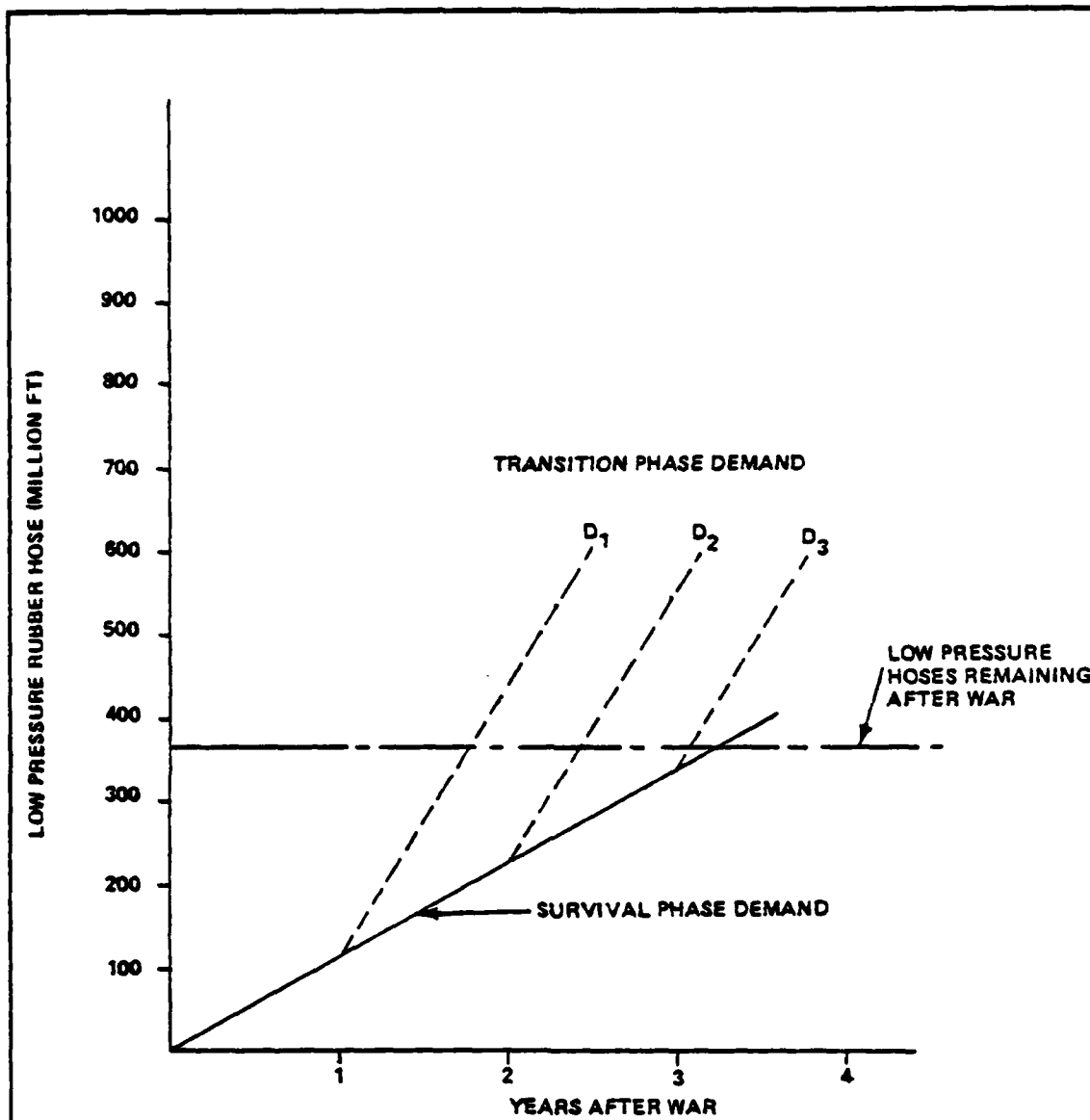


SAI-8957

NOTE: TRANSITION PHASE DEMAND BEGINS ONE YEAR AFTER WAR (D<sub>1</sub>) OR TWO YEARS (D<sub>2</sub>) OR THREE YEARS (D<sub>3</sub>).

Figure 3-4. High Pressure Hose Availability in Post-War Environment





SAI-9960

NOTE: TRANSITION PHASE DEMAND BEGINS ONE YEAR AFTER WAR (D<sub>1</sub>) OR TWO YEARS (D<sub>2</sub>) OR THREE YEARS (D<sub>3</sub>).

Figure 3-5. Low Pressure Hose Availability in Post-War Environment



Table 3-5. Peacetime Shipments of Rubber Belting

CLASSIFICATION	NUMBER OF COMPANIES	SHIPMENTS <sup>1</sup> (MILLION UNITS) 1977
Flat Conveyor Heavy Material Transport (Raw material, Agricultural, Industrial)	14	112.9 lb.
Power Belts		
Automotive	3	99.3*
Agricultural	3	7.6*
Industrial	6	26.7*
		<hr/> 133.6

\*Based on 1972 Shipments

<sup>1</sup> 1977 Census of Manufacturers, April 1979, U. S. Department of Commerce



The estimated market distribution for rubber belts is shown in Table 3-6. In the flat belt market, raw material conveying, including coal and ores, comprises about 50% of the market; agriculture and industrial flat belts comprise about 25% each. Coal burning power plants are a major user of flat belts. Considering the power belt market distribution, the automotive market is about evenly split, 20% cars and 20% trucks. Agriculture comprises 20% with the remaining 40% for the industrial belt market.

The performance life of belts is a function of many factors, including temperature, load weight, abrasion, frequency of use, speeds and maintenance. Maintenance appears to be a major factor influencing belt life. Estimates of belt performance life are shown in Table 3-7. Some of the life-times show wide spreads in years because the application and conditions of service vary such that no one performance life value can be applied generally. Recapping belt carcasses is feasible and such a service is provided by a few firms. However, maintenance is a key factor to recapping feasibility. It is assumed that a good maintenance schedule will not be part of the post-war application of belts, thus recapping is not considered part of the demand analysis.

Data revealing belt inventories were not readily available from open literature. Estimates supplied by B. F. Goodrich experience revealed that both flat conveyor belting and power belting inventories represent about six months supply each, including stock in plants and warehouses.

The approach used to estimate post-war demand for belts was based on 1977 shipments, assuming that shipment quantities represented 1977 production quantities of replacement belts. Shipment levels of each class of belt were calculated using market distribution estimates. The approach for calculating belt demand, similar to that used for hose demand, accounted for the market distribution and the expected reduced demand in the post-war environment. A constant demand rate per phase was assumed for the survival and transition phases. These factors were multiplied by the peacetime shipments (replacement production) to derive estimates of yearly post-war demand. The post-war demand factor is a weighting multiplier used to calculate the change in demand between survival and transition phases for each classification of rubber hose. The rationale for assigning the relative values to the factors follows below.

Table 3-6. Peacetime Market Distribution for Rubber Belts<sup>1</sup>

CLASSIFICATION	MARKET DISTRIBUTION (PERCENT OF DOLLARS)
Flat Belts	
Raw Material (coal, ore, steel)	50
Agricultural	25
Industrial	25
	—
	100
Power Belts	
Automotive	
Truck	20
Car	20
Agricultural	20
Industrial	40
	—
	100

<sup>1</sup> B. F. Goodrich



Table 3-7. Performance of Rubber Belting

CLASSIFICATION	LIFETIME <sup>1</sup> (YEARS)
<b>Flat Belts</b>	
Coal Mining	2 to 3
Hard Rock Mining	5 to 10
Agriculture	5 to 20
Industrial	5 to 10
<b>Power Belts</b>	
Truck	2 to 10
Agriculture	1 to 2
Off-the-Road Equipment	1 to 2
Industrial	1 to 2

<sup>1</sup> B. F. Goodrich Estimates



Demand for flat belts to transport raw materials is assumed very low (0.1) in the survival phase. There is little or no hard rock mining (iron, mineral ores) but some coal transportation may exist in the survival phase. In the transition phase the demand rate should increase (0.6 of peacetime) to support industry rebuilding, increased energy needs, and also to replace belts whose performance life is exceeded. Demand for agricultural flat belts is also expected to be low in the survival phase even if agricultural activity increases because performance life expectancy should carry over to the transition phase. In the transition phase, agricultural belt demand is expected to increase (0.5 of peacetime demand) since performance limits are exceeded but only at an average 50% level of failure over 10 years. Industrial belts also are expected to be in low (0.1) demand in the survival phase since little or no major manufacturing activity is expected, some cannibalization can satisfy needs, and the expected performance life is greater than the survival period. A slight increase in demand (0.4) might occur in the transition phase as belt performance life is exceeded and industry is rebuilt.

Power belt demand in the survival phase is expected to be relatively high (0.3) for trucks because of high truck use. While the performance life is 2-10 years, the high use rate could greatly decrease belt performance life. In the transition phase, truck belt demand is likely to be very high (0.7) mainly due to performance life limits. Car power belt demand is also expected to be low (0.1) in the survival phase mainly because automobile use will be limited due to fuel rationing. Car power belt demand may increase to 0.4 if automobile use increases in the latter part of the transition phase.

The post-war demand for agriculture power belts in the survival phase is expected to be nearly equal to the peacetime demand (0.8) because of the continued agricultural activity and belt low performance life. In the transition phase, the demand may be equal to, or greater than, peacetime (1.0) because farm production may increase and performance life is low. In the survival phase, demand for industrial power belts is expected to be low (0.2) since production is low and 50% of existing belts exceed performance life. In the transition phase, industrial power belt demand may increase slightly (0.5) as light industry rebuilds and performance life is exceeded.

The resulting demand rates (units per year) for each belt class are presented in Table 3-8 for the survival and transition phases. Considering flat belts, the demand might reach a total of 11 million pounds per year in the survival phase and increase to 60 million pounds per year in the transition phase. The greatest portion (greater than 50%) of the demand appears to be for raw material transportation.

Power belt demand in the survival phase may reach 31 million units per year and increase to 76 million units per year in the transition phase. The greatest portion of the demand is for trucks, as shown in Table 3-4.

The cumulative demand for rubber flat belting is shown in Figure 3-6. Shortages will occur in one to two years unless production is restored by those times to about 50% of the peacetime rate.

The cumulative demand for power belts is presented in Figure 3-7. Shortages will occur in one year unless production is restored by those times to about 60% of the peacetime rate.

### 3.5 POST-WAR DEMAND FOR STYRENE BUTADIENE RUBBER (SBR)

Total styrene butadiene rubber production in the U.S. during 1978 was approximately 2,473,500,000 pounds. Tires account for about 80% (by weight) of the rubber consumption in the peacetime economy. Not all types of tires would be required in the early post-war environment. From 1978 tire production data, passenger and light truck tires are found to constitute about 70% (by weight) of the overall production of tires--these tires would not be essential in the immediate post-war period. The remaining tires (30%) are the medium and large truck tires, off-the-road tires, and agricultural tires--all required in the early post-war period.

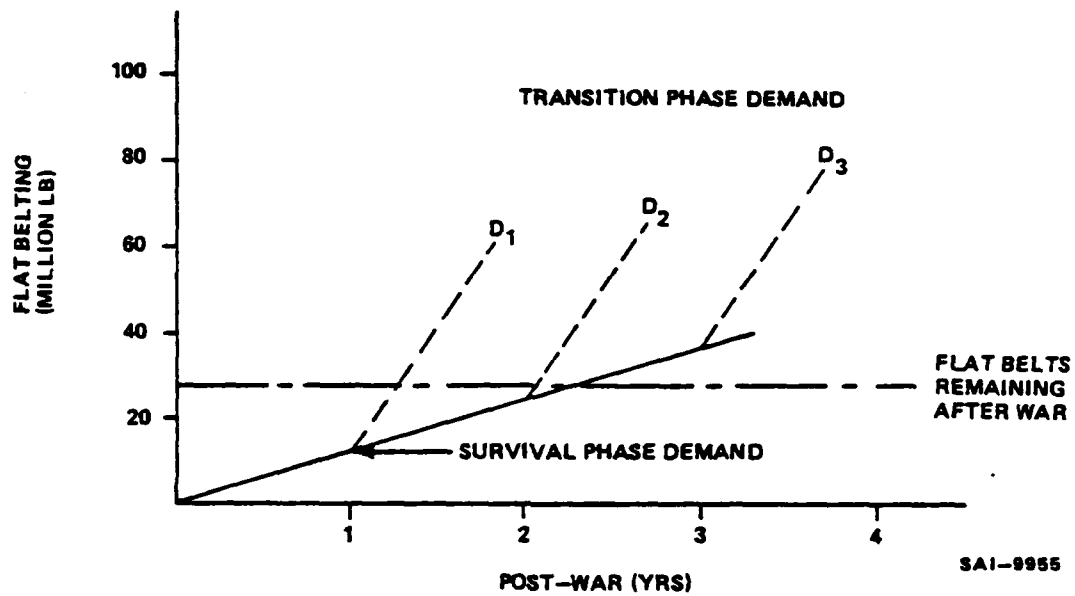
In 1978, conveyor and power transmission belting production required approximately 130,400,000 pounds of rubber. This belting is assumed to be essential in the early post-war period and would be produced completely from SBR. Thus, belting would require about 5% of peacetime SBR production.

There are several categories of hoses produced in the U.S. peacetime economy--not all of which are essential in the early post-war environment. Sixty-four percent of the number of hoses produced in 1978 are low pressure

Table 3-8. Post-War Rubber Belt Demand Rates

CLASSIFICATION	PEACETIME SHIPMENTS (MILLION UNITS)	DEMAND FACTOR		DEMAND RATE	
		SURVIVAL	TRANSITION	SURVIVAL (MILLION UNITS/YEAR)	TRANSITION (MILLION UNITS/YEAR)
Flat Conveyor Belts					
Raw Materials	56.5 lb.	.1	.6	5.7	34.0
Agricultural	28.2 lb.	.1	.5	2.8	14.0
Industrial	28.2 lb.	.1	.4	2.8	11.3
	—			—	—
	112.9 lb.			11.1 lb.	59.3 lb.
Power Belts					
Automotive					
Truck	49.6	.3	.7	15.0	34.7
Car	49.7	.1	.4	5.0	20.0
Agricultural	7.6	.8	1.0	6.0	7.6
Industrial	26.7	.2	.5	5.4	13.4
	—			—	—
	133.6			31.4	75.7

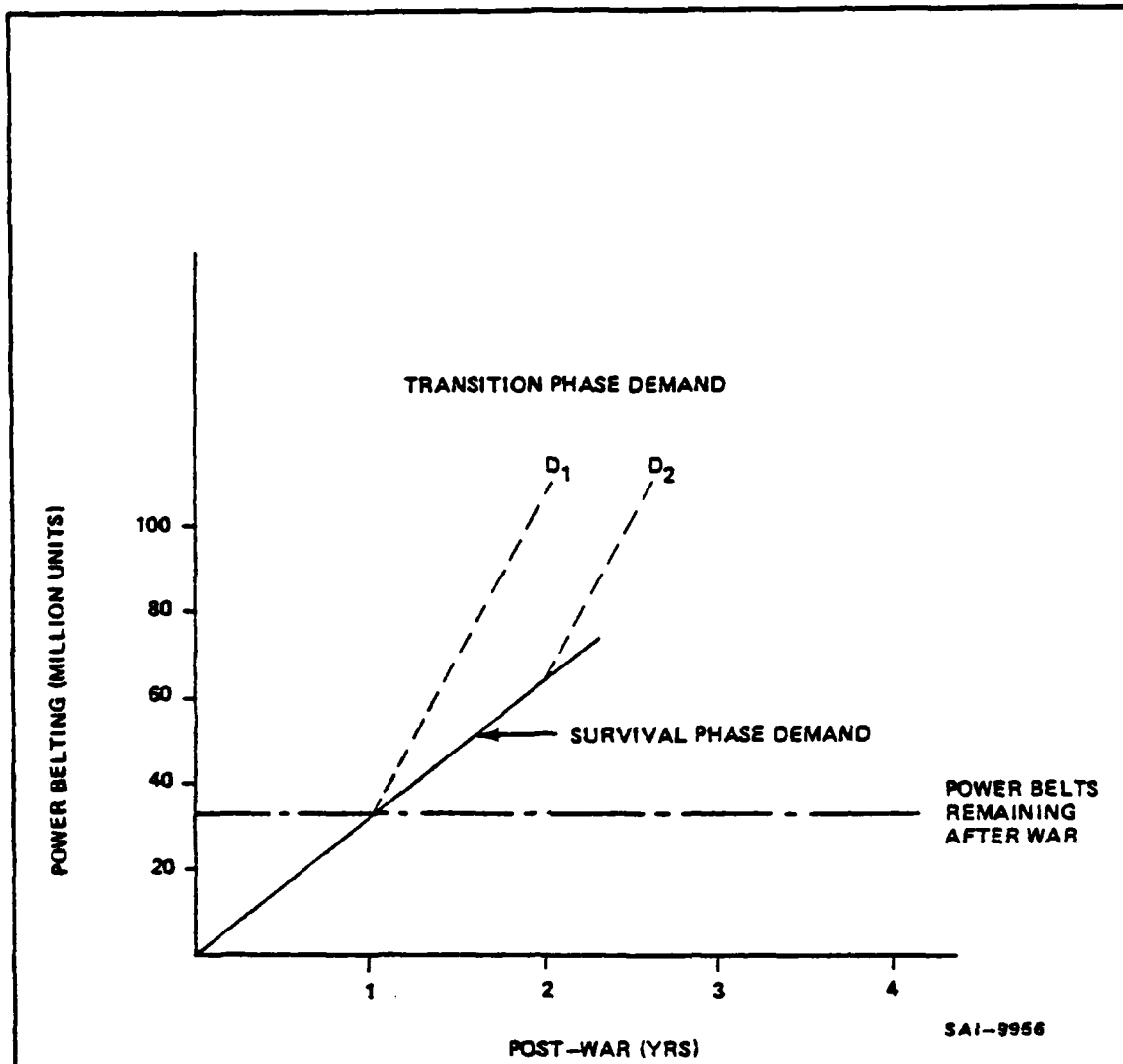




NOTE: TRANSITION PHASE DEMAND BEGINS ONE YEAR AFTER WAR (D<sub>1</sub>) OR TWO YEARS (D<sub>2</sub>) OR THREE YEARS (D<sub>3</sub>).

Figure 3-6. Flat Belt Availability in Post-War Environment





SAI-9956

NOTE: TRANSITION PHASE DEMAND BEGINS ONE YEAR AFTER WAR ( $D_1$ ) OR TWO YEARS ( $D_2$ ).

Figure 3-7. Power Belt Availability in Post-War Environment



hoses, using about 10% of the rubber required for hoses. It was thus estimated that approximately 90% of current hose production (by weight) would be needed in the post-war environment. If one uses a simplification of approximating all categories of essential post-war hoses through use of an "average" hose of 4 inches OD and ½-inch wall thickness, then based upon 1978 hose production data about 31,000,000 pounds of hoses would need to be produced per year to meet the anticipated post-war demand. This quantity amounts to about 1% of 1978 SBR production. It is assumed in this instance that the desired hoses would be produced entirely from SBR. Hence, if 70% of that product capacity survives, about 20% to 30% of current SBR capacity is required.

If essential rubber products are assumed to be predominately produced from SBR, then the post-war requirements for SBR to fulfill the demand for essential products would be from about 15% to 40% of peacetime SBR production. The 15% demand rate is for early survival and transition phases and the 40% rate is for the beginning of a mature recovery phase when the full peacetime production of essential products is expected to be utilized. These minimum and maximum demands for SBR are estimated in Table 3-9 and shown in Figure 3-8 as a function of the surviving capacity to produce essential post-war rubber products.

The U.S. Government maintains a strategic stockpile of natural rubber, which can be used for producing any of the rubber products nominated as being essential after a war, assuming other necessary ingredients (which are not part of the stockpile) are available. The stockpile was purchased in the mid-50's and is stored in 14 locations, with 70% of the quantity in 5 of the 14 locations. Since there are 119,202 long tons\* (267,012,480 lbs) stored in a few locations, and most locations are on military depots, these locations are an inviting target set during a strategic nuclear war. Hence, this stockpile should not be counted upon for post-war use. If available after a war, the stockpile would provide 2/3 of the early post-war demand rate (estimated at 15% of peacetime production) for one year. Because the rubber is crystalized, it needs to be preheated and worked in a mill to a much greater extent than does a newer supply.

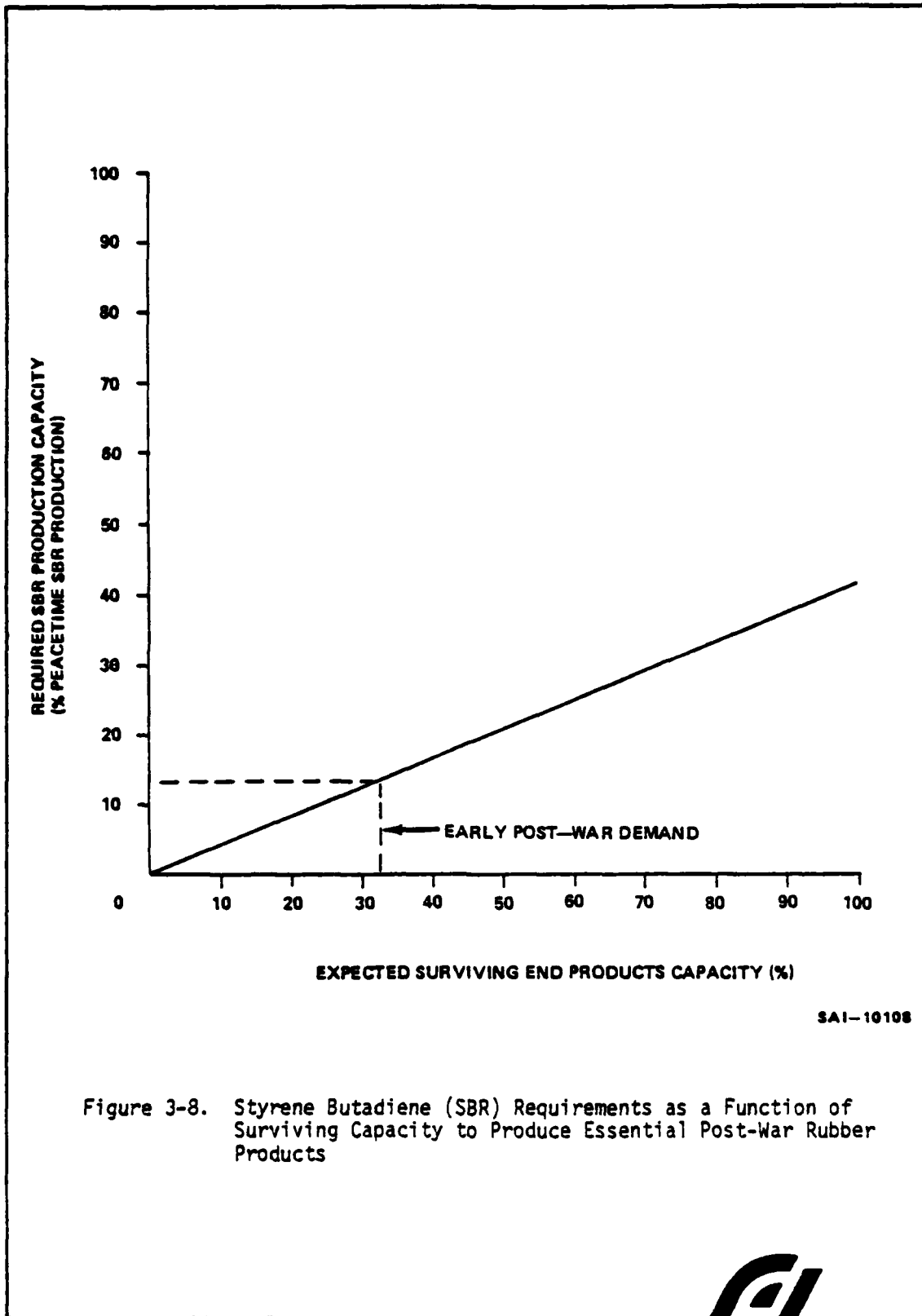
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\*The goal is 513,134 long tons.

Table 3-9. SBR Required to Support Essential Rubber Product Demand Shortly After a War

<u>PRODUCT</u>	<u>PEACETIME PRODUCTION (lbs)</u>	<u>POST-WAR PRODUCTION (Rate/lbs)</u>
Medium and Large Truck Tires	1,700 M	20%/340 M
Farm Tires	405 M	60%/243 M
Off-the-Road Tires	294 M	55%/162 M
Hose	31 M	30%/9 M
Belts	130 M	60%/78 M
	<hr/>	<hr/>
	2,560 M	832 M
<hr/>		
Rubber Content @ 40% Total Weight	1,024 M	333 M
% of SBR Production	41.4%	13.5%





SAI-10108

Figure 3-8. Styrene Butadiene (SBR) Requirements as a Function of Surviving Capacity to Produce Essential Post-War Rubber Products



## SECTION 4. INDUSTRIAL PROTECTION

### 4.1 INTRODUCTION

This section describes the need for industrial protection of the rubber industry, and postulates means of hardening facilities against the fire or pressure damage that is likely to result from collateral effects. The most critical population skills are also identified. No attempt has been made to discuss protective measures (other than noting a need for active defense) in the event of a direct hit by a Soviet nuclear weapon. In that case, the production facility would have to be completely rebuilt.

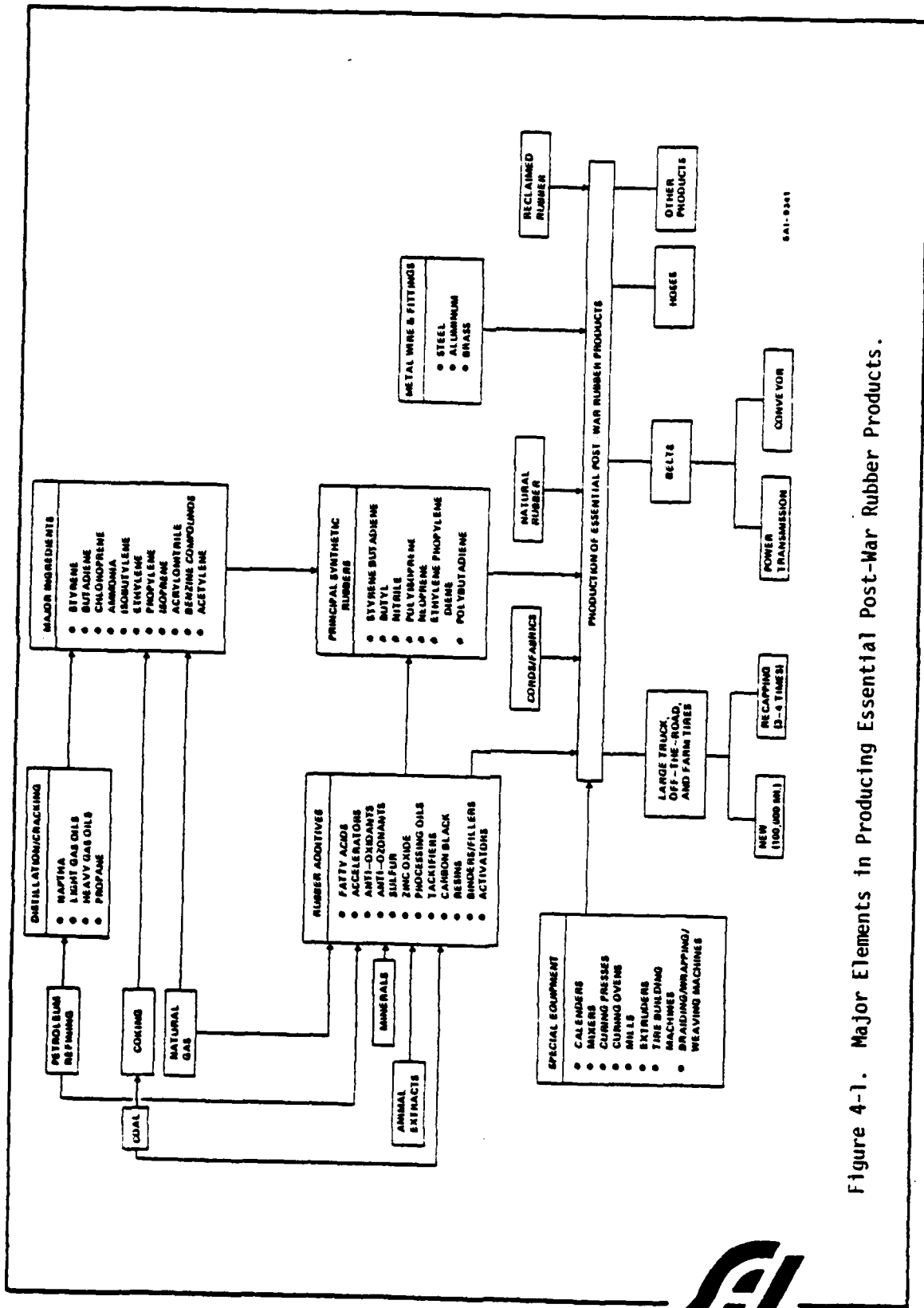
The rubber industry has a fairly complicated infrastructure of suppliers and producers, as shown in Figure 4-1, and is briefly discussed below. The discussion will point out major problems in rebuilding and operating those portions of the rubber industry most vital to early post-war recovery activities\*. The overview is followed by a more detailed discussion of industrial protection for each of the rubber products essential to post-war activities: tires for large trucks, industrial hoses, and industrial belts.

The U.S. rubber industry relies heavily on synthetic rubber produced from by-products of crude oil refining. The principal synthetic rubbers account for about 74% of the rubber used today. Natural rubber accounts for 22%, and reclaimed rubber for 4%. Automobile tires provide the largest requirement for synthetic rubber. Tires for use by large trucks and off-the-road vehicles account for large amounts of the current demand for natural rubber.

In a post-nuclear war environment, the U.S. will probably not have the ability to produce rubber unless protective measures are implemented in the petroleum refining and rubber production industries. The U.S. may not be able to import natural rubber unless it has goods to trade or the necessary military force to take natural rubber from the producing countries. Accordingly, industrial protection in the broadest sense is necessary in order to provide rubber needed in the manufacture of essential post-war rubber products. Reclaimed rubber cannot be used to a sufficient extent in tire production to

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\*Such activities are postulated in Reference 1.



SAI-9301

Figure 4-1. Major Elements in Producing Essential Post-War Rubber Products.



provide a temporary supply of rubber, although it can be used in producing hoses and belts if used with natural rubber as a binder. Recapping will not reduce the demand for large truck tires because the dominant mode of failure expected after a war is sidewall damage due to a combination of truck overloading and poorly maintained roads.

The rubber industry is vulnerable to both fire-induced and pressure-induced damage from nuclear weapons. Facilities producing synthetic rubber store large quantities of hazardous materials produced in the petrochemical industry. Because of the volatility of these materials and the large quantities involved, drainage or transporting these materials away from danger zones is unlikely. Therefore, fire (or detonations at low material/air mixtures) caused by sparks, resulting from airborne debris created at about 2.0 psi pressure, is the most likely cause of damage to rubber production facilities. If not damaged by fire or detonation from debris, drag pressure would topple the large, vertical vessels. The resulting fires or detonations could damage beyond repair these vessels and the miles of piping connecting them. End item production facilities contain small enough quantities of hazardous materials (solid rubber blocks, fuels, and solvents) that their removal from the premises is possible.

The supplies and equipment that can be used in a shortage situation for producing essential post-war rubber products are a subset of those used in peacetime production, as shown in Figure 4-1. In most cases, the use of the minimal essential supplies and equipment noted below will result in added production costs. Styrene butadiene rubber (SBR) is the basic synthetic rubber needed for tires, most hoses, and belts. Natural rubber is a viable substitute. Neoprene is needed for those products in contact with materials such as gasoline.

The major ingredients required for producing SBR are styrene and butadiene. Butadiene is the major ingredient required in the production of neoprene. All three of these major ingredients are products of the petroleum, coking, or natural gas industries.

The additives required for use with the SBR used in tires are accelerators, anti-oxidants, anti-ozonants, carbon black, fatty acids, processing oils, resorcinol resins, sulfur, and zinc oxide. Reclaimed rubber for most hose and belt applications needs the same additives as does new rubber. Additives

needed for use with natural rubber are processing oils, accelerators, activators, sulfur, and anti-oxidants. Additives needed for use with neoprene are activators, carbon black, mineral fillers, anti-oxidants, accelerators, and a vulcanizing agent such as sulfur or zinc oxide. These additives are derived from a variety of sources, as shown in the figure.

Cords and fabrics are needed in the production of tires, belts, and hoses. Rayon can substitute for any of the other materials used in making cords and fabrics. Steel wire is needed for the bead of a tire. Fittings are required on hoses, but hose clamps can substitute in some cases where pressures are low enough to preclude a safety hazard.

The equipment used in producing synthetic rubber is typical of the type of equipment used in many chemical industries: reactors, strippers, flash tanks, etc. This type of equipment lends itself to substitution with similar vessels which can be produced in any of the large number of tank and vessel fabricating facilities scattered throughout the U.S. Pipe is used extensively in synthetic rubber production facilities. Pipe systems are easily damaged. Their repair and replacement are time-consuming and may be the pacing item in process installation schedules. Manual operation and jury-rigging can substitute for most instrumentation and controls. Those for which no substitution is feasible are highly specialized, and thus difficult to obtain. Pumps and valves are generally rugged (particularly those pumps with explosion-proof motors) and readily replaced because of common applications of their functions. Boilers are easily damaged and difficult to replace. Hardening measures can increase the resistance of the above equipment to fire and blast, but cannot protect against a directly targeted Soviet nuclear weapon. Only active defenses can protect against such dedicated targeting.

The equipment used in producing rubber products includes some that perform essential functions and for which manpower or general purpose machinery, or machinery from other industries, cannot be substituted. The specialized equipment consists of mixers, calenders, tire curing presses, large belt curing presses, tire building machines, and braiding/weaving machines. All but the tire building machines and the braiding/weaving machines are rugged. All are produced in a small number of U.S. facilities and require significant procurement lead times.

Building and equipping a typical rubber industry production facility under expedited peacetime conditions takes about three years. Extensive modernization of an existing facility takes about two years. Long lead time components that drive the schedule for industry-peculiar equipment are large electrical motors and forgings for gear drives. The expected post-war shortage of cobalt (it is imported) may cause early wear-out of surfaces that need to be hardened, thus inhibiting a quick return to peacetime production capacity levels because of the need for frequent maintenance.

Specialized production skills are required in formulating rubber mixture specifications, in operating tire building machines, and in maintaining equipment. In addition, trade skills are needed for rebuilding or restoring production capabilities.

The following portions of this section discuss, in turn, detailed findings concerning production of large tires, synthetic rubber, industrial hoses, and industrial belts. Production of other products such as gaskets and seals was not examined beyond the point of determining that their rebuilding and producing problems are trivial compared to the problems involved with rebuilding and producing synthetic rubber, large tires, industrial hoses, and industrial belts.

## 4.2 ESSENTIAL TIRES

### 4.2.1 Introduction

The tires which have been identified in Section 3 of this study as being essential after a war, are those for large trucks, off-the-road vehicles, and farm vehicles. In this part of Section 4, we first describe the general production process followed in the manufacture of these essential tires. Next, we list the basic input materials. Then we list the initial utilities and equipment used in the manufacturing process. Having thus provided a background to the reader, we discuss (1) bottlenecks to rebuilding and to operating this type of manufacturing facility, including lead times and substitution possibilities; and (2) vulnerabilities to damage and potential solutions, based upon a visit to a representative manufacturing plant.

#### 4.2.2 Production Process for Essential Tires

The process for manufacturing conventional ply tires is illustrated in Figure 4-2 and is briefly described below.

Step 1. Rubber is cut into large chunks, heated to improve its ability to accept additives, and then shredded into small pieces. Rubber and other ingredients are measured according to a desired formulae (recipe) which differs according to use in the tire and type of tire, then mixed in a large mixing machine (often known by a trade name--Banbury Mixer). Because considerable heat is generated in this process, the mixer has to be cooled in order to prevent premature vulcanization of the rubber. The product from the mixing process is a sheet of blended rubber, which is stored until needed.

Step 2. Small quantities of rubber blended for use in the bead are mechanically worked to make the rubber pliable. Steel wire is fed through an extruder which coats the wire with rubber, then through a machine that forms the wire into a number of hoops (appropriate to the type of tire being built), and finally, into a machine that places a cover over each assembly bead (or groups of hoops). Then, the beads are stored.

Step 3. Tread is produced by mechanically working a rubber blended tread, then by extruding the ungrooved tread in long strips. These strips are cooled and slit on a bias to a length dictated by the type and size of tire desired. The tread is then stored for a short time (no more than three days) until needed.

Step 4. The inner liner and the plies are prepared separately in this step. Rubber of the proper blend is worked mechanically, then formed into a strip. At that point, rolls of fabric or cords are embedded in the strip of rubber. Inner liner stock is stored until needed.

Step 5. Ply stock is cut on a bias and spliced to form a long strip with cords at an angle to the length of the strip. These strips are stored until needed.

Step 6. All the above materials are brought to a tire building machine, where an operator builds the tire by hand in successive stages. At this point, the product is shaped like a barrel and is called a green tire.

Step 7. In Step 7, the green tire is painted to prevent it from sticking to the mold in the curing press.

Step 8. In Step 8, the tire is vulcanized. The curing press has a mold which imparts the tread and sidewall design, and which gives the tire its final shape. From this point, cured tires are inspected and such cosmetic steps as trimming, cutting stock to expose white-walls and letters, etc., are performed.

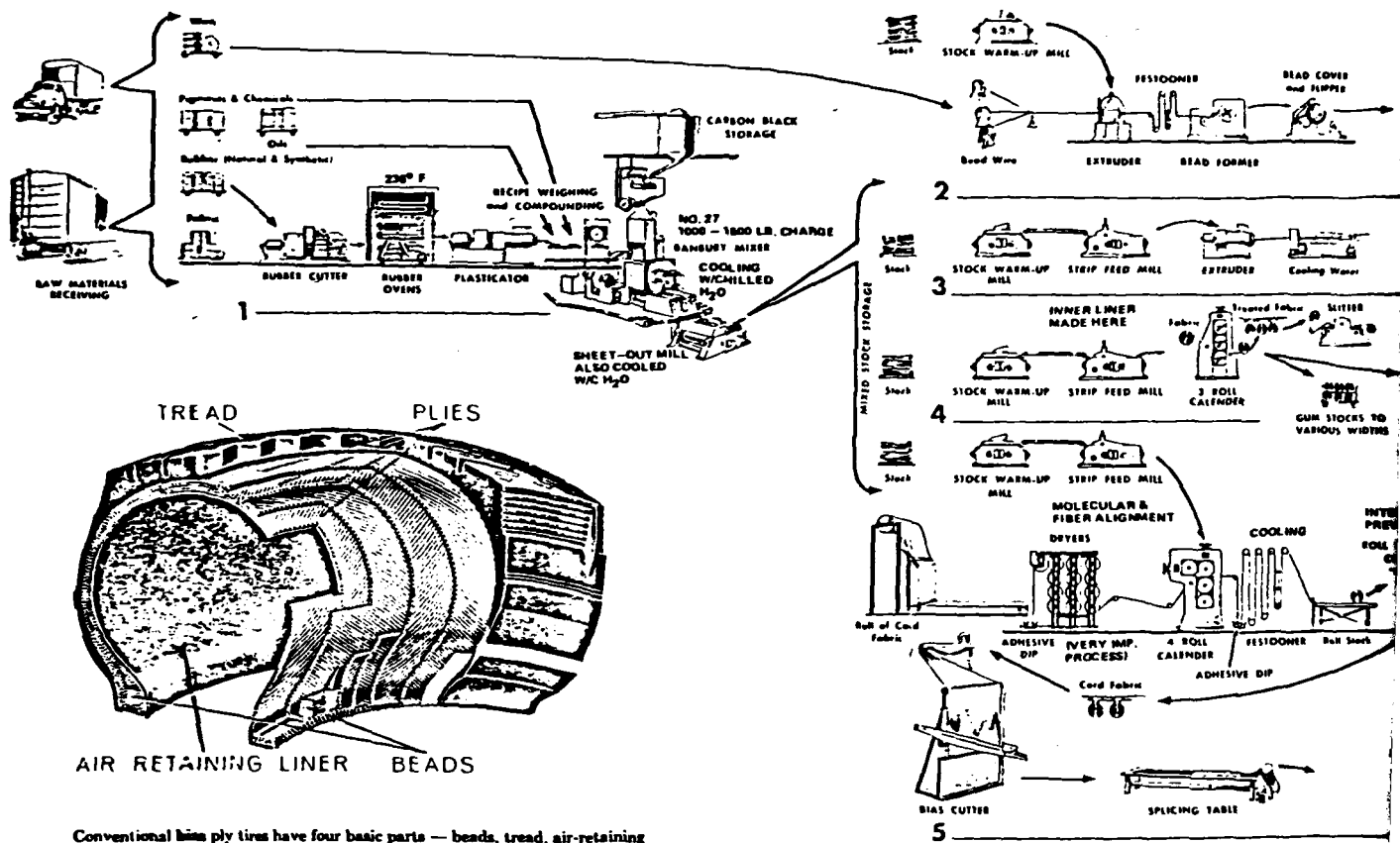
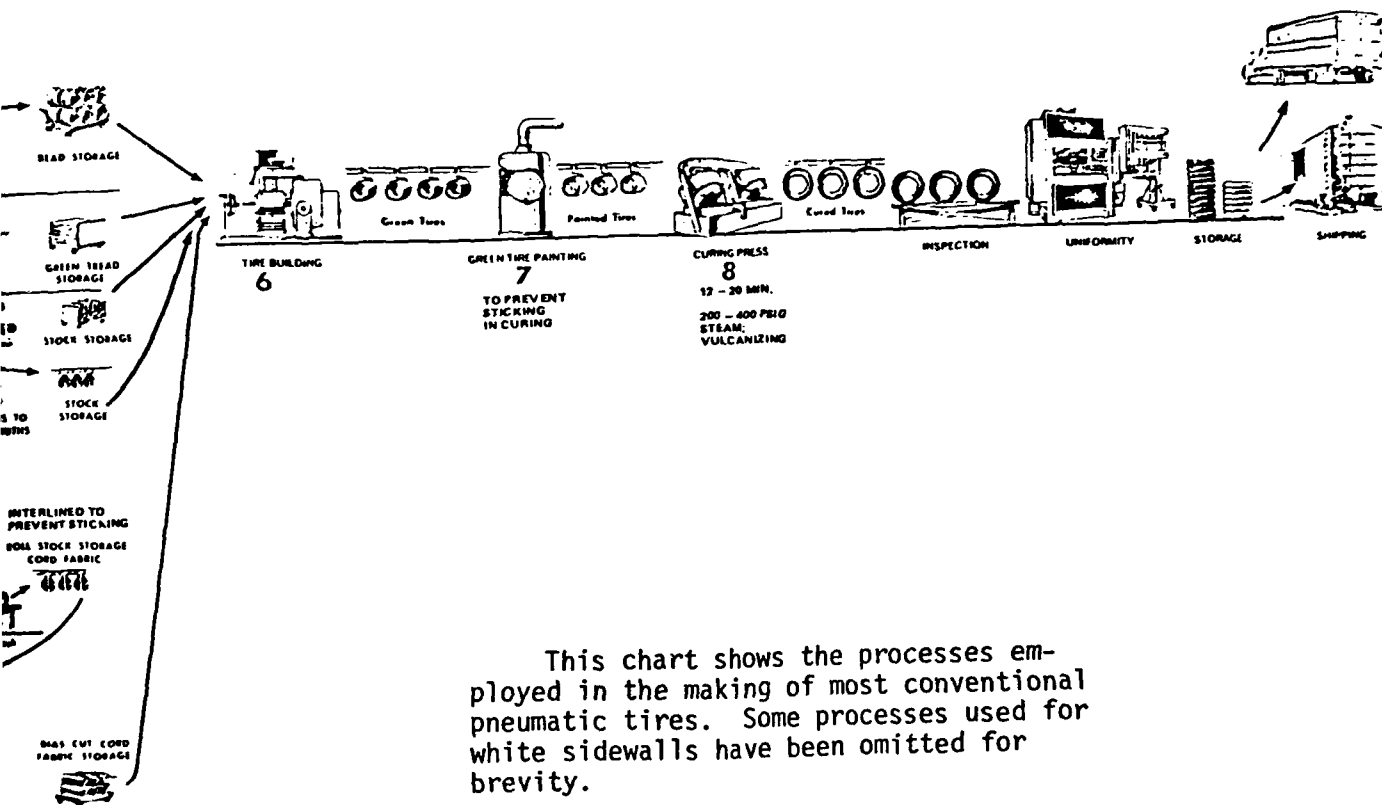


Figure 4-2. Typical Production Process



This chart shows the processes employed in the making of most conventional pneumatic tires. Some processes used for white sidewalls have been omitted for brevity.

This chart does not represent the manufacture of radial-ply, or belted-bias ply tires.

conventional tire

2

All of the eight steps described above are necessary in the manufacture of large truck tires, off-the-road tires, and agricultural tires, with the exception of the cosmetic step at the end of the process. The degree of automation varies with peacetime tire production quantities. Passenger car tire production is automated, while large sizes of specialty tires are made exclusively by hand. Minor variations of the process just described are used in the production of radial and belted bias ply tires.

#### 4.2.3 Input Materials

In the U.S. peacetime economy, tire manufacturing consumes about 3% of oil-derived hydrocarbons. There are four major categories of materials used in the manufacture of tires: rubbers, cords, adhesives, and additives. Combinations of these materials are used in the tire carcass, tread, sidewall, and inner liner. The materials used in each of these categories are listed below.

- Rubber used in tire production.
  - Styrene butadiene rubber (SBR)
  - Butadiene (BR)
  - Natural rubber (NR)
  - Butyl rubber, isobutylene isoprene (IIR)
  - Reclaimed rubber
- Cords used in tire production.
  - Nylon
    - Petroleum-derived material; cyclohexane, benzene, or butadiene is required
  - Rayon
    - Derived from cellulose (i.e., wood pulp); caustic soda, carbon disulphide, and cellulose are required
    - 92% of wood pulp input to process can be converted into rayon
    - Drying operation energy requirements: 50,000-60,000 BTU/# Rayon
  - Polyester
    - Derived from petroleum products; xylene and ethylene are required

- Fiberglass
  - Derived from silica sand
- Cotton (not currently used)
  - Derived from cotton plants
  - Potential problem: bringing enough cotton to the mills
- Adhesives
  - Resorcinol (principal adhesive)
    - Derivative of coal tars
    - Used in tire adhesives; also as cross-linking agent in rubbers
- Additives
  - Accelerators
    - Anti-oxidants
      - Aids rubber to resist degradation by oxygen
    - Anti-ozonants
      - Protects rubber from degradation caused by sunlight
    - Butyl curing resins
      - Aids in providing "tackiness" to rubber
    - Carbon black (reinforces and extends rubber)
      - Oil furnace black
        - \* Large particle size used in tire sidewalls
        - \* Intermediate size particle used in tire sidewalls
        - \* Fine particle size used in tire tread
      - Thermal black (used in hose production, but not in tire production)

- Mineral clays
  - --- To reduce cost
- Coal dust
  - Extender, filler in rubber
- Fatty acids
  - Aids in quick curing of rubber
  - Stearic acid
  - Liquids
- Flame retardants
  - Antimony oxide
  - Alumina trihydrate
  - Zinc Borate
  - Phosphate plasticizers
  - Chlorinated paraffins
- Mineral rubber
  - To reduce cost
- Miscellaneous resins
- Peptizers
  - Chemical agents used to soften rubber
- Processing oils
  - Promotes rapid incorporation of reinforcing and loading materials
    - \* Asphaltic
    - \* Lubricating oil blending stocks
- Silica
  - Silica is used as a component of adhesives; it enhances physical characteristics
- Solvents
  - Used in adhesives; freshening compounds
- Sulfur
  - Non-soluble preferred; soluble, acceptable
  - Required in curing of rubber

- Waxes
  - Used for dynamic aging protection of synthetic rubbers
- Zinc oxide
  - Activator for accelerators for all types of rubber
  - Manufacturing requirements: refractory furnace and zinc ore (virgin or reclaimed. About 55% of all zinc oxide produced in the U.S. is used in rubber industry--this amounted to about 150,000 tons consumed annually by the rubber industry.

#### 4.2.4 Utilities

The following utilities are predominantly utilized in the manufacture of tires:

- Steam - Used in the vulcanization of rubber products. Boilers are required to generate the steam.
- Water - Used in the boilers for steam production and for cooling mixers, mills, and extruders.
- Electricity - Used to drive the large horsepower motors of production process equipment. Can be up to several hundred horsepower.
- Fuel - Natural gas, fuel oil, or coal required to feed the boilers for steam generation.
- Air - Process air is required to actuate various pieces of production equipment.

#### 4.2.5 Production Process Equipment

The following is a list of the major equipment used in the production of tires:

Rubber cutting/shearing machines  
 Ovens  
 Plasticators  
 Banbury mixers  
 Mills  
 Extruders  
 Bead extruders  
 Bead cover and flipper machines  
 Slitters  
 Festooners  
 Dryers  
 Bias cutters  
 Tread forming machines  
 Tread cutting machines

Splicing tables  
Tire building machines  
Tire painting equipment  
Tire curing processes  
Tire inspection and trimming equipment  
Fabric adhesive-dipping equipment

#### 4.2.6 Bottlenecks in Post-War Production of Essential Tires

Bottlenecks critical to the post-war manufacture of essential tires can be divided into four groups; utilities, process equipment, materials, and personnel. Each of these will be examined in detail below.

##### 4.2.6.1 Utilities

- Steam - Provides the heat needed.
- Water - Needed primarily for steam generation within the boilers and cooling processing equipment.
- Electricity - Required to drive the many motors (from one up to several thousand horsepower) required to operate the production equipment and materials-handling conveyors.
- Fuel - Oil, natural gas, or coal would be needed to feed the boilers.
- Air - It is used for process controls generally supplied by an on-site compressor system.

##### 4.2.6.2 Process Equipment

A listing of the basic tire manufacturing equipment and its vulnerability is presented in Table 4-1. Whether or not that equipment is a bottleneck in the overall production process is also noted. An attempt at determining reorder lead times of the various pieces of tire manufacturing equipment is also included in this table.

##### 4.2.6.3 Materials

The materials are grouped into the following major categories for further consideration: rubbers, cords, adhesives, and additives. The following are the predominant rubbers used in tire production.

- Styrene butadiene rubber - essential to tire manufacturing
- Natural rubber - used in conjunction with synthetic rubbers in tire manufacturing

Table 4-1. Selected Information About Tire Manufacturing Equipment (Page 1 of 2)

Equipment	Vulnerability*	Bottle-neck		Reorder Leadtime	
		Y	N ?	(>6 mos)	(≤6 mos) (?)
Bead extruder	Hard		X		X
Bead former	Hard		X		X
Banbury mixer	Hard	X		X	
Rubber ovens	Soft		X		X
Rubber cutter	Hard		X		X
Plasticator	Hard			X	
Mill	Hard	X		X	
Extruder	Hard	X		X	
Bead cover & flipper	Hard		X	X	
Calender	Hard	X		X	
Slitter	Hard		X		X
Adhesive dip tank	Soft		X		X
Dryers	Soft		X		X



Table 4-1. Selected Information About Tire Manufacturing Equipment (Page 2 of 2)

Equipment	Vulnerability*	Bottle-neck		Reorder Leadtime	
		Y	N ?	(>6 mos)	(≤6 mos) (?)
Festooners	Soft		X		X
Bias cutter	Soft		X	X	
Curing press	Soft	X		X	
Splicing table	Soft		X	X	
Green tire painting	Soft		X	X	
Tire building machine	Soft	X		X	
Wire creels	Soft		X		X

\*Vulnerability is designated as hard if the basic equipment is expected to survive the collapse of the building, or soft if the equipment is not expected to survive.



- Butyl rubber - used in conjunction with above rubbers in tire production
- Reclaimed rubber - used as an extender in tire production

The tires essential to post-war activities can be built with either styrene butadiene rubber (SBR) or natural rubber, or some combination of both. Any substitutions for SBR are also derived from the petroleum refining process but none are as good as SBR. Natural rubber is imported from Malaysia and Indonesia. We assumed that natural rubber would not be available to the U.S. after a war because of our potential inability to trade or force the importation of most goods. Butyl rubber is used as a liner to retain air pressure. It, too, is essential. Reclaimed rubber is used in small amounts only as an extender to reduce the cost of rubber in tires. Significant percentages of reclaimed rubber cannot be used in manufacturing tires, if more than 5 to 10% of current tire life is expected.

Various types of cords are used in tire production. Nylon, polyester, steel, aramid, rayon, fiberglass, and cotton cords can be used in tire production. Petrochemical shortages, due to targeting of petroleum refineries, will preclude use of nylon and polyester cords. Bringing sufficient cotton from the fields to the textile mills in sufficient quantities for tire production may be a problem. In any event, cotton is not currently used in tire production because of a very short lifetime (approximately 25%). Steel used in the U.S. for tire beads and belts is obtained from U. S. Steel. Others could manufacture steel for beads without much difficulty, but for belts they would have to implement the purity requirements and the ability to draw that material into wires of 0.001 inch OD and 300,000 psi tensile strength.

Rayon, fiberglass, aramid or steel are used in producing tire belts, but nylon or polyester can be used in an emergency. Nylon, polyester, and aramid are derived from petroleum refining; they may not be available because petroleum refineries are likely targets. Fiberglass may not be available because its production process is energy-intensive. Steel may not be available because steel plants are likely targets. Rayon is likely to be available because it is manufactured from cellulose, which can be produced easily.

Steel is required for tire beads. It may be available through reclamation of damaged tires of the same size needed after a war.

Adhesives are needed to hold several tire constituents together while the tire is being produced. One critical adhesive, resinified resorcinol is used in coating fabrics and metal wire to promote good adhesion of those items to rubber. Without that adhesion, the bead and belting in tires would not be practical. Resorcinol resins are made from resorcinol; resorcinol, in turn, is made from coal tars. Resorcinol is manufactured by only one U.S. firm, Koppers Manufacturing. The production process of resorcinol is a specialized, capital-intensive one. Resorcinol is perishable; it has a shelf life of 6-12 months. Resorcinol is not easily substitutable without significant degradation of the rubber product; pine tars may be used, but provide a poor quality product having a drastically reduced lifetime.

Additives are described in Table 4-2 in terms of their contribution as bottlenecks. Those additives which are essential to the production of synthetic rubber (primarily styrene butadiene rubber) are designated with an "E". Those additives marked "E" are the minimum ones needed to produce a degraded, but usable tire in the post-war environment.

The people who operate tire building machines and those who maintain equipment in the plant need to be trained. These two skills are the bottleneck skills for operating and maintaining the tire production capability. Rebuilding or jury-rigging requires skills in a number of trades.

#### 4.2.7 Vulnerabilities and Potential Solutions

One representative manufacturing facility was visited to determine ways in which such facilities could be hardened against the effects of collateral damage. The facility visited was the B. F. Goodrich Tire Plant in Miami, Oklahoma.

##### Examples of fire-induced damage are:

- Processing oils are flammable; oils are stored underground in bulk storage tanks and delivered by pipe to holding tanks near the mixers via air pressure.
- Fuel oil (heated to reduce viscosity) is flammable.
- Synthetic rubber stock is flammable (difficult to start and difficult to extinguish); several areas are used for storage of styrene butadiene rubber or finished tires.

Table 4-2. Additives Essential to the Production of Synthetic Rubber

ADDITIVE	ESSENTIAL	NUMBER OF MANUFACTURING LOCATIONS
Accelerators	E	18+
Anti-oxidants	E	23+
Anti-ozonants	E	11+
Butyl curing resins	-	9
Carbon black	E	30
Clays, mineral	-	7
Coal dust	-	2+
Fatty acids	E	14
Flame retardants	-	13
Mineral rubber	-	2



- Adhesive dip operations are flammable, dryers and festooners are susceptible to damage (critical equipment).
- Tire building machines (critical equipment), especially motor windings, would be damaged by fire.

Pressure-induced damage to critical equipment (approximate values):

- Carbon black hoppers are toppled at 1½ psi dynamic pressure.
- Additives holding tanks/drums are destroyed at 1 psi dynamic pressure.
- Buildings would be torn apart at 2-5 psi overpressure. The following equipment within the buildings would be severely damaged or destroyed by missiles in the form of flying debris:
  - Smooth surfaces of calender rolls
  - Materials-handling equipment
  - Tread cutting equipment
  - Wire beading equipment
  - Instrumentation and process controls
  - Wire creels (handling steel wire for belts)
  - Adhesive dip equipment
  - Festooners for cooling dipped fabrics
  - Tire building machines

Hardening Recommendations - There is no effective hardening measure against a direct nuclear hit. Recommendations given below are confined only to collateral damage expected from nearby nuclear blasts. The hardening measures suggested below provide the following approximate improvements:

- For any process equipment within buildings, the main damage will come from the collapse of the building onto the process equipment (fire not being considered). With protective measures such as building a sandbag and cribbing enclosure around equipment, the equipment can be hardened to at least 40 psi overpressure.
- Vessels and fluid lines can be most readily hardened by being filled with fluids. The increase in mass alone can double the resistance level of typical vessels. Wherever possible, the fluids should be water (with a soluble rust inhibitor) or other non-flammables. Anti-freeze would be essential for situations involving potential freezing. Some production materials have the capability of mixing with water to form a non-flammable anti-freeze mixture.

Suggested hardening measures are:

- Activate emergency shutdown of process in 1 hour; 2-4 hours preferred for normal shutdown.



- Install diagonally-placed tie rods with turnbuckles between vertical support columns of the building.
- Fill all vessels and lines with non-flammable fluids.
- Use shear bolts in flanged connections (e.g., on steam lines) to obtain pre-designed failure locations.
- Coat polished surfaces of calenders with non-flammable rust-proofing materials.
- Use soil berm/sandbag/cribbing shielding of centralized process/control instrumentation; same with similar control panels located around process equipment.
- Turn off heat to fuel oil (fuel oil is heated to reduce viscosity) to reduce fire hazard.
- Transport selected hand tools, oxyacetylene/heliarc welders, machine shop items, etc., with evacuating personnel for return and use in post-war repairs.
- Use soil berm/sandbagging/cribbing to protect major pieces of machinery in machine shops from flying debris.
- Transport all flammable supplies and products (e.g., tires) away from the facilities or bury them on-site.
- Transport easily-removable critical items (e.g., selected large truck and off-the-road tire molds, fork lifts, etc.) away from site or bury them on-site.
- Turn off electric and gas utilities at locations outside plant property to reduce fire hazards. Sprinkler systems should be left operational.
- Evacuate drawings and specifications with evacuating personnel for use in repair activities.

#### 4.3 SYNTHETIC RUBBER

##### 4.3.1 Introduction

In this part of Section 4, we first describe the general production process followed in manufacturing synthetic rubber. Next, we list the basic input materials. Then, we list the critical equipment used in the manufacturing process. Having thus provided a background to the reader, we discuss (1) bottlenecks to rebuilding and to operating this type of manufacturing facility, including lead times and substitution possibilities; and (2) vulnerabilities to damage and potential solutions, based upon visiting a representative plant.

#### 4.3.2 Synthetic Rubber Production Process

The production process for styrene butadiene rubber (SBR) is shown in Figure 4-3 and briefly discussed below. Basic input materials include styrene and butadiene. In addition, processing oils, anti-oxidants, soap solutions, activators, and catalysts are used. The styrene and butadiene are mixed in a ratio of about one to three, then placed in a soap solution to prevent separation. The mixture is agitated and allowed to polymerize in a reactor (forming into a large molecular chain). The polymer reaction is stopped at a desired point and then, in the blowdown tank, unreacted butadiene is removed for reuse. The polymer is then transferred into a stripping column where unreacted styrene is removed for reuse. The remaining polymer is next blended with processing oils and anti-oxidants and then allowed to coagulate to form into a solid. Solids are separated from liquids in the conversion tank. The solids are then filtered and dried to remove excess fluids, then the solids are packaged into bales. The above process takes 8-14 hours.

Styrene butadiene rubber is produced through one of two processes: a "cold" (approximately 42<sup>o</sup>F) process and a "hot" (approximately 150<sup>o</sup>F) process. The former requires refrigeration of the ongoing process to maintain production temperatures. Although the "cold" process is used primarily for making the rubber for tire production, the "hot" process (i.e., minimal refrigeration needed) could be used, if the refrigeration is unavailable.

#### 4.3.3 Input Materials

- Styrene
- Butadiene

#### 4.3.4 Utilities

- Steam
- Water
- Electricity
- Fuel
- Air

#### 4.3.5 Production Process Equipment

- Reactor Vessels
- Vacuum Flash Tanks
- Styrene Stripping Columns
- Latex Blend Tanks
- Coagulation Tanks

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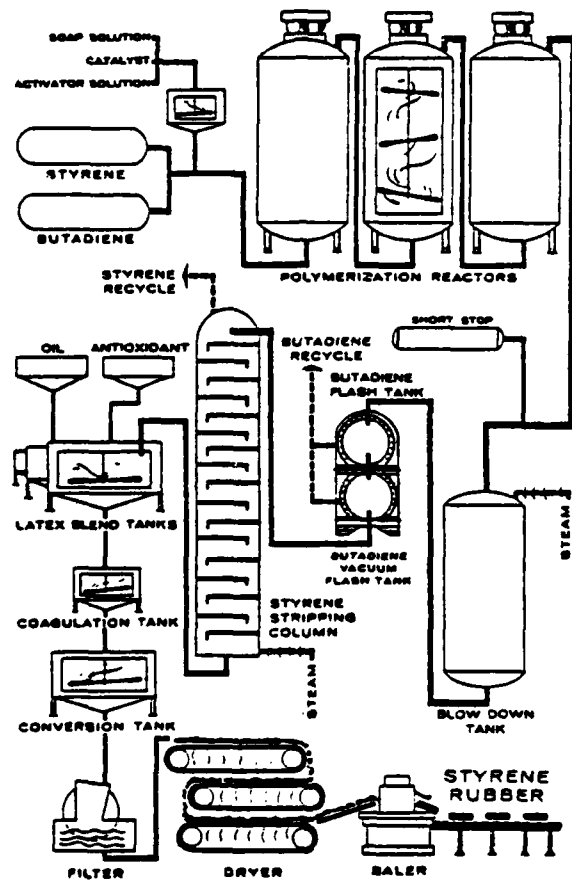


Figure 4-3. Production Process for Styrene Butadiene Rubber (SBR)



- Conversion Tanks
- Filters
- Dryers
- Balers

#### 4.3.6 Bottlenecks in Post-War Production of Synthetic Rubber

The discussion of potential post-war bottlenecks is divided into four groups: utilities, process equipment, materials, and personnel.

##### 4.3.6.1 Utilities

The same statements made earlier about utilities for tire production apply here.

##### 4.3.6.2 Process Equipment

None of the equipment is unique or difficult to manufacture.

##### 4.3.6.3 Materials

Styrene and butadiene are both required in the producing of SBR. Styrene is a flammable liquid having limited lifetime before use. It is stored in refrigerated tanks maintained at approximately 50°F. Butadiene is a flammable gas having limited lifetime before use. It is stored in liquid form at a pressure of approximately 50 psig; at ambient pressure it reverts back to gaseous form, having a density about two times that of air.

##### 4.3.6.4 Utilities

Steam is the most critical utility. Without steam, the vulcanization of styrene butadiene rubber is not possible. Water and fuel are required to produce steam. Electricity is required to power motors.

##### 4.3.6.5 Personnel

The essential skills are in determining and adjusting mixtures and in maintaining equipment. Supervisory personnel usually define the adjustments. Trades people of all types, particularly pipefitters, are required to rebuild or jury-rig equipment.

#### 4.3.7 Vulnerabilities and Potential Solutions

A representative facility producing styrene butadiene rubber (SBR) and a facility producing butadiene were visited to determine vulnerabilities and ways in which such facilities could be hardened against the effects of collateral damage. Both of these facilities are in Port Neches, Texas.

Examples of fire-induced damage to SBR production are:

- Liquid butadiene evaporates to form a heavier-than-air gas. Butadiene has an auto-ignition temperature of 788<sup>o</sup>F, but can be ignited at as low a temperature as 20<sup>o</sup>F. If the butadiene to air mixture is within a range of 2-11%, a detonation will result instead of a fire. The on-site tank farm stores 375,000 pounds of butadiene. The butadiene, if ignited or detonated, could destroy the entire facility.
- Styrene has an auto-ignition temperature of 914<sup>o</sup>F. Up to 150,000 gallons are stored in on-site storage tanks close to the butadiene storage. Ignition of the styrene from a damaged tank would spread to the rest of the storage complex and then (via the butadiene ignition) to the total facility.
- Kerosene, which is used as a solvent, is flammable and would cause extensive damage in the areas in which it is stored and used.
- Styrene butadiene rubber stocks are hard to ignite, but when ignited, are hard to extinguish. Burning rubber stocks would extensively damage or destroy the areas in which they are stored.

Pressure-induced damage to critical SBR equipment:

- Toppling of storage tanks containing butadiene, styrene, solvents, etc., at 3-4 psi dynamic pressure (13-14 psi overpressure\*).
- Piping including steam lines from Neches Butane next door would be destroyed at 3/4-2½ psi dynamic pressure (6-11 psi overpressure), depending on the type of pipe rack.
- Outdoor process and control instrumentation would be destroyed at ½-1 psi dynamic pressure (5-7 psi overpressure).
- Water cooling tower would be destroyed at ½ psi dynamic pressure (3 psi overpressure).
- Styrene stripper would be toppled at 6 psi dynamic pressure (17 psi overpressure).
- Brine refrigeration equipment would be damaged at 15 psi dynamic pressure (30 psi overpressure).
- Railroad car unloading piping, pumps, valves would be destroyed at 2 psi dynamic pressure (9 psi overpressure).
- Carbon black hoppers would be toppled at 1½ psi dynamic pressure (8 psi overpressure).

\*Where the dominant failure mode is caused by dynamic pressure, the equivalent overpressure is provided in parenthesis, based on Glasstone, Figure 3.55.

- Buildings would be torn apart at 2-5 psi overpressure or  $\frac{1}{2}$ -1 dynamic pressure. The following equipment within the buildings would be severely damaged or destroyed by missiles in the form of flying debris:
  - Centralized control rooms and instrumentation in general
  - Particle rubber production equipment
  - Materials-handling equipment
  - Drying ovens

Hardening recommendations for SBR production facilities - There is no effective hardening measure against a direct nuclear hit. Recommendations given below are confined only to collateral damage expected from nearby nuclear blasts. These hardening measures complement those given earlier for general tire manufacturing facilities and provide similar improvements.

- Shutdown the process: emergency shutdown can be implemented in 4-8 hours, minimum; but a normal shutdown of the process takes 8-24 hours.
- Fill all vessels with water or non-flammable fluids.
- Drain process lines (especially of flammables) and fill with water.
- Use shear bolts in flanged piping connections to predetermine failure points (e.g., after valves to save valve-tank connections).
- Use guy straps over storage tanks and secure to support pillars for additional reinforcement. Additional anchor positions can be drilled into the concrete foundations to accommodate the straps for anchoring.
- Wooden chocks can be wedged between the two to three story reactor tanks and the concrete "floors" near the tanks.
- Rigid instrumentation lines (hydraulic/pneumatic) should have expansion loops formed within them to minimize rupturing.
- Low-lying piping running between equipment or buildings may be coated with rustproofing material and buried.
- Transport all flammable supplies away from the facility or bury them on-site.
- Use cribbing/sandbags/soil berms around process control instrumentation in central control buildings and elsewhere, as applicable. Protect instrumentation in central control room from collapse of roof by use of timber covers, etc.
- Brace wall-type concrete pedestals supporting tanks by building additional wall structure perpendicular to existing two pedestals and fastening it to them.

- Use bands on vacuum flash tanks (horizontal, cylindrical) both over the ends of the tanks and diagonally opposite (i.e., criss-cross) supports and fasten to the supports.
- Evacuate all hand tools, oxyacetylene/heliarc welders, machine shop items, etc., with evacuating personnel for post-war repairs.
- Use sandbags/cribbing to protect major pieces of machinery in machine shops.
- Structures presenting large surfaces for wind loading should be diagonally guyed or braced to improve wind resistance.
- Turn off electric and gas utilities away from plant site to reduce potential of fire hazard. Sprinkler systems should be left operational.
- Piping tiedowns should be fabricated and stored near where they will be used. They can easily be installed after the system temperature is reduced to ambient.
- Evacuate drawings and specifications with evacuating personnel for use in repair activities.

Fire-induced damage to butadiene production equipment:

Butadiene - A typical production process and several alternate processes for butadiene are schematically represented in Figure 4-4. The trend to make "on-purpose" butadiene, via petroleum or natural gas, is being supplanted by production of "by-product" butadiene resulting from the production of ethylene and propylene. One process utilizes petroleum cracking to obtain intermediate products (i.e., butulene) which, in turn, are used to produce "on-purpose" butadiene. A comparable process utilizing natural gas yields intermediate butanes and butenes from which "on-purpose" butadiene is also processed. However, the recent trend is to use the natural gas and naptha/gas oil cracking processes to produce ethylene and propylene as primary products with butadiene being processed as a by-product. Accordingly, this process produces butadiene at a lower cost than the "on-purpose" processes.

We visited a facility producing "on-purpose" butadiene. Approximately 180,000 barrels of butadiene are stored in 20 storage spheres. As noted earlier, butadiene is extremely flammable and burns with great intensity. Any fire originating in the storage tank farm will result in the destruction of the entire facility. Draining the tanks to remove the product is not feasible; butadiene is heavier than air and drainage would create a worse fire hazard.

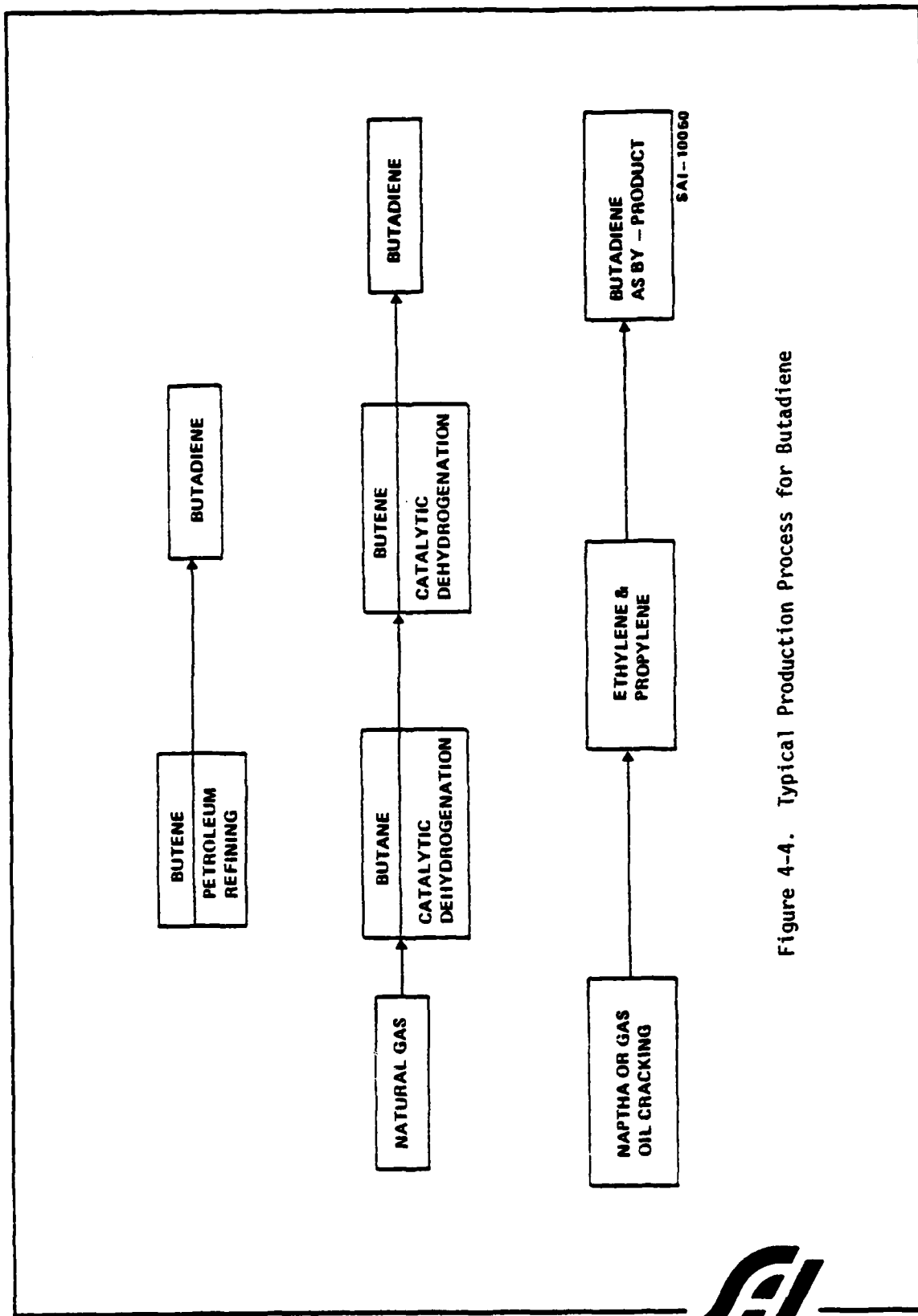


Figure 4-4. Typical Production Process for Butadiene



Because of the large storage volume, it is not practical to transport the butadiene supply away from the site. Normal usage depletes the supply in about one week, but just transfers the fire hazard to the user.

Pressure-induced damage to critical butadiene production equipment:

- Fractionating towers (including solvent strippers) are toppled or damaged at 3 psi dynamic pressure (13 psi overpressure).
- Boilers are destroyed at 1-2 psi overpressure.
- Piping is destroyed at  $3/4$ - $2\frac{1}{2}$  psi dynamic pressure (6-11 psi overpressure), depending on the type of pipe rack (the facility visited has more than 3,000 miles of pipe).
- Storage tanks are toppled at 2-3 psi dynamic (9-13 psi overpressure).
- Outdoor instrumentation is destroyed at  $\frac{1}{2}$ -1 psi dynamic pressure (5-7 psi overpressure).
- Buildings would be torn apart at 2-5 psi dynamic pressure or  $\frac{1}{4}$ -1 psi dynamic pressure. The centralized control rooms and instrumentation in general within the buildings would be severely damaged or destroyed by missiles in the form of flying debris.

Hardening recommendations for butadiene production facilities - There is no effective hardening measure against a direct nuclear hit. Recommendations given below are confined only to collateral damage expected from nearby nuclear blasts. These hardening measures complement those given earlier for general tire manufacturing facilities, and provide similar improvements.

- Shutdown the process: emergency shutdown can be implemented in 1-2 hours, minimum; but a normal shutdown of the process takes 24 hours.
- Fill vessels with water or non-flammable fluid.
- Cross-brace the butadiene storage tank supports.
- Cross-brace the process tanks to their support structures.
- Drain process lines and fill with water.
- Use soil berm/sandbag/cribbing shielding of instrumentation in central control room and elsewhere.
- Use shear bolts in flanged connections (e.g., valve locations) to obtain predesigned locations of failure.
- Rustproof and bury piping presently mounted in shallow trenches close to ground.



- Drain all process equipment of products (especially flammables) and fill with water.
- Guy accumulator and other critical tanks to floor beams and tie them to existing supports for additional reinforcements.
- Transport all flammable supplies away from facility to an off-site location or bury them on-site.
- Remove all portable equipment (e.g., hand tools, oxacetylene/heliarc welding equipment, essential instrumentation, etc.) with personnel during evacuation for later use in repair activities.
- Turn off electric and gas utilities at locations outside plant property to reduce fire hazards. Sprinkler systems should be left operational.
- Prefabricate, then install piping reinforcement tiedowns after system temperature is reduced to ambient during a process shutdown.

The concern expressed for damage or destruction of butadiene facilities supplying inputs to the production of styrene butadiene rubber is underscored by observations based on a visit made to a butadiene production facility in Texas. The Neches Butane Products Company facility in Port Neches, Texas, is located in Figure 4-5 as the center of a circle equivalent to a 2 psi overpressure contour from a 1 Mt weapon. This facility is the largest producer of butadiene in the U.S. As noted elsewhere in this report, butadiene is an essential ingredient of styrene butadiene rubber--the principal synthetic rubber. As such, loss of this facility would severely curtail the ability of the U.S. to produce rubber products essential to post-war activities. Therefore, this facility is a likely target. If this facility is not hardened against nuclear effects, and nearby facilities are targeted (as shown at the end of each of the four radial lines in the figure), there is some chance of the Neches Butane facility being destroyed by fire from debris caused by 2 psi overpressure at the facility. If hardened, there is a good chance the facility would not be damaged. However, targeting this facility for collateral damage is not an offense conservative strategy. Because of the value of a facility such as this one, an offense conservative strategy would be to target it directly. In that event, hardening measures would be insufficient to protect the facility from being destroyed by Soviet nuclear weapons.

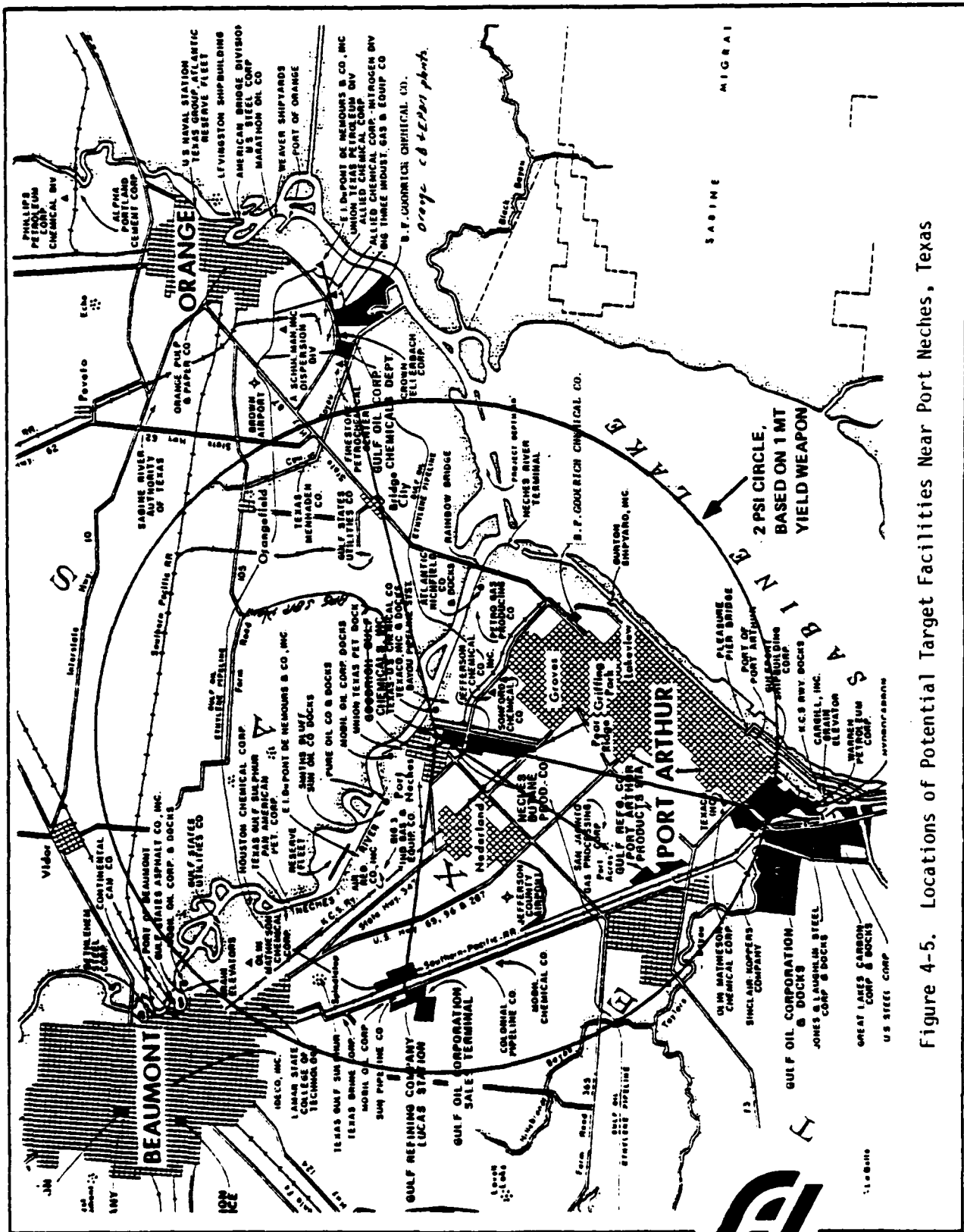


Figure 4-5. Locations of Potential Target Facilities Near Port Neches, Texas

#### 4.4 ESSENTIAL HOSES

##### 4.4.1 Introduction

The discussion on essential hoses describes production processes for hoses, then lists the essential materials, utilities, and process equipment. Next, potential bottlenecks are discussed, and finally, vulnerabilities to damage and potential solutions are described.

##### 4.4.2 Production Process for Essential Hoses

There are seven types of hoses which will be essential in the post-war phase: circular woven hoses, machine-wrapped hoses, hand-built hoses, horizontal braided hoses, horizontal loomed hoses, horizontal spiraled hoses, and continuous thermal cure.

Each hose consists of three major components:

- Tube. Its purpose is to contain and convey the medium being handled and to resist deterioration resulting from contact with the medium; also to protect the reinforcement from direct contact with medium. It consists of various synthetic/natural rubbers. Up to 100% re-claimed rubber can be used in manufacture of the tube for limited applications.
- Reinforcement. The reinforcement provides strength to the tube to withstand delivery pressures of the medium being handled; it can be of various fabrics, yarns/cords/ropes/fibers, metals, or combinations thereof.
- Cover. The cover protects the combined tube and reinforcement from the external environment; it consists of various fabrics, metals, rubbers, or combinations thereof. In some instances, the reinforcement also acts as its own cover (e.g., fire hoses).

Various couplings, as required, may be fitted onto the ends of the hoses. Couplings may be made of steel, brass, aluminum, or plastics.

The following are generalized descriptions of the manufacturing processes for the major categories of hose previously described.

Circular Woven (typical uses: fire hose, etc.). Fire hose is an example of this type of hose. A single sheet of rubber is fed in a tube machine which forms the hose (i.e., a flexible extruded tube), then that tube is dipped into a zinc-steareate/water solution to prevent the extruded tube from sticking to itself or to anything else during the handling. A length of short, uncured

rubber (tie gum) is wrapped around the tube to permit the tube and its reinforcement to become bonded. The tube (with the tie gum attached), is then pulled through the reinforcement (e.g., canvas hose covering). The assembly is then cured by pressurizing the hose with steam while individually tensioning the hose. Molds may be used to shape the hose, particularly the ends. After curing, the hose is fitted with couplings.

Machine-Wrapped (typical uses: acid, air, water, sandblasting, food handling). Rubber is fed into an extruder to form the tube for the hose. The extruded tube is placed around a steel mandrel with the aid of a small conveyor. The tube-covered mandrel is then placed on a "making" machine. The reinforcement, bias-cut fabric, is applied to the tube previously coated with an adhesive. Additional adhesive is sometimes used on the reinforcement and a cover is then wrapped onto the reinforcement. Both the reinforcement and the cover are wrapped onto the tube under tension while the tube is on the mandrel. A nylon cross-wrap (coated with a release agent) is then tightly wound around the hose. This cross-wrap is essential to the curing of the hose, for it contains the expansion of the hose materials during heating and permits curing the hose under pressure. This pressure compresses the heated, softened rubber and permits it to fill any voids around the reinforcement. This prepared length of hose, along with similarly-prepared hoses, is placed into a steam-heated curing oven and cured (typical temperature: approximately 300<sup>o</sup>F; pressure: approximately 50 psig). After vulcanization, the hose is removed from the oven and the nylon wrapping is removed. The cured hose is separated from the mandrel which is temporarily held in a vise, by having air blown into the hose.

Hand-Built (typical uses: suction/discharge hose). These hoses can have either fabric or wire reinforcement. For wire reinforcement (i.e., suction service), a wire helix with attached couplings is drawn onto the rough bore mandrel--this forms the bore of the hose. A sheet of specially compounded red rubber is cemented onto each coupling. A layer of rubber is then applied around the helix and additional reinforcement (e.g., spiral body metal wire) is wound around the tube for its entire length to provide additional strength and to resist kinking. The space between adjacent turns of metal wire is filled with rubber to permit more uniform adhesion of the first fabric ply. Additional layers of fabric plies (bias cut) are then added and, finally, the cover is similarly applied. Nylon cross-wrapping is performed on this hose prior to curing or vulcanizing.

Horizontal-Braided (typical use: hydraulic hoses). Extruded tubing is placed onto a mandrel, then a horizontal braiding machine braids reinforcement (textile or metal) onto the tube as a continuous sheath. The braid may then be coated with rubber cement, which aids the adhesion between this layer of reinforcement and the next layer of reinforcement to be applied. When the required number of reinforcing layers have been applied, a final coat of rubber cement is applied and then, if required, a cover is applied.

Horizontal-Loomed (typical uses: water/oil suction, tank truck, bulk station, tank car. While on a mandrel, the extruded tube is fed into a loom which weaves both wire and textiles onto the tube to create the reinforcement. Each wrap yarn is individually tensioned; this insures a tight and controlled weave. On the opposite side of the loom wrap yarns, both metals and textiles are woven circumferentially; this process provides extra rigidity. The hose is then coated with rubber cement and the cover is applied. The adhesive helps the fabric reinforcement adhere better to the cover and tube.

Horizontal-Spiraled (typical use: high pressure hose for hydraulic fluids). An extruded tube is installed onto a mandrel. A special fine mesh base fabric is spiraled around the tube under wire spiraled around the tube. All of the reinforcement wires are parallel to each other. One ply of wire runs in one direction; the next, in the opposite direction. Smaller hoses are encased in a lead sheath prior to vulcanizing. A press can be used to extrude soft lead around the hose carcass and mandrel. The leaded hose/mandrel combination is then placed into a curing oven. During vulcanization, the lead cover compresses the hose and helps bond the hose elements together. After vulcanization, the hose is removed from the oven and the lead sheath is stripped from the cured hose. Larger hoses are covered with a nylon cross-wrap before vulcanization and cured in the same manner as the smaller hoses. After vulcanization, the nylon cross-wrap is removed from the cured hoses.

Continuous Thermal Cure (typical use: low pressure applications). This hose production process is automated and operates continuously. The first step is the extrusion of the rubber tube to precise tolerances. Air is injected at low pressures to support the system during the remaining portions of the process. The tube is cooled to achieve sufficient rigidity to feed it through the rest of the process. Two spirals of cord (e.g., polyester) are applied by

winding around the tube. Each layer is wound in an opposite direction from the other-- this provides stability and reinforcement in the final hose. If additional layers of cord are to be applied, a layer of rubber is applied over the first two layers of cord before the next two layers of cord are applied. The rubber insulation is forced between the two layers of cord to bond directly to the tube. The hose receives its cover and then passes into the curing process. A bed of small diameter glass beads is heated by hot air passing upwards through the bed of beads; the hot air being admitted from the bottom of the bed. This process forms a fluidized bed into which the uncured hose is drawn. Length of cure time is regulated by speed to permit full curing of the hose.

#### 4.4.3 Input Materials

The following materials are required as inputs to the production of the various types of essential hoses:

- Rubber (for tubes)
  - Butyl rubber
  - Styrene butadiene rubber
  - Natural rubber
  - Ethylene propylene diene rubber
  - Nitrile rubber
  - Reclaimed rubber
- Reinforcements
  - Natural/synthetic yarns, fibers, cords, fabrics
    - Cotton, polyester, nylon, rayon, aramid
  - Metals
    - Stainless steel and brass plated wires and strips
  - Adhesives
    - Uncured rubber
    - Rubber cement
  - Cover stock
    - Fabric
      - Canvas
      - Synthetics
      - Rubber
      - Armored metals



- Couplings
  - Metallic
    - Steel
    - Brass
    - Aluminum
  - Plastic

#### 4.4.4 Utilities

The following utilities are predominantly utilized in the manufacture of hoses:

- Steam - Used in the vulcanization of the hoses.
- Water - Used in the boilers in the production of steam and for cooling mixers, mills, calenders, etc..
- Electricity - Used to drive the motorized production equipment.
- Fuel - Natural gas, fuel oil, or coal, required to feed the boilers for steam generation.
- Air - Used in hose production processes.

#### 4.4.5 Production Process Equipment

The following is a list of the major equipment used in the production of hoses:

Calenders  
 Mills  
 Extrusion machines  
 Mixers  
 Mandrels  
 Braiding machines (vertical and horizontal)  
 Spiral wrapping machines  
 Wrapping (roll) machine  
 Weaving machines (vertical and horizontal)  
 Vulcanizing sheath wrapping machines  
 Lead-stripping machines  
 Curing ovens and steam vulcanizers  
 Boilers (steam)  
 Instrumentation and Control (Automated and Manual)  
 Lead presses and lead extruders

#### 4.4.6 Bottlenecks in Post-War Production of Essential Hoses

The bottlenecks which would be critical to the post-war manufacture of hoses are identified in three different areas: utilities, process equipment, and materials.

#### 4.4.6.1 Utilities

- Steam - This is the most critical utility in hose production.
- Water - This utility is needed primarily for steam generation within the boilers. It is also used to hydrostatically test the completed hoses. Water is also required to extract flexible mandrels from vulcanized hoses.
- Electricity - Needed to drive the rotating equipment involved in hose production.
- Fuel - Fuel oil, natural gas or coal is needed to feed the boilers for steam generation. Also, it is needed to heat the lead furnaces when lead sheathing of hoses is utilized.
- Air - Used to make the insertion and extraction of hoses on rigid mandrels easier to accomplish by providing an air bearing between the hose and the mandrel. Process air is usually supplied by an on-site compressor system.

#### 4.4.6.2 Process Equipment

A listing of the basic hose manufacturing operations and the respective equipment and their vulnerabilities to collateral damage is presented in Table 4-3. Whether or not that equipment is a bottleneck in the overall production process is also noted. An attempt at determining reorder lead times of the various pieces of equipment for hose manufacturing is included in this table.

#### 4.4.6.3 Materials

The materials are grouped into the following categories for further consideration: rubber stocks (synthetic and natural), reinforcements, adhesives, cover stock, and couplings.

- Rubber Stock
  - Butyl rubber - Bottlenecks associated with production of butyl rubber for use in hose production are the same as those given in the "tire" section.
  - Styrene butadiene rubber - Bottlenecks associated with the production of styrene butadiene rubber for use in hose production are the same as those given in the "tire" section.
  - Natural rubber - Bottlenecks associated with production of natural rubber for use in hose production are the same as those given in the "tire" section.

Table 4-3. Selected Information About Hose Manufacturing Equipment (Page 1 of 2)

<u>Equipment</u>	<u>Vulnerability*</u>	<u>Bottle-neck</u> $\frac{Y}{N}$	<u>Reorder Leadtime</u> $\frac{(>6mos)}{(\leq 6mos)}$ (?)
Calenders	hard	x	x
Mills	hard	x	x
Extrusion machines	hard	x	x
Mixers	hard	x	x
Mandrels	soft	x	x
Braiding machines (vertical & horizontal)	soft	x	x
Spiral wrapping machines	soft	x	x
Wrapping (roll) machines	soft	x	x
Weaving machines (vertical & horizontal)	soft	x	x
Vulcanizing-sheath wrapping machines	soft	x	x
Lead-extruding machines	soft	x	x



Table 4-3. Selected Information About Hose Manufacturing Equipment (Page 2 of 2)

<u>Equipment</u>	<u>Vulnerability*</u>	<u>Bottle-neck</u> $\frac{V}{Y \cdot N}$	Reorder Leadtime ( $>6mos$ ) ( $\leq 6mos$ ) (?)
Vulcanizing-sheath removal machines	soft	x	x
Lead-stripping machines	soft	x	x
Curing ovens and steam vulcanizers	hard	x	x
Boilers (steam)	soft	x	x
Instrumentation/controls (automatic & manual)	soft	x	x
Fuel stock (natural gas, fuel oil, etc.)	soft	x	x

\*Vulnerability is designated as hard if the basic equipment is expected to survive the collapse of the building, or soft if the equipment is not expected to survive.



- Ethylene propylene diene rubber - Critical material inputs are ethylene and propylene, both of which are derived from the petroleum industry.
- Acrylonitrile rubber - Acrylonitrile rubber has two monomer inputs: butadiene and acrylonitrile. Butadiene has been examined earlier. Acrylonitrile is itself produced from petrochemicals; specifically, propylene.
- Reclaimed rubber - Five commercial processes are presently used to reclaim rubber. They are:
  - (1) Heater or Pan Process
  - (2) Dry Digester Process
  - (3) Wet Digester Process
  - (4) Reclamator Process
  - (5) Banbury Process

The major bottleneck is that there are only three rubber reclaimers operational in the U.S. today. Older reclaimers have gone out of business and dismantled their operations. The present reclaimers could not meet the total demand for reclaimed rubber, if reclaim is used well above and beyond its present demand. Production schedules for setting up reclaiming facilities for rubber would have about a two to three year lead time before operations could begin.

Hoses for water handling can be made from ordinary reclaim and a small percentage of natural rubber. Hoses for handling oil based fluids can also be made from reclaim, but the reclaim must be from oil-resistant rubber (which may not be available). A small percentage of natural rubber is also required as a binder.

#### 4.4.6.4 Personnel

Only the equipment repairmen have skills essential to the production of hoses.

#### 4.4.7 Vulnerabilities and Potential Solutions

Two facilities involved with hose manufacturing were visited and examined on a first-hand basis to determine vulnerabilities and ways in which those facilities could be hardened. The facilities visited were the B. F. Goodrich Hose Plant in Akron, Ohio, and the B. F. Goodrich Hose Plant in Marion, Ohio.

Fire-induced damage: Rubber stock, finished hoses, and other flammables (e.g., fuels and solvents) would be easily ignited by sparks created by collapse of the building.

Examples of pressure-induced damage to critical equipment for hose manufacturing (approximate levels)

- The building housing hose production equipment would be destroyed at 2-5 psi overpressure or  $\frac{1}{2}$ -1 dynamic pressure. Portions of this structure would become flying debris, causing extensive damage to the hose production equipment contained within the building. Multi-story buildings would cause further damage as the upper levels collapse into the lower ones and drop equipment and debris onto equipment on lower levels. The following would be extensively damaged or destroyed by flying debris generated by collapse of the building:
  - Hose molding, building, weaving, braiding, wrapping, and sheathing (lead and fabric) equipment. Also the creels and bobbins supplying wire and fabric to these machines.
  - Mandrels, both rigid and flexible.
  - Controls and instrumentation.
  - Boilers.
  - Pressure and proof testing equipment.
- The curing ovens for the hoses are relatively hard. They would be destroyed at 10-15 psi dynamic pressure (24-30 psi overpressure). However, debris from the collapse of the building may damage the instrumentation and controls associated with the ovens.

Hardening Recommendations - The hardening recommendations noted below will produce results similar to those noted for tire production.

- Incorporate building supports to strengthen against pressure effects.
- Move and tie materials-handling cranes to the ends of the building to minimize damage if those cranes should fall.
- Transport all flammables (e.g., fuels, finished hoses, rubber stocks, solvents) off-site or bury on-site to minimize fire hazards.
- Build sandbag and cribbing enclosures around the hose production equipment to protect it from damage caused by debris from collapse of the building. Especially protect the controls and instrumentation of the production equipment.

- Wrap and store certain critical items (i.e., selection of mandrels, critical instrumentation or controls) within curing ovens.
- Turn off electric and gas utilities outside the premises of the hose production facility. Sprinkler systems should be left operational.
- Disconnect all wires and cords from creels and bobbins to the hose weaving, braiding, and sheathing equipment to reduce the potential for damage caused by debris falling onto the wires and cords, thus stressing rotary weaving and sheathing heads.
- Evacuate drawings and specifications with evacuating personnel for use in repair activities.

#### 4.5 ESSENTIAL BELTS

##### 4.5.1 Production Processes for Essential Belts

There are two categories of belting required in the post-war environment: conveyor belting and power transmission belting. Conveyor belting is divided into two categories: heavy belting and lightweight belting. Heavy belting is primarily used in three applications: steel service (35-40%), coal service (25-30%), and agricultural service (30-40%). Power transmission belting primarily consists of V-belting used in automotive (40%) and non-automotive (60%) applications. The major constituents of belting are:

- Carcass - The carcass provides the substrate for supporting the loads to be conveyed. The carcass itself consists of plies or fabric (metallic or non-metallic) covered with rubber. Load-bearing cords of various materials (e.g., polyester, rayon, nylon, aramid, fiberglass, steel) are also incorporated into the carcass, as needed. For severe impact service, breakers or impact layers are added to the carcass.
- Protective covers - Protective covers of rubber are applied on both sides of the carcass to contain the carcass and protect it from the external environment.
- Fasteners - Fasteners are provided on the belting to form it in a continuous loop for use in the field. If fasteners are not provided, the belt ends may be vulcanized together to form the desired continuous loop.

Below are generalized descriptions of the manufacturing processes for the various types of belts described earlier.

Flat belting (conveyor and power transmission). The rubber for this belting is mixed and processed into sheets into which the appropriate cords are imbedded to form the carcass of the belt. Additional plies or layers are added as necessary. A cover is applied onto one side of the carcass and the other cover is applied on the remaining side of the carcass. This unit is then exposed to sufficient heat and pressure to cure the cover/carcass combination to form the completed belt.

V-belting. The rubber for the belting is mixed and prepared to accept the cords required for reinforcement. A cover is applied to the finished carcass, if required, and the whole assembly is then cured in ovens to vulcanize the final belt.

#### 4.5.2 Input Materials

The following materials are required as inputs to the production of the types of belts described earlier:

- Rubbers
  - Styrene butadiene rubber
  - Natural rubber
  - Neoprene
  - Isoprene
  - Butyl rubber
  - Acrylonitrile butadiene rubber
  - Reclaimed rubber
- Cords and fabrics
  - Polyester
  - Rayon
  - Nylon
  - Aramid
  - Fiberglass
  - Steel
- Fasteners
  - Metal

#### 4.5.3 Utilities

- Steam - Used in the vulcanization of hoses.
- Water - Used in the production of steam required for vulcanizing.

- Electricity - Used to drive the rotating equipment used in belt production.
- Fuel - Natural gas, fuel oil, or coal required to feed the boilers for steam generation.

#### 4.5.4 Production Process Equipment

The following is a list of the equipment required to manufacture belts described earlier.

Building machines  
 Wrapping machines  
 Unwrapping machines  
 Cutting, skiving, and trimming machines  
 Matching and measuring machines  
 Curing presses

- batch process
- continuous process

Wire creel  
 Mixer  
 Mill  
 Calender

#### 4.5.5 Bottlenecks in Post-War Production of Essential Belts

The bottlenecks which would be critical to the post-war manufacture of belts are identified in four different divisions: utilities, process equipment, materials, and personnel.

##### 4.5.5.1 Utilities

- Steam - This is the most critical utility in belt manufacture. Without it, no vulcanization of the uncured ("green") belts can be obtained.
- Water - Required for steam production.
- Electricity - Used to drive heavy rotating equipment (take-up rolls for conveyor belting, etc.). Without it, many of the automatic operations (continuous belt building, for example) would be severely affected.

##### 4.5.5.2 Process Equipment

A listing of the basic belt manufacturing operations and the respective equipment and their vulnerabilities to collateral damage are presented in Table 4-4. Whether or not that equipment is a bottleneck in the overall production

Table 4-4. Selected Information About Belt Manufacturing Equipment

<u>Equipment</u>	<u>Vulnerability*</u>	<u>Bottle-neck</u> Y N ?	<u>Reorder Leadtime</u> (>6mos) (<6mos) (?)
Building machines	soft	x	x
Wrapping machines	soft	x	x
Unwrapping machines	soft	x	x
Cutting, Skiving, & Trimming machines	soft	x	x
Matching & Measuring machines	soft	x	x
Curing presses - batch process	hard	x	x
- continuous process	soft	x	x
Wire creel	soft	x	x
Mixer	hard	x	x
Mill	hard	x	x
Calender	hard	x	x
Grommet winder	soft	x	x

\*Vulnerability is designated as hard if the basic equipment is expected to survive the collapse of the building, or soft if the equipment is not expected to survive.



process is also noted. An attempt at determining reorder lead times of various pieces of equipment of belt manufacturing is also included in this table.

#### 4.5.5.3 Materials

- Styrene butadiene rubber - Bottlenecks associated with production of styrene butadiene rubber are the same as those given in the "tire" section.
- Natural rubber - Bottlenecks associated with the production of natural rubber are the same as those listed in the "tire" section.
- Butyl rubber - Bottlenecks associated with the production of butyl rubber are the same as those listed in the "tire" section.
- Acrylonitrile butadiene rubber - Bottlenecks associated with the production of acrylonitrile rubber are the same as those in the "hoses" section.
- Neoprene - Butadiene is essential to the production of neoprene. Butadiene is obtained from petroleum or natural gas.
- Isoprene - Depending on the process under consideration, either petroleum or natural gas products are needed as input items in the production of isoprene. The only deviation from this is the process involving pine trees. Although the "pine tree" approach is technically feasible, it is not known how practical this process is in generating adequate amounts of isoprene for demand.

#### 4.5.5.4 Personnel

Only the equipment repairmen have skills essential to the production of belts.

#### 4.5.6 Vulnerabilities and Potential Solutions

The B. F. Goodrich Belting Plant in Akron, Ohio, was visited to aid in determining vulnerability levels and hardening potentials.

An example of fire-induced damage is: rubber stock, finished belting, and other flammables (e.g., fuels, solvents, cloth liners used between layers of belting) would be easily ignited by sparks created by collapse of the building.

##### Pressure-induced damage to critical equipment:

- Large batch process belt curing presses would be destroyed at 30-40 psi overpressure.
- Large belt take-up and supply reels would be destroyed at 30-40 psi overpressure.

- The building housing the belt production would be destroyed at 2-5 psi overpressure or  $\frac{1}{2}$ -1 psi dynamic pressure. Portions of this structure would be converted into flying debris which would cause extensive damage to the belt production equipment housed inside. For a multi-story building, the upper levels would collapse into the lower ones and cause even greater damage, both to equipment falling from the upper levels and to equipment on ground level having debris and other equipment falling onto it.
  - Carcass building equipment.
  - Belt wrapping and unwrapping equipment.
  - Belt cutting, skiving, and trimming equipment.
  - Wire creels supplying the reinforcing cords for carcass fabrication.
  - Roller die.
  - Controls and gauges on the large, three-stage belt curing press.
  - Automated continuous-curing belt presses for small belts.
  - Piping (e.g., steam, water lines).
  - Conveyors delivering materials to the continuous-belt curing presses.
  - Process instrumentation and controls.
  - Small belting take-up and supply reels.
  - Boilers.

#### Hardening Recommendations

- Incorporate diagonal cross-bracing between building supports to strengthen the building against the effects of pressure.
- Move and tie overhead cranes to the ends of the building to strengthen the building and to minimize damage if the cranes should fall.
- Transport all flammables (e.g., fuels, finished belting, raw materials, solvents) off-site or bury on-site to minimize fire hazards.
- Build sandbag and cribbing enclosures around the production equipment to protect it from debris caused by collapse of the building. Especially protect the instrumentation and controls associated with each piece of production equipment.

- Build earthen berms around or bury outside storage tanks of solvents to contain spills and reduce the probability of fire.
- Turn off electric and gas utilities outside the production premises to minimize fire hazards. Sprinkler systems should be left operational.
- Leave the belt curing presses in the "closed" position to protect mating surfaces.
- Evacuate all portable tools and repair equipment (e.g., oxyacetylene welders, machine shop tools) with evacuating personnel for later return and use in repair work performed on the facility.
- Build sandbag and cribbing enclosures around machine shop equipment.
- Evacuate drawings and specifications with evacuating personnel for use in repair activities.

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