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NATIONAL DEFENSE STOCKPILE PROGRAM
PHASE I: DEVELOPMENT AND ANALYSES

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March 1990

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PREFACE

Since June 1988, the Institute for Defense Analyses (IDA) has been assisting the Department of Defense in developing a systematic process to estimate U.S. stockpile requirements for strategic and critical materials. This report documents the work the IDA team has accomplished during Phase I of this effort, describes the principal results and uses of the analyses, and defines the scope of IDA's current initiatives and proposed efforts to strengthen this process in the coming year.

This paper was prepared in partial fulfillment of IDA Task Order T-B6-656, National Defense Stockpile Analyses, for the Office of the Under Secretary of Defense for Acquisition (OUSD(A)), under Contract MDA 903 89 C 0003.

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I. INTRODUCTION

A. BACKGROUND

In peacetime, the United States does a large volume of trade with the rest of the world. From this commerce, which includes an appreciable volume of imports, the country reaps considerable benefit. There is little question that, in general, the nation does well to focus on exploiting its own comparative advantage, relying on imports to provide goods and services our trading partners can supply at lower costs than domestic sources.

In a major national security emergency, however, demands for many defense-related items would increase rapidly and dramatically from peacetime levels. Moreover, ordinary patterns of international trade would be put at serious risk. In those cases where the United States in peacetime relies heavily upon foreign sources of supply for materials and components of major weapons systems, the adequacy of wartime sources of supply to meet greatly expanded emergency levels of demand needs careful, frequent review.

Ultimately, the basic emergency planning problem is more complex than simply providing insurance against disruptions of peacetime levels of critical imports. In some cases, the United States may obtain little or none of a vital defense good from abroad under ordinary circumstances, yet U.S. domestic suppliers may be unable to expand production quickly enough to keep pace with defense-related demands in a major national emergency. In other cases, reliable foreign sources may be fully able to accommodate U.S. emergency demands. The situation almost certainly depends on the specific goods or materials in question. Accordingly, proper emergency planning requires detailed, case-by-case assessments of the items of concern. Yet it also requires flexibility--to avoid the all-too-common trap of misplaced precision. Actual emergencies inevitably differ from planning cases. The challenge is to establish reasonable benchmarks, not hard-wired allocation plans for every last resource that might be available.

B. STRATEGIC AND CRITICAL MATERIALS

One class of defense-related items that has been of particular concern to the Congress in national emergency planning for many years is that of the strategic and critical

materials (SCMs). No fixed, universally acceptable definition of SCM exists; for purposes of a national stockpile, U.S. law (PL 96-41) defines these materials as follows:

The term "strategic and critical materials" means materials that (a) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency and (b) are not found or produced in sufficient quantities to meet such a need. The term "national emergency" means a declaration of emergency with respect to the national defense made by the President or by the Congress.

For present purposes, critical materials are considered to be those essential in a national emergency, strategic materials as those in potentially short supply from regular domestic sources. SCMs, then, are viewed as materials that are necessary in a national emergency and are not likely to be produced domestically at levels sufficient to meet essential U.S. demands.

Some stocks of these materials have been maintained by the U.S. government since World War II, and goals for SCMs have been subject to periodic review. Over the last several years, Congress has expressed new interest in having the goals for these materials assessed regularly, with strong continuous supervision by the Department of Defense (DoD).

C. DEPARTMENT OF DEFENSE MANAGEMENT OF THE NATIONAL DEFENSE STOCKPILE

Late in 1987, through the National Defense Authorization Act for Fiscal Years 1988 and 1989 (Public Law 100-180), Congress established a new requirement for an annual report from the Secretary of Defense concerning U.S. needs for SCMs in the context of a three-year, global, conventional war scenario. Then, in February 1988, in response to the new laws governing the stockpile, the President designated the Secretary of Defense as the National Defense Stockpile (NDS) Manager.

In June 1988, the Under Secretary of Defense for Acquisition (USD(A)) asked the Chairman of the Joint Chiefs of Staff (JCS) to provide SCM requirements associated with the congressionally mandated scenario. The JCS approached the Institute for Defense Analyses (IDA) and asked for assistance. Initial discussions indicated that considerable methodological development, data gathering, and extensive cooperation among military and civil agencies would be required. The JCS advised the USD(A) that such an analysis could be produced by December 1988, but only by adapting existing data bases and analytical programs to the scenario parameters specified in the legislation.

D. IDA'S ROLE

Between June and December 1988, IDA designed and implemented the basic stockpile planning process that the JCS used to provide initial estimates and documentation of its effort to USD(A) in December 1988 [1].

USD(A) then requested additional assistance in preparing final estimates for submission to Congress. A variety of efforts were undertaken for DoD in building the final estimates and methodological appendices. This work is documented in the *Secretary of Defense's Report to the Congress on National Defense Stockpile Requirements, 1989* [2].

The Subcommittee on Seapower and Strategic and Critical Materials of the House Armed Services Committee (HASC) conducted public hearings on the report in April 1989. The chairman of the subcommittee, Representative Charles Bennett (Fla.), responded favorably to the effort (HASC News Release, April 20, 1989):

This report marks a great breakthrough after decades of struggle to get the executive and legislative branches pulling together on the National Defense Stockpiles. Things are moving in exactly the direction that Congress intended when it recently amended the Strategic and Critical Materials Stockpiling Act.

From April 1989 to the present, the study efforts have focused on designing and conducting a variety of sensitivity analyses (excursions from the Office of the Secretary of Defense (OSD) Base Case presented to Congress), documenting the process and the modules that have been developed for DoD in this effort, structuring procedures to institutionalize the data and planning factor development elements of the process, and initiating research in several key related areas to assist DoD in refining NDS requirements estimates for future recommendations to the Congress.

E. SCOPE OF THIS REPORT

This report documents the work accomplished in this area thus far, describes the principal results and uses of the analyses, and defines the scope of IDA's current and proposed efforts to strengthen this process in the coming year.

Chapter II describes the basic estimation process that has been developed for NDS goals. Chapter III presents the initial applications and analyses that DoD requested in FY 1989 using this process. Chapter IV summarizes more than a dozen tests that probe the effects of changing some of the principal planning assumptions in DoD's 1989 Base Case. Chapter V documents assessments of the appropriateness of establishing NDS goals for

specific high-technology, advanced materials. Chapter VI provides an overview of a number of additional NDS-related initiatives that IDA recommended and assisted DoD in implementing during FY 1989. Chapter VII summarizes *IDA's principal observations and recommendations* at the conclusion of the first phase of the development effort. Finally, several appendices offer more detailed documentation concerning components of the process, results of specific assessments to date, and suggested conceptual approaches to methodological issues yet to be addressed.

II. A STRATEGIC AND CRITICAL MATERIAL REQUIREMENTS ESTIMATION PROCESS

A. INTRODUCTION

This chapter describes the basic estimation process that has been developed to assist the DoD in calculating U.S. stockpiling requirements for strategic and critical materials.

B. THE ESTIMATION PROCESS

The process has three principal steps:

- 1) Estimating the U.S. demands for new production of military weapon systems in the context of the scenario;
- 2) Deriving the quantities of strategic and critical materials needed as inputs to the new production of these systems as well as of civilian sector wartime needs (including the quantities of such materials needed to construct any new production facilities for this effort); and
- 3) Comparing these requirements with estimated U.S. and foreign production of these materials judged likely to be available to the United States during the scenario.

Strategic and critical materials for which shortfalls are identified in this process are assumed to be strong candidates for inclusion in the national defense stockpile, in quantities as estimated by the demand/supply comparisons in the third step of the process.

The primary focus of this process is the military requirement for strategic and critical materials in the emergency planning scenario. However, the United States would also have needs for these materials as inputs to the production of goods and services to supply essential civilian (non-DoD) functions during the emergency. While the magnitude and timing of these demands are subject to considerable uncertainty and controversy, they cannot be ignored. Accordingly, the estimation process developed here permits the DoD to take explicit account of a set of civilian demand planning factors for strategic and critical materials in the overall calculations.

Each major step in this process contains a number of internal elements. The remainder of this chapter provides an overview of each. More detailed aspects of the process are included in subsequent parts of the report, along with results of the actual estimation process.

Figure II-1 offers a diagram of the overall process. In this scheme, key scenario planning factors are shown as inputs to the Joint Industrial Mobilization Planning Process (JIMPP) Requirements Module, which is used to generate estimates of U.S. demands for new production of weapon systems [3]. This portion represents Step 1 of the three-step process outlined in preceding paragraphs.

Outputs from the Requirements Module, along with estimates of civilian demand planning factors, are then fed to the JIMPP Macro Module [4], which is used in conjunction with Material Consumption Ratios (MCRs) to prepare estimates of U.S. military and civilian demands for strategic and critical materials in each year of the emergency planning scenario [5]. This part of the procedure represents Step 2 of the process.

The bottom half of Figure II-1 depicts the final step. During this phase, U.S. scenario demands for strategic and critical materials are explicitly compared, material by material, with projected U.S. and foreign emergency production of these materials likely to be available to the United States in the particular planning case. For this step, IDA has developed a Stockpile Sizing Module capable of incorporating a variety of demand and supply data bases as well as a number of planning factors needed to prepare systematic comparisons and to estimate any resultant materials shortfalls for each year of the planning scenario [6].

1. Step 1: Estimating New Weapon System Production Requirements

The JIMPP Requirements Module is used to estimate the total U.S. demands for military weapon systems and sustainability items required during the scenario and to compare them with projected D-day inventories. (Appendix A provides a non-technical description of the Requirements Module.) The result is a profile of the quantities of systems and support items needed during each year of the scenario that exceed projected D-day inventories. These requirements for new systems are then assumed to represent U.S. demands for military production in the scenario.

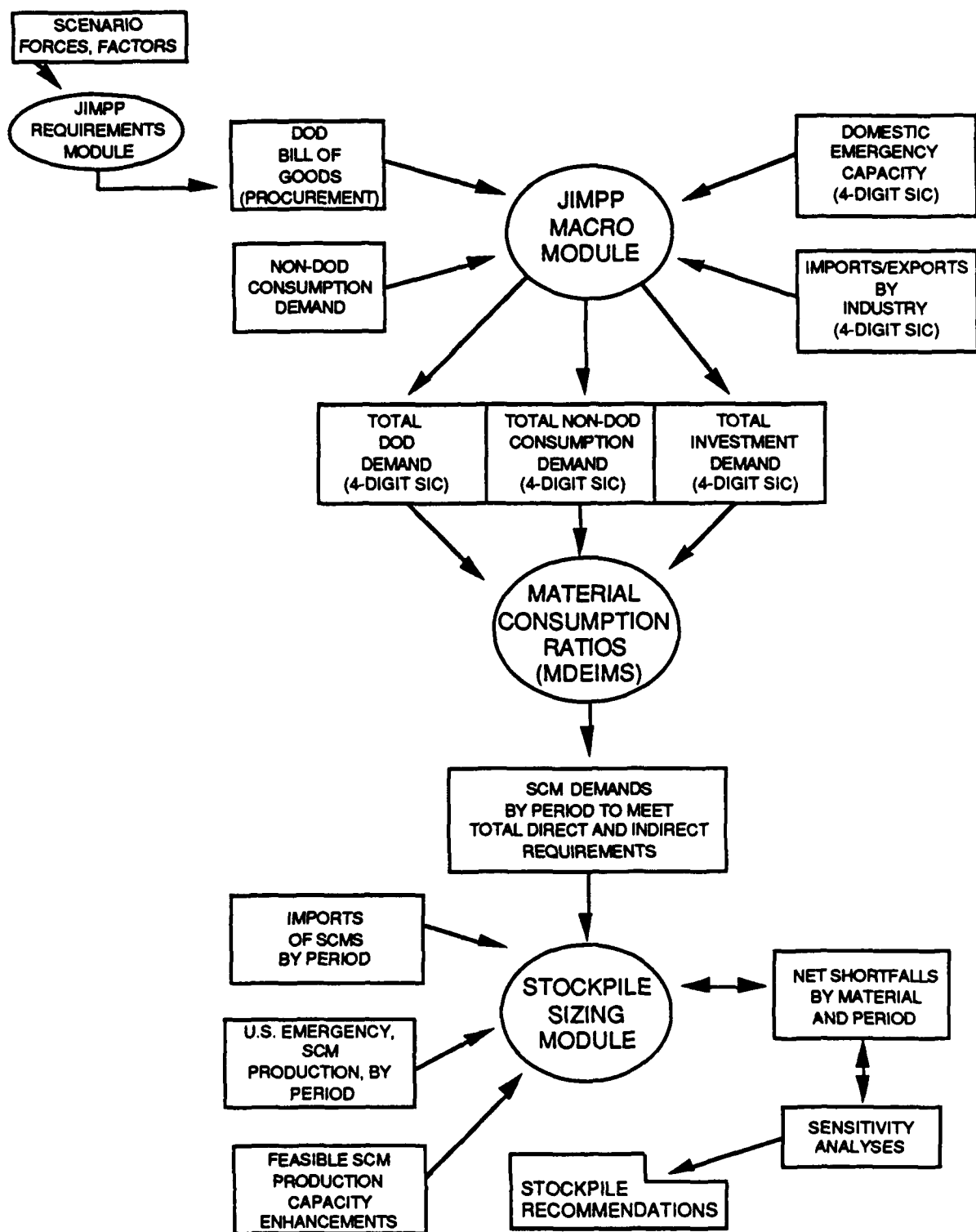


Figure II-1. Stockpile Sizing Process

To estimate the total U.S. requirements for weapon systems and support items in the scenario, the Requirements Module works as follows. For each month of the battle, the forces needed by each Service are specified. The module currently permits the user to play up to 13 types of Army battalion equivalents, 32 types of Air Force aircraft squadrons, notional carrier battle groups (and associated land-based assets), and Marine Corps expeditionary forces in up to four separate theaters in the simulation.

Based on the force deployments for the simulation and data bases that specify the weapon systems and equipment each type of force unit requires for full readiness, the module calculates the total set of military assets needed by the force as each unit first enters the conflict.

For each type of force unit involved, the user may also specify the weapon-system attrition and consumable usage rates likely to prevail in the conflict, by system, month and theater. Finally, the user selects the attrition replacement schedule he desires to employ in the particular simulation.

Using these scenario planning factors and data bases, the Requirements Module then calculates the total monthly requirements for specific weapon systems for each theater and across all theaters.

The final element in the first step is to estimate projected D-day inventories of these specific weapon systems (under business-as-usual, peacetime assumptions) and compare them with the total monthly requirements for the scenario. D-day inventories are estimated using two principal data bases: an initial inventory count (as of January 1987) combined with actual and projected peacetime weapon system procurement data up to the month specified as D-day in the scenario. (The module also provides the user with a basic capability to specify peacetime consumption and retirement profiles for major items during the pre-D-day period.)

2. Step 2: Estimating Strategic and Critical Material Requirements for the Planning Scenario

The second major step is to determine the quantities of strategic and critical materials needed to support the new military production as well as any essential civilian (non-DoD) demands for these materials in the planning case. The basic analytic mechanism used here is the JIMPP Macro Module in conjunction with the MDEIMS data base. (See Appendices B and C.)

Key elements within this step may be summarized as follows.

- First, using a mechanism known as the Defense Translator [7], the Macro Module converts the dollar value of procurement costs for new weapon systems (from the Requirements Module) into a set of month-by-month final direct demands upon each of 236 U.S. industries (at the four-digit Standard Industrial Classification (SIC) level).
- Second, these final demands are converted into a set of total (direct plus intermediate good) demands on these same 236 U.S. industries through a time-phased Input/Output (I/O) matrix that has the same basic structure as its predecessor version [8].
- Third, total monthly non-DoD (civil sector) demands on industry that are assumed for the scenario are accepted as an input to the Macro Module.
- Fourth, the resultant total demands are compared, industry by industry and month by month, with the total industrial supply estimated to be available from existing U.S. industrial emergency capability and imports.
- Fifth, if industrial capacity fails to meet the industrial output demands of the scenario at this stage, the Macro Module then estimates the feasibility, timing, and costs associated with the construction of new facilities required to resolve the shortfall. (This estimation process is iterative within the Module: initial investments to construct new facilities create new demands on industries throughout the economy, which may in turn create new shortfalls, and necessitate new rounds of investment to fully resolve all shortfalls.)
- Sixth, for each of the three principal components of U.S. industrial output requirements for the scenario identified through the process described in the preceding bullets (direct military, investment, and non-DoD demand), the MDEIMS Material Consumption Ratio data base is employed to estimate the strategic and critical material inputs needed by period in the scenario to achieve this overall U.S. industrial output. Essentially, the MDEIMS data base represents a set of recent estimates of the quantities of each of 57 high-priority strategic and critical materials required by industry to produce a given amount of output. MDEIMS is an invaluable component of this overall process; it is the only comprehensive profile of its kind.

The result of this second major step is an estimate of the total direct military, non-DoD, and industrial investment requirements each year for 57 strategic and critical materials, aggregated across all U.S. industries needing them as inputs to their respective production processes.

3. Step 3: Strategic and Critical Material Demand/Supply Comparisons

The final step in this process involves comparing strategic and critical material demands with projected U.S. and foreign production of these materials judged likely to be available to the United States during the scenario period.

For this step, estimates of the U.S. and foreign production capabilities for the strategic and critical materials of interest were requested from and provided by the U.S. Bureau of Mines (Department of Interior) [9].

The United States will not be able to rely on unrestricted access to foreign production capability of these materials during the emergency. Several major types of constraints will apply, including

- War damage of the production capability of some other countries;
- Unwillingness/incapability of some producers to supply the United States;
- Competing demands the United States could encounter in attempting to buy much-larger-than-normal shares of even friendly foreign production (such as producer countries' own domestic demands for these materials or allies' demands for them in their own attempts to improve their military postures); and
- The potential losses of materials en route to the United States due to enemy action.

To permit systematic and explicit recognition of these constraints on foreign supply estimates, the Stockpile Sizing Module permits DoD to apply assessments of political reliability, war damage, foreign demands, and shipping losses in developing material-by-material demand/supply comparisons for the scenario of interest. (Appendix D offers a detailed description of the module logic.)

C. DISCUSSION

The three-step NDS goal estimation process outlined here provides DoD with a basic capability to develop systematic assessments of strategic and critical material shortfalls in a specified scenario. This process provides estimates that are only as valid as the underlying data bases and planning factors that are used to prepare any particular set of NDS estimates. Nevertheless, the process itself is systematic and coherent, and the objective in this effort has been to design a decision-making aid for DoD that can be used to draw upon the best available data and planning factors to prepare estimates of what the nation is projected to need to supplement likely sources of supplies of strategic and critical

materials in a major conflict scenario. Chapter III describes the initial applications and analyses that DoD has requested that IDA undertake in the development of this process.

III. INITIAL ASSESSMENTS

A. INTRODUCTION

This chapter describes IDA's initial assessments of NDS requirements for strategic and critical materials, based on the methodology outlined in Chapter II. Two initial assessments were conducted. The first was prepared for the JCS based on a full mobilization scenario and delivered in December 1988. A detailed, classified description of the results is provided in IDA Memorandum M-551 [1]. The second was conducted directly for the Office of the Assistant Secretary of Defense (OASD) (Production and Logistics (P&L)) and was based on the congressionally-required total mobilization scenario. The results of that analysis were used and are documented in the *Secretary of Defense's Report to the Congress on National Defense Stockpile Requirements, 1989* [2].

B. STOCKPILE ANALYSIS FOR THE JOINT CHIEFS OF STAFF

The JCS first developed a scenario consistent with the congressional requirement for a stockpile planning scenario of at least three years duration. However, it was based on a full mobilization force structure rather than the congressionally-mandated total mobilization force structure. IDA then assisted the JCS in developing the operational planning factors suitable for use in the full mobilization analysis. Stockpile requirements estimates were then developed based upon these planning factors, the underlying SCM supply data from the Bureau of Mines and the methods outlined in Chapter II.

C. 1989 SECRETARY OF DEFENSE REPORT TO THE CONGRESS (BASE CASE)

The OASD(P&L)(Strategic and Critical Defense Materials (S&CDM)) then asked IDA to make several adjustments in the basic structure of the JCS stockpile scenario, some of which were necessary to bring it into conformity with statutory requirements. OASD (P&L) also requested that IDA use the methodology described in Chapter II to construct a Base Case set of estimates which served as the basis for determining NDS requirements presented to the Congress in February 1989. This section provides an overview of those

estimates, including a brief description of the key planning factor values agreed on for this Base Case.

The report which the Secretary of Defense forwarded to Congress also contained the dollar value of requirements for four advanced materials and 20 other "non-model" materials which were not appropriate for quantitative analysis. In addition, OSD did not recommend changes in goals unless the new estimates differed by more than 10 percent of the pre-existing official goals. Therefore, the dollar value of requirements for the IDA Base Case reported in this paper and the Secretary of Defense report are not the same.

Of the 49 strategic and critical materials examined in this assessment, the 1989 Base Case analysis identified a total of 22 materials for which reliable sources of production were unlikely to be sufficient to meet U.S. demands in this emergency scenario. At current market prices, the estimated dollar value of these shortfalls is approximately \$4.294B. Materials displaying the largest shortfalls (in dollar value) among these include titanium, chromium, bauxite, tantalum and cobalt. Shortfalls in these five material groups together constitute about 80 percent (\$3,376M) of the total estimated in the Base Case. Table III-1 provides a material-by-material profile of these shortfall estimates.

Table III-1. 1989 Base Case Shortfalls*
(\$ Millions)

MATERIAL	SHORTFALL			
	TOTAL	SECTOR		
		DEFENSE	INDUSTRIAL	CIVILIAN
Antimony	207	190	2	15
Bauxite	475	474	1	0
Beryl	7	2	1	4
Chromium Group	634	487	47	100
Cobalt	360	348	12	0
Columbium	50	47	3	0
Germanium	46	45	1	0
Graphite	9	3	6	0
Mercury	12	0	0	12
Mica	3	3	0	0
Platinum Group	234	85	144	5
Quartz	1	0	0	1
Tantalum	405	279	8	118
Tin	33	18	15	0
Titanium	1,502	1,496	6	0
Tungsten	316	238	28	50
TOTALS	4,294	3,715	273	306

* Slight differences are due to rounding.

These estimates are based on systematic, year-by-year comparisons of demands posed by the defense and civilian sectors of the U.S. emergency economy in this scenario

with anticipated supplies of these materials from U.S. and reliable foreign producers. Two fundamental principles underlie the calculations. First, defense (and investment) demands can only be met by supplies from producers deemed exceptionally reliable (i.e., assured), whereas civilian demands may be met by any remaining assured supplies (after defense-related demands are satisfied) as well as by likely available production from foreign suppliers in the scenario considered (merely) reliable. Second, production can only be used to meet demands if it occurs on a timely basis. In short, "later" production cannot be used to offset "earlier" demands in the emergency. Earlier production is, however, assumed available to offset subsequent demands.

The principal planning factor assumptions underlying these Base Case estimates are depicted in Figure III-1. Eleven major categories are highlighted. Assumptions in each category were proposed and then negotiated in detail with relevant DoD and civil agency officials in building the Base Case for the Secretary's 1989 report to Congress.

PLANNING FACTOR	PRINCIPAL ASSUMPTIONS
Nature of Emergency	Major conventional conflict with the Soviet Union and its allies beginning in late 1989
Duration and Warning	One year warning; three-month initial conflict followed by three-year emergency build-up
Intensity of Conflict	Intense, multi-theater conflict followed by stalemate and major force rebuilding effort
U.S. Force-Building Targets	Replace losses from initial conflict and expand to planning force levels, including six months of sustainability
Support of Allied Force-Building Goals	General support but no explicit U.S. production to rebuild allied losses
Civil Sector Demands	Consumer durables, residential investment and general non-residential investment decrement based on consensus among civil agencies (See Appendix E)
War Damage	Classified; See [1]
Trade Conditions (General)	Exports reduced across-the-board 50%; imports reduced an average of 30% due to war damage, shipping losses and reliability
Shipping Losses	Classified; See [1]
Strategic and Critical Material Supply Availability	Assured suppliers: Canada, Mexico (and U.S.) (existing facilities only) Reliable foreign suppliers: Classified; See [1] (existing facilities only)
General U.S. Production Conditions <ul style="list-style-type: none"> • Production Process Times • Shifts • Time to Build New Plants • Time to Hire and Train New Workers 	75% of Peacetime 3-8-5 (3 eight-hour shifts, 5 days/week) 12-month average 3-month average

Figure III-1. 1989 Secretary of Defense Report, Base Case Assumptions

D. DISCUSSION

A key advantage of the strategic and critical materials planning process developed thus far for DoD is its flexibility. It is now feasible to examine the sensitivity of NDS requirements estimates to changes in the values of many of the planning factors outlined in Figure III-1. Carefully structured sensitivity analyses will permit the DoD and the Congress to gain far clearer insight into the major determinants of any specific Base Case NDS estimates. Toward this end, Chapter IV presents the results of a range of such sensitivity analyses IDA has conducted this year for the DoD.

IV. SENSITIVITY ANALYSES

A. INTRODUCTION

Previous analyses have suggested that NDS requirements may be significantly affected by the specific planning assumptions underlying such estimates. This chapter describes the results of a range of assessments IDA has conducted to probe the sensitivity of the FY 1989 Base Case estimates (presented in Chapter III) to major modifications in some of the principal planning assumptions depicted in Figure III-1.

B. APPROACH

Fifteen separate sensitivity cases have been explored. They fall into three broad categories: Type I, in which the effects of more robust demand-side assumptions, weaker supply-side assumptions, or combinations of stronger demand and weaker supply-side assumptions were assessed (nine cases); Type II, in which the effects of weaker demands, stronger supplies, or combinations of weaker demand and stronger supply assumptions were tested (five cases); Type III, a historical comparison (one case).

The specific excursions from the Base Case assumptions are described in summary form in Table IV-1.¹ (Table IV-1 presents the results of Cases 2 through 16; the specific structure of Case 1--an oil supply disruption excursion--is still being developed within DoD.)

¹ The differences between the Base Case and each excursion are generally depicted in Table IV-1. In several cases, however, additional information will be of interest to some readers. See Appendix F for a more detailed discussion of the tier-by-tier composition of the estimated shortfalls. Also see [10] for the tier-by-tier, material-by-material shortfalls estimated for each of these excursions.

Table IV-1. Excursions From 1989 Base Case Assumptions

Case No.	Difference(s) from the Base Case	Shortfall (\$M)	Percent of Base Case Shortfall
	Base Case	4,294	100
	Type I: Larger Demand/Smaller Supply		
2.	25% Greater Military Production Requirement	8,475	197
4.	Double the Shipping Losses	4,949	115
7.	One More Country Assumed Unreliable	6,220	145
8.	Less Civilian Austerity	5,379	125
9.	No Civilian Austerity	14,507	338
10.	Slightly Stronger Economic Growth Assumptions	4,254	99
13.	85% of Base Case U.S. SCM Production Capability	10,326	240
14.	115% of Base Case SCM Requirements Demands	15,545	362
15.	Combines Differences from Cases 2, 4, 7, 8, 13, 14	35,179	819
	Type II: Smaller Demand/Larger Supply		
3.	25% Smaller Military Production Requirement	2,688	63
5.	No Shipping Losses	4,257	99
11.	Weaker Economic Growth Assumptions	4,130	96
12.	Greater U.S. SCM Production Capability	2,216	52
16.	Combines Differences from Cases 3, 5, 11, 12 and Assumes Reliable Foreign Supplies Usable for All Tiers	1,598	37
	Type III: Historical Comparison		
6.	Uses Department of State Reliability Estimates from 1982 Stockpile Study	4,237	99

C. RESULTS

As anticipated, where significant differences from Base Case results are observed, Type I sensitivity cases result in larger SCM stockpile requirements estimates and Type II cases lead to smaller-than-Base Case estimates.²

As Table IV-1 shows, the Base Case estimates are, in some cases, extremely sensitive to underlying planning assumptions. Among Type I excursions, for example, changing a single assumption can more than triple the overall estimated stockpile requirement (Cases 9 and 14). Similarly, among Type II cases, modifying a single assumption can reduce the requirement estimates by half (Case 12).

² Case 10 does show a very slightly counterintuitive result. See Appendix F for details.

These analyses indicate that civilian austerity ("belt-tightening") assumptions can significantly affect stockpile requirement estimates. If no civilian austerity is assumed (Case 9), stockpile goals are more than three times as large (338 percent) as the Base Case estimates.

Case 7 shows the marked sensitivity of the resulting estimates to foreign supply reliability assumptions as well. The only difference from the Base Case is that one more country was assumed to be unreliable. The effect is dramatic--an increase of 45 percent in the stockpile goal estimate. While the particular country examined was certainly not randomly selected (its name is classified), the analysis demonstrates the potential risks of misspecifying reliability estimates for certain foreign suppliers.

The excursions presented here were structured principally to anticipate potential congressional requests for cases of this kind, not to formally assess the relative sensitivity of stockpile goals to comparable changes in one or another planning factor. Readers are cautioned against concluding that one planning factor causes a greater goal change than another based on casual inspection of the results in Table IV-1. Nevertheless, certain inferences of this kind can be drawn.

Cases 2, 4, 13 and 14 are excursions that represent percentage changes in key planning factor values. Case 14 assumes that the material inputs required to produce the Base Case goods were underestimated by 15 percent in the Base Case. Case 13 assumes that U.S. SCM production capability is only 85 percent of Base Case estimates. Case 2 arbitrarily assumes that true defense production demands are 125 percent of those in the Base Case, and Case 4 posits that true commercial shipping loss rates in the scenario would be twice those assumed to prevail in the Base Case.

Within the ranges examined by modifying each of these four factors, the stockpile goals appear most sensitive to changes in material input requirements (material consumption ratios (MCRs)); second, to changes in assumptions concerning U.S. SCM production capabilities; third, to assumptions concerning defense production demands; and least sensitive to changes in estimates of shipping losses. The evidence is as follows: a 15 percent increase in MCRs resulted in a 262 percent increase in the overall shortfall; a 15 percent reduction in assumed U.S. SCM production led to a 140 percent increase in the estimated shortfall; a 25 percent increase in assumed military production demands increased the estimated SCM shortfall by 97 percent. A doubling of the assumed shipping losses resulted in a 15 percent increase in the estimated SCM shortfall. On average, therefore, a 10 percent change in each of these factors, respectively, led to a 175 percent

increase in the shortfall (MCRs), a 94 percent increase in the shortfall (reduced U.S. production), a 39 percent increase in the shortfall (higher U.S. military production), and a 1.5 percent increase in the shortfall (higher shipping losses).³

On the other hand, these estimates of average relative sensitivity of overall shortfalls to changes in these planning factor values do not necessarily apply outside the ranges examined. There are significant non-linearities and threshold effects in the module. These effects are described in more detail in Appendix F.⁴

D. DISCUSSION

The excursions presented here are extremely sensitive to some key underlying planning factor values. These values may depend in a particular study on subjective policy preferences as well as scientifically validated estimates of emergency conditions or demands for (or supplies of) SCMs. Some subjective planning factor values are imbedded in the Base Case estimates presented in Chapter III. Civilian austerity adjustments are a good example. These observations should not be construed as a criticism of such subjective components: forecasts of the characteristics of an emergency of the sort employed for stockpile planning purposes necessarily involve such policy judgments. A virtue of the present process is that it enables planners to systematically assess the consequences of their policy choices--and of alternative choices.

³ Along these lines, it is worth re-emphasizing here that NDS requirements estimates are also very sensitive to changes in import reliability assumptions. The results of Case 7, cited earlier, offer a good illustration. Accordingly, DoD decision-makers should focus closely on the effects of their choices concerning this key planning factor as well.

⁴ One major type of threshold effect present in this module may be illustrated as follows. Consider a set of demand and supply assumptions that result in supply-demand balances for many materials that are all strongly positive, i.e., not at all close to exhibiting a shortfall. In such a case, increasing the demands (or decreasing the supplies) by a given (even appreciable) percentage may still not result in a shortfall. At some (threshold) point, however, increasing the demands (or reducing supplies) by one more additional comparable percentage increment will suddenly result in a very sizable estimated shortfall.

V. ADVANCED MATERIALS

A. INTRODUCTION

The NDS program--both the goals for specific materials and the status of current inventories of these materials--has evolved as the types of materials included in NDS inventories have changed in response to technology, the production capabilities of assured and reliable suppliers, the nature of the threat, etc.

New types of materials are now being used in military systems--materials that, in many instances, were irrelevant in defense-related production 20 or even 10 years ago. Conversely, some types of materials that were once extremely important to military operations are much less important or completely obsolete.

This chapter presents the results of an investigation the IDA team has undertaken concerning the appropriateness of including a set of seven advanced materials in the NDS. These seven materials were nominated by OSD for study as potential candidates for the NDS. OSD asked IDA for an independent assessment, conducted off-line since these materials are not used widely enough for quantitative analysis.¹ This chapter provides the results of IDA's analyses. Further details are provided in Appendix G.

B. CANDIDATE MATERIALS AND APPROACH

The advanced materials covered in this chapter are: boron, gallium, hafnium, rhenium, tellurium, yttrium and zirconium. Most of the stockpile candidates considered in this report already have significant applications in the defense sector. These are summarized in Table V-1. Further analysis of the four advanced materials recommended for stockpiling in last year's SECDEF report (indium, rhodium, ruthenium and aerospace rayon fiber) is still on-going and will be reported in a supplemental paper that is classified corporate proprietary.

¹ Updated 1990 supplier country reliability assessments were used in this analysis.

Table V-1. Applications of Selected Advanced Materials

Material	Applications
Aerospace Rayon Fiber	<ul style="list-style-type: none">• Various insulator applications in missiles, rockets, space vehicles and advanced aircraft.
Boron	<ul style="list-style-type: none">• More than 95 percent of domestic consumption is in manufacture of traditional products such as soaps, glass, abrasives and refractories• Minor quantities are used in advanced products such as filaments and boron whiskers used in aerospace vehicles, reactive armor and other military applications where weight and strength are critical
Gallium	<ul style="list-style-type: none">• Used in light-emitting diodes, laser diodes, photodiodes, photo-voltaic cells and integrated circuits
Hafnium	<ul style="list-style-type: none">• Used in naval reactors and in some superalloys
Indium	<ul style="list-style-type: none">• Electrical and electronic components• Solders, alloys, and coatings• Research, especially on semiconductors
Rhenium	<ul style="list-style-type: none">• Used as an oil refineries catalyst• Now coming into use as a superalloy additive in the manufacture of jet engine turbine blades.
Rhodium	<ul style="list-style-type: none">• At least 75 percent of domestic rhodium is used in automotive catalytic converters• Also used as a catalyst in the chemical industry and for extrusion bushings in the manufacture of special glasses, especially S-2 glass for military applications
Ruthenium	<ul style="list-style-type: none">• Small amounts are used in thick film resistors for integrated circuits and high-voltage relays and switches• Used for electronic applications in Sparrow, Hawk, Patriot, Standard-2 and Stinger missiles
Tellurium	<ul style="list-style-type: none">• Most is used to produce free-machining steels• Small amounts of high-purity tellurium are used in making mercury-cadmium-telluride (MCT). MCT is critical to the production of focal plane arrays used in military applications such as night-vision equipment
Yttrium	<ul style="list-style-type: none">• Used in production of phosphors for TV and computer monitors• Also used in laser crystals, catalyst substrates, heating elements, synthetic garnets for microwaves, and advanced ceramics• Used with a zirconium compound as a thermal barrier coating on turbine blades
Zirconium	<ul style="list-style-type: none">• Used for crucibles and investment casting molds in production of jet engine turbine blades• Used in nuclear reactor control rods

For each of these materials, the methodology for this study required completion of the following tasks:

- Technical characterization of the material.
- Assessment of the resource base and determination of the degree of import dependence.
- Quantification of key variables where possible.
- Estimation of defense requirements and comparison with North American availabilities.

- Description of the industry's structure and isolation of potential production bottlenecks.
- Development of recommendations for possible NDS actions.

C. PREVIOUS ASSESSMENTS

Analysis and projection of advanced materials requirements and availabilities are complicated by the fact that, in most cases, small quantities are used per unit of final product, frequently by manufacturers who are far upstream from the final product assembly contractor. The Services have not required their contractors to collect bill-of-materials information for materials used in such small amounts. Furthermore, in some cases (for example, gallium, tellurium and rhenium) processing and utilization technologies are still evolving and it is not yet clear how extensive future military use of these materials will be.

Most of these materials were examined by ASM International advisory panels during 1987-88 as potential additions to the NDS. Table V-2 summarizes the recommendations of these panels and the IDA recommendations developed in this study.

**Table V-2. Comparison of ASM and IDA NDS Recommendations
(Selected Materials)**

Material	Stockpile Recommendations	
	ASM*	IDA
Boron	Not considered	No
Gallium	No	Consider
Hafnium	No	No
Rhenium	No	Consider
Tellurium	No	No
Yttrium	No	No
Zirconium	Stockpile Baddeleyite	Stockpile Baddeleyite
Aerospace Rayon Fiber	Not considered	Research in progress
Indium	Stockpile	Research in progress
Rhodium	Stockpile	Research in progress
Ruthenium	Stockpile	Research in progress

* See ASM International Final Reports for each material (ASM International, Metals Park, Ohio).

D. IDA ASSESSMENTS

A summary of IDA's unclassified assessments of seven advanced materials appears in Table V-3. Results for these specific materials are discussed in the following sections.

Table V-3. Estimated War Scenario Surpluses/Shortfalls for Selected Materials

Material	Unit	War Years			
		I	II	III	Total
Gallium	Metric Ton				
Military Requirement ^a		20.00	20.00	20.00	60.00
Civilian Requirement ^a		.60	.60	.60	1.80
Total Requirement		20.60	20.60	20.60	61.80
N. AMERICAN SUPPLY		23.09	25.39	27.69	76.17
SHORTFALL/SURPLUS		+ 2.49	+ 4.79	+ 7.09	+ 14.37
Hafnium	Metric Ton				
Military Requirement		45.00	45.00	45.00	135.00
Civilian Requirement		5.00	5.00	5.00	15.00
Total Requirement		50.00	50.00	50.00	130.00
N. AMERICAN SUPPLY		55.00	55.00	55.00	165.00
SHORTFALL/SURPLUS		+ 5.00	+ 5.00	+ 5.00	+15.00
Rhenium	1,000 LB				
Military Requirement		15.50	15.50	15.50	46.50
Civilian Requirement		1.00	1.00	1.00	3.00
Total Requirement		15.62	15.62	15.62	45.86
N. AMERICAN SUPPLY		11.50	11.50	11.50	34.50
SHORTFALL/SURPLUS ^b		- 3.62	- 3.62	- 3.62	- 10.86
Tellurium	Metric Ton				
Military Requirement		4.00	4.00	4.00	12.00
Civilian Requirement		88.00	88.00	88.00	264.00
Total Requirement		92.00	92.00	92.00	276.00
N. AMERICAN SUPPLY		122.00	122.00	122.00	366.00
SHORTFALL/SURPLUS		+ 30.00	+ 30.00	+ 30.00	+ 90.00
Zirconium (Baddeleyite)	Metric Ton				
Military Requirement		200.00	200.00	200.00	600.00
Civilian Requirement		—	—	—	—
Total Requirement		200.00	200.00	200.00	600.00
N. AMERICAN SUPPLY		0.00	0.00	0.00	0.00
SHORTFALL/SURPLUS		- 200.00	- 200.00	- 200.00	- 600.00
Boron	Metric Ton				
Military Requirement		65.00	65.00	65.00	195.00
Civilian Requirement ^c		465.00	465.00	465.00	1,395.00
Total Requirement		530.00	530.00	530.00	1,590.00
N. AMERICAN SUPPLY ^d		624.00	624.00	624.00	1,872.00
SHORTFALL/SURPLUS		+ 94.00	+ 94.00	+ 94.00	+ 282.00
Yttrium	Metric Ton				
Military Requirement		60.00	60.00	60.00	180.00
Civilian Requirement		5.00	5.00	5.00	15.00
Total Requirement		65.00	65.00	65.00	195.00
N. AMERICAN SUPPLY		190.00	190.00	190.00	570.00
SHORTFALL/SURPLUS		+ 125.00	+ 125.00	+ 125.00	+ 375.00

^a Refined gallium required to produce end-use gallium of 5.00 MT for military and .15 MT for civilian sector.

^b Based on low-side rhenium supply assumption. See rhenium section in Appendix G.

^c This is total domestic consumption for 1988.

^d This is total domestic production for 1988.

1. Gallium

The table indicates no shortfall for gallium during a war emergency notwithstanding current dependence of the United States on refined gallium imports, mostly from Western Europe. In part, this is because a domestic source of primary gallium, the Utah mine owned by Hecla Mining Co., began production in January 1990.² The Hecla mine is planned to produce nine metric tons of gallium per year after ramp-up in 1990. According to Hecla officials, production could be increased to 11 metric tons per year in an emergency without substantial additional investment in facilities. A second reason for the absence of a projected shortfall is that the conversion of refined gallium to electronic devices generates substantial scrap because yields are very low--currently 20 percent or below. Gallium costs about \$400,000 per metric ton and all grades and forms can be recycled economically. No one throws it away.³ The estimation technique used in IDA's gallium analysis assumes that 90 percent of the gallium scrap generated in a given year will be recovered and recycled, becoming available for re-use as refined metal the following year.⁴

The Warning Year scrap supply used in IDA's analysis is based on 1988 domestic consumption data provided by the U.S. Bureau of Mines for this study. It represents the new scrap generated by end-use military consumption of gallium estimated to have taken place in 1988. In reality, there are substantial inventories of gallium scrap in the economy generated by manufacturing activities in previous years. There is also considerable gallium in government and private sector laboratories. These initial inventories are not included in the analysis because no one knows how large they are. Similarly, it is known that there are substantial inventories of primary gallium products in the economy. Again, no one knows how large these inventories are and they are also excluded from IDA's analysis. From the perspective of primary and secondary metallics availabilities, therefore, the estimation technique used by IDA for gallium is very conservative.

² Telephone interview with Ms. S. Maher, Product Manager for germanium and gallium, Hecla Mining Co., September 21, 1989. The mine and extraction plant in question were discussed in the ASM International Panel Final Report on gallium, 1988.

³ Ms. D. Kramer, gallium specialist, U.S. Bureau of Mines. Ms. Kramer indicates that processors recover every shred of gallium scrap and that inventories of scrap are large. See D. Kramer, *Gallium and Gallium Arsenide: Supply, Technology and Use*, Bureau of Mines Information Circular, IC 9208, U.S. Bureau of Mines, 1989.

⁴ Industry sources indicate that 90 percent is a conservative assumption. Recovery rates of 92 to 95 percent, according to these sources, would not be unreasonable.

Primary and secondary feedstocks, however, must be refined to high-purity (6N and 7N) material before use in manufacturing electronic devices.⁵ There has been concern among planners as to the adequacy of North American gallium refining capacity and IDA has investigated this issue for the present study.

IDA's investigation reveals that there are two U.S. companies currently producing high-purity refined gallium: Eagle-Picher Industries, Inc., and Recapture Metals, Inc. A third company, COMINCO in Canada, has extensive facilities that could be used to refine high-purity gallium (in excess of 10 MT per year) as well as staff who have had experience in high-purity gallium refining. COMINCO's plant is currently producing mainly germanium but could easily resume gallium refining.⁶ The two American companies currently have capacities summing to five metric tons per year of high-purity gallium (6N and 7N). Their managements indicate that expansion to 25 or 30 metric tons per year could be accomplished in a year, provided essential construction materials and feedstocks were available.⁷ A fourth firm, Rhone-Poulenc, the world's largest producer of refined gallium, has plans to build a major gallium refining plant in Texas as soon as market conditions warrant. If it is built, this plant would probably be a high-purity refinery for 4N material imported from Rhone-Poulenc's joint venture with ALCOA in Australia.⁸

Electronics manufacturers have favored sources of high-purity gallium and are generally reluctant to change sources. These relationships are built up over time as the gallium supplier learns to produce the quality of material needed by the electronics manufacturer on a consistent basis. But others can learn, too, especially under pressure. There is no reason to assume that domestic refiners cannot produce material of the same quality as is currently being imported from Western Europe. Furthermore, many electronics manufacturers have their own zone refining facilities which they use to purify materials from primary producers and refiners. Electronics firms producing focal plane

⁵ "6N" is a shorthand for 99.9999% pure, i.e., six 9s. "7N" means seven 9s. A material that is 99.9995 percent pure would be reported as "5N5" material.

⁶ Telephone interview with Mr. Hugh Kennedy, COMINCO, Ltd., October 4, 1989. Recently, COMINCO sold its Electronic Materials Division, which owns the capacity under discussion, to Johnson Matthey, a British company known primarily for its operations in the platinum markets.

⁷ Telephone interviews with Mr. Jack Adams, Vice President, Eagle-Picher Industries, Inc., October 4, 1989, and Mr. Peter Black, Plant Manager, Recapture Metals, Inc., October 13, 1989.

⁸ ALCOA has a large alumina plant in Australia. Rhone-Poulenc owns the gallium extraction circuit associated with this plant. The annual gallium capacity of this venture is said to exceed total Free World gallium consumption at the present time. The ready availability of 4N gallium from this plant plays an important role in discouraging the recovery of gallium from alumina plants in the United States.

arrays from cadmium-mercury-telluride, for example, regularly re-refine even the highest purity materials they use. There is thus no domestic shortage of practical know-how with respect to the zone refining of high purity electronic materials, including gallium.

IDA concludes that existing North American refining capacity together with additional capacity available in an emergency in Canada and in the electronics sector are sufficient to meet projected emergency defense requirements if it is assumed that this capacity remains in place. Continuing industrial base losses, however, could undermine this conclusion. These losses could be critical at all levels of the gallium industry, including the critical wafer-pulling stage of production. IDA calls attention to the fact that there are now only two surviving domestic wafer pullers. If these firms leave the business and their facilities are not maintained, domestic primary gallium production will survive as an exclusively export-oriented activity. There would be less justification for stockpiling gallium if there is no domestic capacity for converting the material into electronic devices.

Since there is no current shortfall in either primary gallium feedstocks or refining capacity, IDA does not see an immediate need for stockpiling gallium. However, much depends on survival of the Hecla Mining Co. project. This is a start-up project utilizing a new and commercially untried technology. Furthermore, the primary product of the venture is germanium, not gallium. If this venture were to fail or to achieve only a fraction of its planned capacity, a serious shortfall of North American primary gallium supply would immediately emerge. In view of this vulnerability, NDS planners may consider it prudent to stockpile sufficient gallium to maintain adequate supplies for the defense sector under a "worst case" scenario: i.e., the Hecla project fails and there are no alternative sources of primary gallium supply. Since it takes about two years to bring new primary gallium capacity into production, a NDS inventory of approximately 10 MT would be required.

2. Hafnium

The hafnium calculations in Table V-3 do not include nuclear reactor demands because the Department of Energy already maintains stockpiles of reactor-grade hafnium for both civilian and military needs. The military demand reported for this metal is thus primarily for superalloy purposes. Hafnium is recovered during the production of metallic

zirconium. Domestic reserves of hafnium-bearing titanium sands and hafnium extraction capacity are ample to meet projected war scenario demands.⁹

3. Rhenium

Rhenium requirements are speculative at this time because the metal's use in military jet aircraft has just begun. Military demand was estimated for the entire War Period by calculating the number of military aircraft jet engines implicit in the JIMPP Requirements Module output (see Appendix 1) and multiplying it by nine pounds per engine.¹⁰ This calculation assumes that the aircraft engine industry will opt for a five percent rhenium superalloy for turbine blades to achieve maximum engine operating temperatures. On the other hand, if the price of rhenium to the engine manufacturers rose sharply, to \$800/lb or more, the industry could go to a superalloy with less rhenium in it. A 3 percent rhenium superalloy, for example, would reduce military requirements for rhenium by more than 6,000 pounds per year.

Implicit in the above discussion is the fact that there is no fixed percentage of rhenium in aircraft superalloys which must be supplied if vital military capabilities are to be achieved. The jet engine industry can adjust to wartime shortages of rhenium if necessary by reducing the percentage of rhenium in superalloys. The tradeoff would be some loss of engine longevity and operating efficiency.

IDA recommends that NDS planners consider stockpiling rhenium because the near-term exhaustion of rhenium reserves at Utah International's Canadian mine will lead to a projected shortfall in North American supply relative to essential requirements. Furthermore, the North American rhenium supply situation is highly vulnerable to possible losses of domestic mining capacity. IDA also recommends that studies be initiated to develop mechanisms for ensuring that the rhenium soon to be released by the oil refinery industry is not lost. Commercial incentives may not be sufficient to ensure capture of this rare material.

⁹ This was the conclusion of the ASM International Panel Final Report on Zirconium and Hafnium, 1988.

¹⁰ B.T. Millensifer, *Rhenium: an Update*. Paper presented by Mr. Millensifer, Vice President of POWMET, Inc. at the Metals Week Conference on Molybdenum, Nickel and Columbium; Tucson, AZ, October 27, 1988. POWMET is the exclusive rhenium marketing agent for Cyprus Mines, the sole U.S. producer of primary rhenium.

4. Tellurium

Tellurium, a by-product of copper refining, is used primarily for making free-machining steels. Very small quantities are also used in night vision equipment for the military. The United States is a major producer of this material but relies on imports for about one-third of its peacetime requirements. Substantial quantities of tellurium-containing copper refinery sludges, however, are exported to Western Europe. If these were to be retained in the United States for refining, the United States would be a net exporter of refined metal.

Considerable quantities of tellurium, in particular most of the high-purity material used in defense-related electronic applications, come from Canada.

Total consumption of tellurium has not been growing in recent years because of substitution in tellurium's largest market: production of free-machining steels. Projected wartime military requirements are small relative to projected North American supply--less than 4 percent. With essential civilian requirements expected to decline, total wartime requirements will be less than current levels of domestic consumption. No shortfalls are projected during the war scenario for this study. Accordingly, IDA sees no need to stockpile this material unless there are significant unanticipated losses of U.S. copper refining capacity in the future.

5. Zirconium

Domestic supplies of zirconium are considered adequate to meet any emergency requirements except for a special grade of high-quality zirconium oxide (baddeleyite) used for aircraft superalloy melting crucibles and investment casting molds.¹¹ This material is found only in the tailings piles of a phosphate mine in South Africa.¹²

6. Boron

The United States is the world's largest producer and exporter of boron. The requirements data in Table V-3 are for high-purity material consumed in the manufacture of boron whiskers and various products made from boron carbide. These estimates are

¹¹ There is some high-quality zirconium oxide in Australia, but it is controlled on long-term contract by Japanese interests. Telephone interview with Mr. James Hedrick, U.S. Bureau of Mines zirconium specialist, September 3, 1989.

¹² Telephone interview with Mr. James Hedrick, zirconium specialist, U.S. Bureau of Mines, September 3, 1989.

considered to be high. The domestic firm dominating the boron whisker business, American Matrix, uses a domestically produced boron precursor, not imported boron carbide.¹³

The potential supply bottleneck in boron is the availability of boron carbide and various intermediate commodities made from it. This range of products is dominated decisively by a West German sole-source supplier, ESK. The nature of the products in question, however, is such that they do not lend themselves to stockpiling.

IDA notes that there are U.S. firms with some boron carbide capacity. Furthermore, the technology involved is well known and understood. Domestic capacity could be expanded sharply within 18 months in the event of an emergency, assuming a concerted effort. IDA also notes, however, that ESK has a silicon carbide plant in Illinois that could easily be adapted to the manufacture of boron carbide. IDA suggests that it would be advantageous to explore mechanisms for ensuring the rapid adaptation of this plant to boron carbide production in the event of an emergency.

There are some important down-stream boron carbide and boron nitride products that were not explored by IDA in this project. These need to be assessed from the national security perspective.

7. Yttrium

Although the United States has in the past been totally dependent on foreign sources of supply for yttrium, this situation is changing rapidly because of major new sources of supply that are coming on line in Canada and in New Mexico. IDA concludes that there is no shortage of either primary yttrium supply or North American refining capacity. It is recommended, therefore, that yttrium not be added to the NDS.

E. DISCUSSION

The results of the IDA analysis to date reveal that NDS action is clearly indicated with respect to baddeleyite and rhenium. The assessment indicates a NDS requirement for at least 600 MT of baddeleyite and 10,000 lb of 4N rhenium metal powder. With respect to gallium, the favorable supply/demand situation could change drastically if the Hecla Mining Co. project should fail or if either of the two high-purity refiners were to leave the business. For this reason, NDS planners may want to stockpile some of the material.

¹³ Telephone interview with Dr. Sam Weaver, President, American Matrix, September 6, 1989.

IDA recommendations with regard to the form in which NDS gallium inventories should be held will be forwarded in a separate analysis as they rest in part on proprietary information.

North American supplies of boron, tellurium, hafnium and zirconium, together with the domestic capacity to process them, are such that there is no need to stockpile these materials at the present time.

The situation with regard to rhenium is more complicated for several reasons. First, it is not yet clear how much rhenium will be required by the jet engine industry. Second, it is also not clear that rhenium-containing alloys will be used in all military jet aircraft, though this seems likely. Third, the oil refining industry will be disposing of substantial quantities of catalytic rhenium in the near future, beginning most likely in the early 1990s. Policies could be developed to ensure capture of this material without exacerbating an already tight rhenium market. On the other hand, a relatively modest NDS rhenium inventory would be sufficient to ensure an adequate supply.

See Appendix G for more extensive discussion of the demand/supply analyses for these advanced materials.

VI. ADDITIONAL DEVELOPMENT INITIATIVES

A. INTRODUCTION

IDA's efforts to design a systematic process for estimating NDS goals have led to the identification of a range of additional features that would make the current version more useful. This chapter provides a brief overview of key initiatives IDA has assisted OSD in implementing during FY 1989 or has recommended for future implementation.

B. OVERVIEW OF CURRENT INITIATIVES

This section presents an overview of development initiatives IDA has undertaken or assisted with thus far in the program. These efforts fall into 13 principal areas. Specifically, the IDA team has

- Developed updated estimates and projections of U.S. peacetime production capability, by four-digit SIC code, for use in the JIMPP macroeconomic model.
- Developed a new benchmark projection of U.S. civil sector demands, based upon growth rates assumed in the Bush Administration's July 1989 forecast of the economy.
- Assisted DoD in developing civil sector austerity adjustment factors for the 1990 NDS scenario. These have been reviewed and approved by consensus of an interagency working group.
- Worked with the Bureau of Mines to structure and obtain updated estimates of U.S. and foreign strategic and critical material emergency production levels. Estimates have been obtained from the Bureau of Mines and converted for use in the 1990 NDS analyses.
- Worked with the JCS to develop estimates of U.S. military force structure and consumable expenditure targets for the 1990 NDS scenario. These have been reviewed and approved by the JCS.
- Designed an import adjustment methodology, consistent with Section 2(b) of the Strategic and Critical Material Stockpiling Act as amended, for potential use in preparing 1990 NDS goal estimates.
- Assisted in developing a process by which the DoD, with support from the Commerce and Interior Departments, will construct updated MCRs for use in future NDS goal estimates.
- Developed initial procedures permitting systematic labor feasibility assessments of proposed emergency production schedules in NDS scenarios. Data linkage

procedures between JIMPP/NDS models and Department of Labor models have been successfully tested with sample data. An institutionalized process for conducting these assessments is being developed.

- Assisted DoD in discussions with the Department of Commerce (DoC) focused on developing more plausible estimates of lead times required to construct new plants and critical equipment in an emergency of the sort envisioned in the NDS scenario. DoC has agreed to conduct a special survey of relevant firms in a set of critical construction industries.
- Conducted a special case study of the ammunition-related demands for tungsten in the 1989 NDS Base Case for the Army at the request of OSD.
- Completed initial design work on a prototype vendor-level module for the SCM production process.
- Conducted a review of potential approaches to the estimation of essential civilian requirements for SCMs. Results of the review have been presented to the sponsor.
- Reviewed prior approaches to emergency substitution possibilities (in civil sector demands for SCMs). A concept has been developed for systematically incorporating available substitution rates into future NDS estimates. Several excursions (from the 1990 Base Case estimates) employing available substitution rates could be readily designed.

C. DISCUSSION

Many of these efforts are scheduled to continue during Phase II of this development project. Detailed working papers and status briefings have been provided on the major initiatives and can be made available. Selected topics are also addressed in appendices to this report.

VII. OBSERVATIONS AND RECOMMENDATIONS

A. INTRODUCTION

This chapter presents IDA's principal observations and recommendations at the conclusion of Phase I of its efforts to structure a systematic estimation process for NDS goals.

B. OBSERVATIONS

Constructing a systematic, coherent NDS goal estimation process has proven feasible during Phase I of this effort. The process has been developed by adapting core elements of the JCS JIMPP; designing and implementing a new module that permits integrated, time-phased comparisons of estimated demands and supplies of approximately 50 major SCMs; identifying and drawing together the nearly 100 data bases required to prepare a set of NDS estimates; articulating major scenario planning factor policy choices and working closely with DoD officials to help ensure the issues were considered.

Significant effort will be required to update and improve relevant data bases for this process to operate truly effectively for NDS planning purposes. Categories of data and planning estimates that will require careful and continuous attention include those described in Chapter III (See Figure III-1) as well as estimates of the quantities of SCMs needed by the U.S. military to produce each of the many specific types of weapon systems that would plausibly be constructed in the emergency planning period. For example, while some research has been done on bills of SCMs required for airframes, engines and other selected aircraft parts by the Air Force and the Navy [11], [12], the available information is far from complete. Considerable ongoing coordination and cooperation among DoD components and numerous relevant federal departments and agencies are essential ingredients in making this overall process viable.

A major strength of the process developed thus far is its flexibility: the planning framework enables the decision-maker to readily assess the consequences of particular policy choices. Chapter IV presents some of the kinds of sensitivity assessments that may be rapidly constructed for this purpose.

C. RECOMMENDATIONS

The IDA project team has developed several core recommendations aimed at strengthening the NDS goal estimation process for future assessments based on their experience during the Phase I effort. In particular, IDA recommends that DoD

- Strongly encourage the individual Services to develop more comprehensive estimates of the quantities and forms of specific SCMs used in especially high-priority weapon systems and sustainability items.
- Undertake development of an operational version of a firm-level module of the SCM production process for several representative SCMs.
- Continue assessments of the merits of including in the NDS new, advanced materials with likely national security emergency applications.
- Encourage relevant JCS/OSD officials to develop new systematic assessments of U.S. force structure building targets for NDS requirements estimates. Dramatic recent changes in Eastern Europe and the Soviet Union highlight the timeliness of fresh assessments. Moreover, since any threat projection can also change markedly, depending on the planning horizon employed (e.g., long-range projections often include adversaries' weapons/technologies now only on the drawing board), OSD should continue to ensure selection of the most appropriate threat planning horizon in structuring any new U.S. force building targets for NDS purposes.
- Consider proposing to Congress that NDS requirements estimates be updated on a two-year basis rather than the current annual cycle.

The Congress and the President have provided the DoD with an outstanding opportunity to structure a NDS that can be truly relevant to military (and essential civilian) production requirements in a major national security emergency. Such an emergency is a low probability occurrence; but that is precisely what catastrophic insurance is designed for. The NDS, at least in principle, represents just such an insurance policy. These observations and recommendations are aimed at updating and continuing to strengthen the national insurance policy that has been developed in this crucial area of industrial mobilization planning and preparedness.

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APPENDIX A

THE JIMPP REQUIREMENTS MODULE

THE JIMPP REQUIREMENTS MODULE

The JIMPP Requirements Module has been used in the National Defense Stockpile (NDS) study to estimate time-phased production requirements for new weapon systems and sustainability items associated with the planning scenario. This appendix offers a brief summary of the module's structure.¹

Essentially, the Requirements Module provides a device to draw together the best of the individual Services' conflict planning factors and thereby allow military planners to assess U.S. military hardware/weaponry requirements for potential cases when full-scale requirements estimates have not already been prepared by the Services themselves. It is intended as a flexible planning tool, not as a replacement for the deliberate planning process. Figure A-1 depicts the structure of the module.

The Requirements Module enables the user to specify time-phased force delivery profiles for each Service in a hypothetical conflict--as well as anticipated attrition, consumption and threat-munition requirement profiles for the scenario. The module then calculates summary lists of the time-phased end-item requirements in the given case, net of projected U.S. inventories at D-Day.

The module has been structured to offer the user considerable flexibility in specifying key features of the conflict case, including such dimensions as the year and month the conflict is to start, how long it is expected to last, the specific forces to be employed, the theaters involved, expected attrition and consumption profiles by month of conflict and theater, and the shares of projected U.S. D-Day inventories assumed available. (These key dimensions are also depicted in Figure A-1.)

The process basically works as follows. The user selects from among a number of Service-provided planning factor data bases to build rapidly the conflict planning

¹ A full non-technical description is available from OJCS(J-4) and the Institute for Defense Analyses. See James S. Thomason, *The JIMPP Requirements Module: Concept and Data Base Development Plan*, IDA Working Paper 88-5, September 13, 1988, UNCLASSIFIED.

assumptions concerning consumption, attrition and other key parameters. The user may quickly modify these profiles for specialized analyses of hypothesized situations. The user

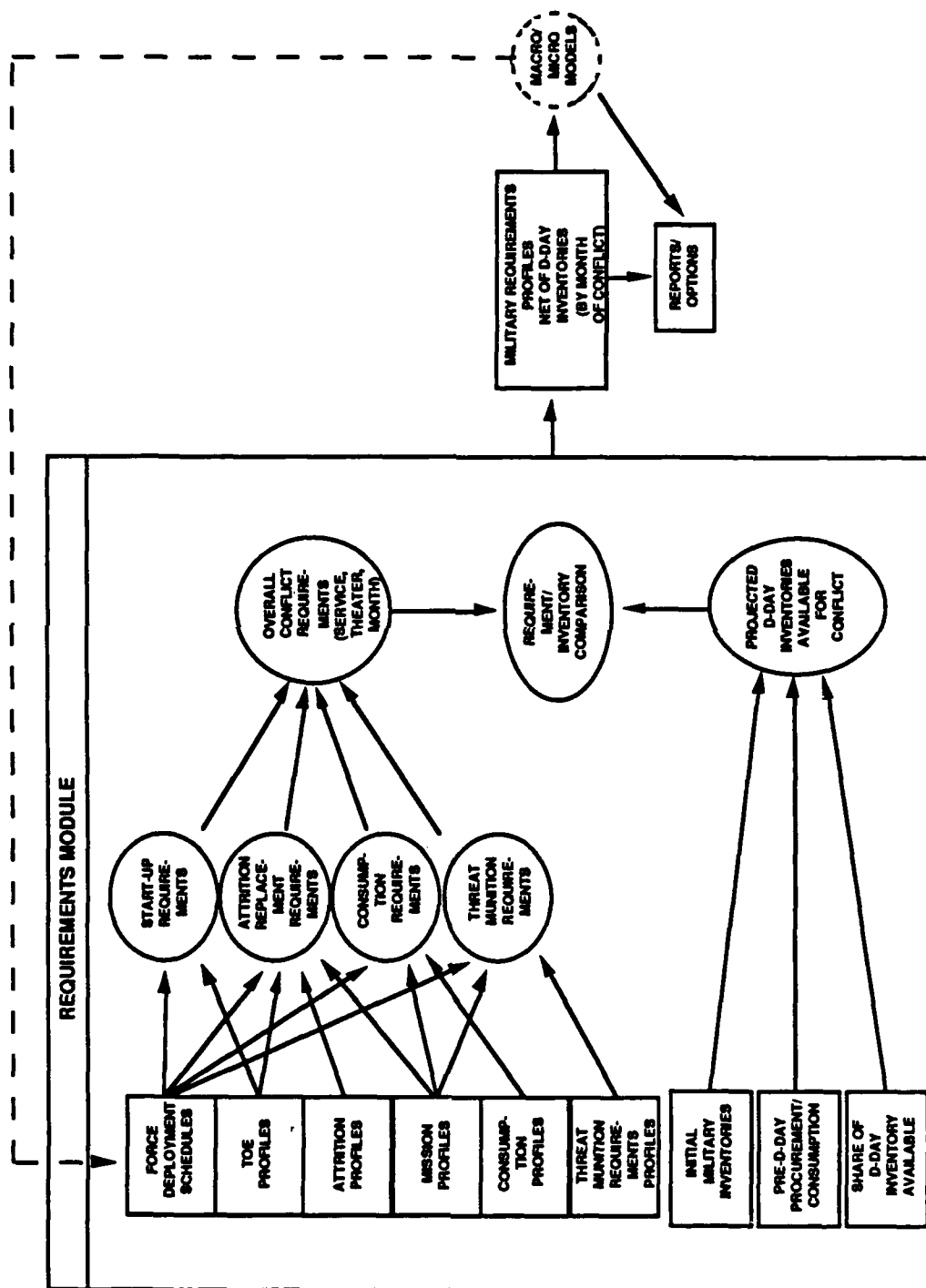


Figure A-1. JIMPP Requirements Module

then specifies the particular force deployment schedules associated with the particular conflict by theater (up to four theaters may be specified). The module will then calculate the expected month-by-month end-item requirements to field and sustain these forces net of projected D-Day inventories. Five major components enter this overall profile: force-unit start-up requirements, attrition-replacement requirements, consumption-item requirements, threat-item requirements (such as most precision-guided munitions) and projected D-Day inventories assumed to be available for the conflict. The principal output of the module is a set of military requirements profiles net of D-Day inventories (by month of conflict).

The shortfalls between requirements and D-day inventories identified in this process are assumed to be the items that must produced in order for the projected force deployment to be sustainable on a timely basis.

APPENDIX B

THE JIMPP MACRO MODULE

THE JIMPP MACRO MODULE

A. INTRODUCTION

This appendix describes the process by which the added investment necessary to avoid bottlenecks in the production of military and civilian goods and services is estimated. The principal analytical mechanism used to perform this supply-side calculation is the JIMPP Macroeconomic Module (or Macro Module), which is discussed in more detail in the following paragraphs.

B. OVERVIEW

Use of the Macro Module involves the following steps:

- First, using a mechanism known as the Defense Translator, the Macro Module converts the dollar value of procurement costs for new weapon systems (from the Requirements Module) into a set of month-by-month final (direct) demands on each of 236 U.S. industries (at the four-digit Standard Industrial Classification (SIC) level).
- Second, these final demands are converted into a set of total (direct plus intermediate good) demands on these same 236 U.S. industries, through a time-phased Input/Output (I/O) matrix.
- Third, total monthly non-DoD (civil sector) demands on industry assumed for the scenario are accepted as an input to the Macro Module.
- Fourth, the resultant total demands are compared, industry by industry and month by month, with the total industrial supply estimated to be available from existing U.S. industrial emergency capability and imports.
- Fifth, if industrial capacity fails to meet the industrial output demands of the scenario and shortfalls are identified at this stage, the Macro Module then estimates the feasibility, timing, and costs associated with the construction of new facilities required to resolve them. (This estimation process is iterative within the module: initial investments to construct new facilities create new demands on industries throughout the economy, which may in turn create new shortfalls and necessitate new rounds of investment to fully resolve all shortfalls.)

The following sections provide additional details about the structure of the Macro Module and an illustration to explain the module logic.

C. MODULE STRUCTURE

The Macro Module projects the available supply from each of the 236 industrial sectors for each month of a simulation. Available supply is a combination of inventories on hand at the beginning of a simulation period, imports, and the amount produced in the course of the simulation period.

As the starting condition, inventories for each sector are based upon current economic data. Similarly, imports and production rates reflect current economic data extrapolated throughout the simulation period. These starting conditions are used for the first iteration of the model in each user session. They are maintained in the supply-side data base, as described subsequently.¹

In the course of a JIMPP simulation, supply conditions are compared with industry demands to assess the balance of supply and demand over the simulation period. To the extent that inventories are available, they are used to offset any shortfalls of supply. The model identifies months with supply shortfalls, and offers options for increasing supply.

The supply-side production options allow the user to vary the factors of production available to each industry to increase the rate of production. These choices include increasing employee weekly hours (workers could work overtime), hiring additional employees and investing in new plants and equipment. A simple proportional relationship is assumed between changes in these variables and the rate of production.² The properties of the assumed relationship are as follows:³

¹ Several alternative trade patterns are available in the data base. These patterns allow different assumptions for imports and exports to be examined.

² The production relationships assume a Cobb-Douglas production function. This function takes the following form:

$$\text{Output} = a \times \text{Labor}^a \times \text{Capital}^b, \text{ where } a + b = 1$$

In the formulation used in the model, the labor input will be decomposed into workers and weekly hours. The assumed relationship is as follows:

$$\text{Labor} = \text{Workers } e_w \times \text{Weekly Hours } e_h, \text{ where } e_w = 1; e_h = .8.$$

Whereas the number of labor hours is simply the product of workers and hours, this relationship includes an efficiency factor for increasing weekly hours. Assuming $e_h = .8$ means that effective labor effort goes up by only 80 percent as much when additional overtime hours are added as when additional

- Constant returns to scale: doubling both the number of workers and the amount of plant and equipment will double the rate of production.
- Returns to added workers' hours are proportional, but less than unitary: a 50 percent increase in workers' hours will yield less than a 50 percent increase in production. (The Base Case assumes that overtime efficiency is 0.8. Thus, a 50 percent increase in worker hours would yield a 40 percent increase in production.)

The model also assumes that adjusting factors of production takes time. The length of the adjustment period varies by factor. Worker hours can be adjusted very quickly; the number of workers can be varied over a period of a few months. (The Base Case assumes that, under total mobilization wartime conditions, within three months, all of the new workers needed to operate existing production lines around the clock could be added. The Base Case also assumes that--given total mobilization--all of the new plants and facilities needed could be built within an average of 12 months.)

A partial (not instantaneous) adjustment process is assumed in the model. For instance, if it is decided to increase the work force in an industry, this process assumes that each month the industry partially closes the gap between the target level of workers and the actual number of workers.⁴ Hence, output will gradually rise to the target level.

workers are added. The rationale for this is that the longer work week reduces the workers' productivity somewhat.

- ³ The relationship between changes in factors of production and output is given by differentiating the Cobb-Douglas production function specified in footnote 2. This yields:

$$\frac{d \text{ Output}}{\text{Output}} = a \times \frac{d \text{ Labor}}{\text{Labor}} + b \times \frac{d \text{ Capital}}{\text{Capital}}$$

Substituting the expression for labor yields:

$$\frac{d \text{ Output}}{\text{Output}} = a \times e_w \times \frac{d \text{ Workers}}{\text{Workers}} + (a \times e_h) \times \frac{d \text{ Hours}}{\text{Hours}} + b \times \frac{d \text{ Capital}}{\text{Capital}}$$

This equation indicates that every one-percent change in labor yields an "a" percent increase in output and a one-percent increase in capital yields a "b" percent increase in output. Similarly, a one-percent increase in both labor and capital yields an "a+b" percent increase in output.

- ⁴ The adjustment process is given by the equation:

$$\text{Workers}_{t+1} = \text{Workers}_t + [a (\text{Target Workers} - \text{Workers}_t)]$$

where "a" is the adjustment parameter. The greater "a" is, the faster is the adjustment from actual levels of workers to the target level. A separate adjustment equation is specified for overtime hours, number of workers and investments. Table B-1 specifies the Base Case values of these adjustment parameters.

This partial adjustment feature is realistic. One of the model's key strengths is its ability to illustrate the time lags between decisions to increase production and the point at which increased output is available.

Decisions to purchase additional plants and equipment to expand industrial capacity will create additional demands on construction industries and producers of machine tools and other manufacturing equipment. Thus, attempts to solve one industry's shortfalls could create shortfalls in other industries. The supply side accounts for this fact by estimating these demands whenever investment decisions are made. These estimates are then added into overall demands on these industries. This critical component of the model allows the user to focus on the industries that supply investment goods as well as on defense-related manufacturers. The investment-related industries may be the most constraining factor in expanding production.

In addition to changes in domestic production, the model also accounts for possible changes in imports as a source of supply. The model allows the user to either increase or decrease imports using a percentage factor adjustment. These factors can be applied uniformly across all industries or more selectively on an industry by industry basis for each year of a simulation.

D. DATA

This section provides a more detailed description of the data bases underlying the Macro Module. The elements of the supply side data base are identified in Table B-1. These data are required for each of the 236 industries.

Table B-1. Supply-Side Data Base

Data Element	Data Source
1. Industry name and number	
2. Current industry output	Data Resources Incorporated
3. Current industry employment	"
4. Current industry capital	"
5. Current industry inventories	"
6. Average worker hours	40 hours per week assumed for all
7. Hours (shifts) per week of industry operation	ORI Inc., Technical Report 2401 and census data
8. Maximum hours (shifts) per week of industry operation	ORI Inc., Technical Report 2401 and census data
9. Production parameters b = Capital = .2 a = Labor = .8 Efficiency Factors : Workers (e_w) = 1 Hours (e_h) = .8	Econometric estimates and assumptions (Same for all industries)
10. Adjustment parameters (coefficient a): Employment = .2 Work Hours = 1 Capital = .1	Assumptions (Same for all industries)
11. Investment spending allocation	National Income Accounts

The data in the supply-side data base provide the initial industry output, inventories and factors of production. They also provide the production and adjustment parameters necessary to relate changes in the target levels of these factors to changes in industry output. Currently the Macro Module uses some general assumptions about these parameters and holds them constant across all industries.

A second supply-side data base is required to estimate how purchases of plants and equipment affect demands on other industries (Table B-2). This data base is the investment spending allocation vector, which (for the current version of the model) is based on overall investment spending patterns for the U.S. economy. The vector shows for each dollar spent on investment how many cents are spent in each of the 236 industries. Multiplying this vector by the level of investment spending yields an estimate of the demands on each industry created by the investment.

In conjunction with the supply decisions made by the user, these two data bases provide the basis for all of the calculations made by the supply-side module.

Table B-2. Investment Spending Allocation Vector

Industry	Allocated Percent of Investment Spending
Construction	20
Machine Tools	30
Steel	5
233 Other Industries	45

E. ILLUSTRATION

The following analysis of acquiring an additional \$1 trillion in defense hardware within two to four years illustrates how the module works. (This figure is roughly equal to half the replacement value of the current force.) In this example, the Macro Module is used to examine the ability of the economy to support military demands. The results reported can provide details for up to 236 individual industrial sectors as well as certain categories of materials, labor and energy. The following discussion focuses on three broad classes of industry: specialized defense industries, nonspecialized dual-use industries and investment industries.

1. Specialized Defense Industries

Prime contractor industries (with end products such as ships, tanks, aircraft, missiles, ordnance and ammunition) tend to be highly specialized. Therefore, it is assumed that in the short run these industries could increase output only by hiring more workers or lengthening the work week. In the long run, output can be expanded by investing to build new plants and equipment. Estimates of the investment required are based on historical capital-output ratios obtained from the Federal Emergency Management Agency.

Since defense production is under \$150 billion per year in the peacetime projection for 1992, the \$1 trillion additional production goal in this example constitutes more than six years of business-as-usual production. Meeting this hypothetical goal in two to four years would require a dramatic increase in defense production.

Figure B-1 illustrates the supply-side calculations for these industries. The top panel shows production rates. An industry can expand to emergency capacity with a relatively short time lag by expanding the work week and hiring more workers, depending upon the production process time. The time required to achieve production rates beyond this level equals the time required to build new facilities, plus the production process time.

Therefore, if it takes 12 months to build a new armored vehicle factory plus six months to build vehicles, the new higher rate is achieved in 18 months.

The lower panel shows cumulative production. On this panel steeper lines indicate higher rates of production. The panel shows that the time to accumulate a target force structure depends primarily on two factors: how long it takes to put new investments in place and begin turning out hardware and the maximum feasible size of these new investments, which depends upon the available supply of investment goods, such as manufacturing equipment and machine tools. Given the large amount of additional hardware required, these two factors will likely be the key variables determining the time required to build additional forces.

2. Dual-Use Industries

The outputs of non-specialized industries (such as basic manufacturing, metals, mining and energy) can be shifted readily between civilian and defense uses. Because defense production normally accounts for a relatively small share of overall output in peacetime, such industries may have adequate capacity in place to support a sizable increase in defense production by diverting resources from civilian to defense uses.

For example, suppose that defense production consumes 8 percent of the copper supply in peacetime. A tripling of defense production could be accommodated by shifting supplies so that defense gets 24 percent of supply. (Alternatively, the added defense demand could be met without cutting back civilian demand if supply were expanded 16 percent.)

Generally, such dual-use industries could support a several-fold increase in defense production without requiring additional capacity investment. Concerns arise for such industries if defense consumption rises beyond the level that can be supported by increasing utilization of existing facilities or diverting supply from civilian to military uses--this may occur once newly expanded defense plants begin production or the supply of imports in these industries is reduced sharply or cut off. Where necessary, the expansion of supply in these industries would follow the same procedures as outlined for the specialized industries detailed in the preceding paragraphs and illustrated in Figure B-1.

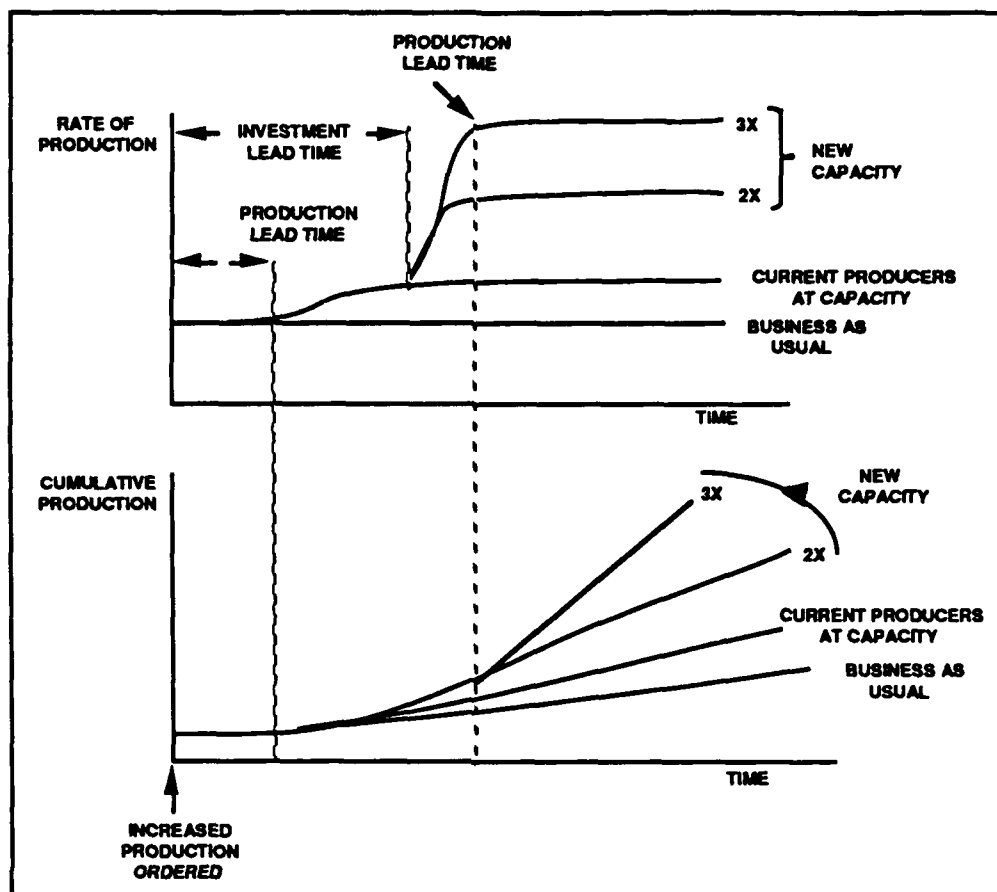


Figure B-1. Macroeconomic Supply Side

3. Investment Goods Industries

Expansion of the defense industries to meet the hypothetical \$1 trillion production goal within two to four years will entail a substantial investment program. Data for 1984 indicate that the U.S. manufacturing sector requires an average \$.57 of capital (book value) to produce each \$1 of annual output. Using this figure, the investment required to meet production rate targets is calculated in columns 1 through 4 of Table B-3.

The calculations in Table B-3 assume that these investment programs could be implemented and that output would be flowing within 18 months. Column 6 displays the time required to achieve the cumulative goal of \$1 trillion additional output. The figures indicate that the first two increments of investment halve the time required to achieve the goal from 80 months to 41 months. The reductions in time drop rapidly after the first \$171 billion is invested: for example, doubling the investment to \$343 billion reduces the build-up time by 9 months to 32 months. This reduction is due to the fact that the additional

investment increments cannot offset the 18-month gestation period needed before new manufacturing plants begin producing additional military hardware. Hence, the primary payoff of the largest investment programs is in expanding long-term production capability, not in reducing the time to achieve near-term force generation goals.

Table B-3. Investments for Production Targets

(1)	(2)	(3)	(4)	(5)	(6)
Production Rate Goal (\$ Bil/yr)	Increase in Production (\$ Bil/yr)	Investment Per \$ of Output	Investment Required (\$ Billion)	Time to Achieve Higher Production Rate (Months)	Total Time to Produce \$1 Trillion of Output (Months)
150	0	.57	0	-	80
300	150	.57	86	18	52
450	300	.57	171	18	41
600	450	.57	257	18	35
750	600	.57	343	18	32
900	750	.57	428	18	29

These calculations illustrate that the ability to provide increased capacity for defense production is likely to be the primary limiting factor in a large-scale mobilization. For large-scale force production, the supply of investment goods is a critical determinant of the feasible rate of investment and, thus, the time needed to meet production goals. Some historical statistics provide perspective. In 1986, business expenditures for new plant and equipment totalled \$395 billion. Expenditures for the manufacturing sector totalled \$151 billion, while investment in metal fabrication, machinery and transportation equipment equalled only \$52 billion. The investment increments outlined in Table B-3 are thus very large compared with U.S. experience, suggesting that the capability of investment goods industries will be an important constraint on our ability to equip an expanded military force.

The Macro Module also can be used to assess the feasibility of specific sets of production targets that could cost significantly less than the hypothetical \$1 trillion target just described. Using the JIMPP Macro Module for such cases essentially involves determining whether sufficient production enhancements can be achieved during the emergency period itself. Within the module, this determination involves adding shifts (longer work week, more workers) to exploit the emergency capacities of relevant production plants, as well as attempting to build new plants to overcome any remaining shortfalls. If sufficient plausible additions to production capability can be made within the time frame and other key parameters of the emergency, the production targets are considered feasible. If not--if significant investment requirements are estimated as needed prior to the warning period--then a new, less ambitious set of production targets is assessed

for feasibility. The process continues until one or more feasible production possibilities are identified.

APPENDIX C

**MATERIALS DEFENSE ECONOMIC IMPACT
MODELING SYSTEM**

MATERIALS DEFENSE ECONOMIC IMPACT MODELING SYSTEM

INTRODUCTION

The Defense Economic Impact Modeling System (DEIMS) consists of several economic models developed to estimate demands on the U.S. economy generated by defense spending. The Materials Defense Economic Impact Modeling System (MDEIMS) is the materials component of that system. The MDEIMS data base estimates the amount of each strategic and critical material used in military goods and services. For this stockpile study, MDEIMS was also used to estimate the strategic and critical material component of civilian goods and services.

MDEIMS makes these estimates by applying material input coefficients. Each such coefficient is a historical ratio of consumption of a particular strategic and critical material (in physical units) to the real dollar value of domestic production of a given industry.

The Office of the Assistant Secretary of Defense (Program Analysis and Evaluation) (OASD (PA&E)) is responsible for maintaining and updating the data bases and models in this system. The last formal update of the material input coefficients was conducted in 1986-87.

LINKING JIMPP TO MDEIMS

As described in Chapter II of this report, overall demands for any given case are expressed as output requirements from each of the 236 Joint Industrial Mobilization Planning Process (JIMPP) industries (shipments needed from each industrial sector, in 1988 dollars). The MDEIMS data base represents estimates of the average input requirements for strategic and critical materials needed to produce a billion dollars of output (shipments) from a given industry. Currently, 57 materials, including several subtypes, are explicitly considered within the MDEIMS data base.

Linking JIMPP outputs with the MDEIMS material input coefficients is a conceptually simple process involving four steps: structuring a crosswalk between JIMPP industrial sectors (236) and DEIMS industrial sectors (458); deflating JIMPP output values

to 1977 dollars; multiplying JIMPP shipment demands (by industry and period in billions of 1977 dollars) by the MDEIMS material input coefficients for each industry, material and period of interest and summing the given material input requirements across all industries for the relevant periods. The industry crosswalk was developed in a collaborative effort between IDA, OASD(PA&E) and Data Resources Incorporated. MDEIMS materials input coefficients were provided by OASD(PA&E). Aside from correcting some internal inconsistencies in the data base, these coefficients were not adjusted in any way for use in the IDA study.

APPENDIX D

THE STOCKPILE SIZING MODULE

THE STOCKPILE SIZING MODULE

A. INTRODUCTION

This appendix describes the process for calculating strategic and critical material (SCM) stockpile targets using the Stockpile Sizing Module developed for the Department of Defense (DoD) by IDA. The module consists of a data base, which contains the supply and demand data necessary for computing the stockpile targets, and a spreadsheet, which is used for the calculations. The module compares estimates of U.S. essential demands for a particular material with estimates of emergency supplies available to the United States during a conflict. The module is designed to enable the user to perform sensitivity analyses by altering a variety of factors affecting the supply of or demand for a material, most principally those factors affecting the estimates of available emergency supplies of SCMs.

B. DATA BASE

The Stockpile Sizing Module data base contains six sets of data necessary for determining stockpile targets for strategic and critical materials. These data sets are

- Estimates of U.S. emergency production capability;
- Estimates of foreign emergency production capability;
- Estimates of U.S. requirements for materials;
- Supply and demand adjustment factors;
- Gross national products for the United States and foreign countries; and
- Official stockpile requirements, inventories and prices.

This section briefly describes each of these inputs and the sources of the data currently in the Stockpile Sizing Module data base.

1. U.S. Production

The Bureau of Mines supplied estimates of U.S. emergency production capability for SCMs. In an emergency, three principal sources of domestic production for materials may be available: facilities that are currently in operation; facilities that are not in operation,

but could be reopened and new facilities that have never been mined or operated. The module permits the user to select the particular combination of production estimates most appropriate to the planning case being analyzed. The Stockpile Sizing Module records data in the units of measure used in reporting the official SCM stockpile goals. When necessary, production data supplied by the Bureau of Mines were converted to match these units of measure.

2. Foreign Production

The Bureau of Mines also provided estimates of foreign emergency production capability for SCMs. When appropriate, these estimates included data for each of the three production sources described for the United States. The data were converted to match the units of measure in the module data base as required.

The data base currently contains U.S. and foreign production estimates for 48 material groupings, which cover nearly all of the 57 Materials Defense Economic Impact Modeling System (MDEIMS) materials. For three of the materials--mica, muscovite block, gauge glass; natural quartz crystals; and rubber--emergency supply data were not available. Estimates for gauge glass are included in the estimates for mica, muscovite block. Emergency supply estimates for rubber are being prepared for the 1990 report.

For several MDEIMS materials, the Stockpile Sizing Module uses the groupings identified in Table D-1. These groupings were formed because the Bureau of Mines provided more aggregated supply data for these materials than are specified in the MDEIMS data base. Other relevant data such as U.S. requirements and official stockpile requirements were also aggregated for these materials.

Table D-1. Material Groupings

STOCKPILE SIZING MODULE	MDEIMS
Chromium, Ferro	Chromium, Ferro, High Carbon Chromium, Ferro, Low Carbon Chromium, Ferro, Silicon
Chromite, Chemical and Metallurgical Grade Ores	Chromite, Chemical Grade Ore Chromite, Metallurgical Grade Ore
Manganese, Ferro	Manganese, Ferro, High Carbon Manganese, Ferro, Low Carbon Manganese, Ferro, Silicon
Manganese Ore, Chemical and Metallurgical Grade Ores	Manganese Ore, Chemical Grade Manganese Ore, Metallurgical Grade

3. U.S. Requirements

The Joint Industrial Mobilization Planning Process (JIMPP) Macro Module and MDEIMS provide estimates of total U.S. emergency requirements for SCMs. U.S. requirements are broken down into three components: demand for materials used in the military tier, demand for materials used in the industrial tier and essential civilian tier demands. The data base contains U.S. demands for each year of the emergency period under consideration. As with the supply data, the requirements data required some unit of measure conversions.

4. Adjustment Factors

Another important input to the Stockpile Sizing Module is the supply and demand adjustment factors, provided for this analysis by the DoD. While domestic production is assumed to be fully available to the United States during a national emergency, the United States will not have access to all foreign production of SCMs. In addition, a variety of factors may affect the capability of foreign suppliers to produce materials at expected levels. To reflect these facts, the module contains a number of factors that can be used to adjust the levels of foreign production or foreign demand for a material. These factors include war damage to foreign production facilities, war damage affecting foreign demand for materials, wartime hostility and reliability of specific foreign suppliers and losses of materials during shipping to the United States.

5. Gross National Product

The module data base contains gross national product (GNP) data for the United States and foreign suppliers and users of SCMs. Most of the GNP data are obtained from *World Military Expenditures and Arms Transfers, 1987*, supplemented for several

countries by *The Military Balance 1988-1989*, *The World Factbook 1987*, and *The Europa Year Book 1988*, *A World Survey, Volume II*. Because estimates of country-specific foreign wartime demand were not available, the Stockpile Sizing Module uses a market-share approach to estimate the quantity of foreign production of SCMs likely to be available to the United States during an emergency. The following section describes this approach in more detail.

6. Stockpile Requirements

The final inputs to the module are the official stockpile requirements, inventories and prices for the SCMs included in the data base. These data were obtained directly from the *Statistical Supplement, Stockpile Report to the Congress*, September 30, 1989, Defense Logistics Agency.

C. PROCESSES

The Stockpile Sizing Module performs two principal processes: calculation of available foreign supply and calculation of stockpile requirements. This section focuses primarily on the calculation of available foreign supply, with a brief discussion of the calculation of stockpile targets.

1. Foreign Supply Calculation

The calculation of available foreign supply considers foreign production capability and foreign demand for materials. In addition, it accounts for the changes to supply or demand that may occur during a wartime environment. The following three steps outline the basic calculations that take place.

The module first identifies the countries that produce a particular material, their emergency production levels, and those countries that demand the material during peacetime.

The module then computes the share of foreign supply to which the United States can reasonably expect to have access. This step can be considered the foreign demand component of the calculation and includes adjustment factors for demand--war damage affecting foreign demand for materials and wartime hostility and reliability of specific countries. Since estimates of wartime demand for each country were unavailable, a market-share approach is used to determine the amount of foreign production available to the

United States. If actual foreign wartime demand estimates were available, the model would be able to use these data in calculating available foreign supply.

The approach used is based on the assumption that the United States, during this emergency, will remain in a strong economic and financial position and will be able to obtain materials from foreign suppliers. The share of foreign production available to the United States is assumed to be equal to no more than the U.S. proportion of the sum of U.S. GNP plus the GNPs (adjusted for war damage) of all friendly nations (those nations willing to trade with the United States during the crisis) that demand the material in peacetime.¹ (This is referred to as the market-share approach.)

The final step in the process calculates the supply of materials available to the United States. This is the supply component of the calculation and takes into consideration war damage affecting the production of materials in foreign countries and losses that may occur during shipping. The model identifies producer countries as either assured, reliable or unreliable sources of supply. Available supplies of materials are calculated separately for assured and reliable suppliers. (Unreliable sources are dropped out of the calculation.) Foreign production is adjusted for war damage and shipping losses and then summed for each type of supplier. The U.S. market share is then applied to these totals to determine the foreign production available to the United States.² The total available foreign supply for both assured and reliable sources is used in the stockpile target calculations.

2. Stockpile Target Calculation

This section provides a brief overview of the algorithm used in calculating the stockpile target. For each year of the scenario, the module compares U.S. requirements for a material with emergency supplies of SCMs estimated to be available--U.S. production plus foreign supply--using a two-tiered approach. In the two-tiered approach, only available U.S. emergency production plus assured foreign supply is used to meet defense

¹ The calculation for each country that demands the material, plus the United States is: $\text{GNP} \times \text{war damage factor (demand)} \times \text{reliability assessment}$. The war damage factor is the percentage by which a foreign economy has been degraded as a result of the conflict. The reliability assessment determines whether the country is willing to trade with the United States--the factor is equal to 0 for unfriendly countries and 1 for friendly countries. Thus, unfriendly countries are not considered in the calculation of market share.

² The calculation--performed separately for assured and fairly reliable suppliers--is the sum of production \times war damage factor (supply) \times shipping losses \times U.S. market share. Shipping loss adjustments are applied before the U.S. Market Share for convenience. The results are the same regardless of the order in which the adjustment factors are applied.

and investment demands--applied first to defense demands, then to investment demands. The surplus, if any, is then added to the reliable imports to meet essential civilian demands for that year.

Any surplus for a material in a given period is carried forward and added to the available supply in the next period of interest, operating under the two-tiered rules. Only U.S. emergency production plus assured foreign supply can be carried forward for defense and investment demands; reliable foreign supply can be carried forward for essential civilian demands. These surpluses cannot, however, be applied to previous periods. Shortfalls are identified during each period for each type of demand: defense, investment and civilian. Both the year-by-year and total shortfall estimates for each demand type are expressed in physical quantities as well as current market value.

The model also calculates stockpile targets for alternative levels of U.S. strategic and critical material production capabilities. The model distinguishes among three levels of U.S. production capabilities: U.S. facilities currently in operation, current facilities plus restarts, and current facilities plus restarts and new starts.

D. MODULE OUTPUTS

For each material, the module produces a Stockpile Targets Worksheet and a Backup Data Sheet. These summaries provide the user with easy reference to the relevant data for each SCM examined. Each worksheet includes a comparison of estimated requirements for the material to the existing stockpile requirements.

Sensitivity analyses can be performed using the module by making changes to any of the data inputs and comparing the results of alternative cases.

APPENDIX E

1989 BASE CASE CIVILIAN AUSTERITY LEVELS

1989 BASE CASE CIVILIAN AUSTERITY LEVELS

This appendix contains a description of the austerity measures and adjustments used for the civilian economy in the stockpile requirements study. These changes were made to the Data Resources Incorporated (DRI) National Income and Product Account (NIPA) final demand categories listed in Table E-1.¹ In general, the adjustments result in a shift in personal consumption expenditures from durable goods to nondurables and services and a reduction in selected investment accounts.

A. PERSONAL CONSUMPTION EXPENDITURES

Consumer spending is adjusted for each of the three years of the emergency, 1990-92. Spending for motor vehicles is reduced 50 percent in the first year, 75 percent in the second year and 100 percent in the third year (NIPA categories 1, 2 and 4). Spending for other consumer durables is reduced 25 percent, 50 percent and 50 percent respectively for each year. Examples include appliances, furniture, jewelry, power tools and sporting equipment (NIPA categories 3, 5-16 and 18-21). Consumer spending from these categories is shifted to nondurable goods and services. Examples include clothing, food, medicine and motion picture theaters (NIPA categories 22-75).

B. INVESTMENT

Reductions are made to several investment categories. Residential investment is reduced 50 percent in the first year, 67.5 percent in the second year and 75 percent in the third year (NIPA categories 76-81). Investment in selected nonresidential structures is reduced 25 percent in the first year, 50 percent in the second year and 50 percent in the third year. Examples include office and educational buildings and hotels and motels (NIPA categories 82-86 and 88-89). Investment in other nonresidential structures remains at business-as-usual levels for each year. Examples include hospitals, electrical and gas utility facilities and farm service facilities.

¹ For a general introduction to NIPA accounts see *Survey of Current Business*, United States Department of Commerce, July 1989.

With two exceptions, investment in nonresidential equipment (NIPA categories 112-137) remains at business-as-usual levels. Examples include engines and turbines, agricultural machinery and railroad equipment. The two exceptions are that investment in new autos (NIPA category 128) is reduced 50 percent, 75 percent and 100 percent respectively for each year and investment in residential producer's durable equipment (NIPA category 137) is reduced 50 percent in the first year, 67.5 percent in the second year and 75 percent in the third year.

Table E-1

**DRI Industry Information Service
Long-Term Model
Final Demand Classification**

<u>Final Demand Categories</u>	<u>Category Description</u>	<u>Final Demand Categories</u>	<u>Category Description</u>
<u>Personal Consumption Expenditures</u>			
1.	New Autos, Domestic	38.	Nondurable Toys & Sporting Goods
2.	New Autos, Foreign	39.	Flowers, Seeds, & Plants
3.	Net Purchase, Used Autos	40.	Expend Abroad by U.S. Residents
4.	Recreational Vehicles	41.	Personal Remittances to Foreigners
5.	Trucks	42.	Electricity
6.	Tires	43.	Natural Gas
7.	Motor Vehicle Accessories & Parts	44.	Sanitary Services
8.	Mattresses & Bedding	45.	Telephone & Telegraph
9.	Appliances	46.	Domestic Services
10.	China, Glassware & Utensils	47.	Misc. Household Services
11.	Floor Coverings	48.	Owner-Occupied Housing (Imputed)
12.	Misc. Household Furniture	49.	Tenant-Occupied Housing
13.	Writing Equipment	50.	Car Repair, Washing, Storage, Rental
14.	Hand, Power & Garden Tools	51.	Transportation Tolls
15.	Radios, TVs, Records, & Musical Inst.	52.	Net Car Insurance
16.	Jewelry & Watches	53.	Misc. Transportation
17.	Ophthalmic & Orthopedic Goods	54.	Rail Transportation
18.	Books & Maps	55.	Airline Transportation
19.	Boats	56.	Misc. Personal Services
20.	Airplanes	57.	Barber Shops, Health Clubs
21.	Wheel Goods, Toys, Sporting Equip.	58.	Brokerage Services
22.	Footwear	59.	Banking Services
23.	Clothing	60.	Financial Services, N.E.C.
24.	Food, Off-Premise	61.	Life Insurance Expenses
25.	Alcohol, Off-Premise	62.	Legal Services
26.	Purchased Meals & Beverages	63.	Personal Business Services
27.	Gasoline	64.	Radio & TV Repair
28.	Fuel Oil & Coal	65.	Motion Picture Theatres
29.	Tobacco	66.	Misc. Amusements
30.	Toilet Articles	67.	Other Recreation
31.	Semidurable Housefurnishings	68.	Doctors & Dentists
32.	Lighting Supplies	69.	Misc. Professional Medical Services
33.	Cleaning Preparations	70.	Hospitals & Sanitariums, Private
34.	Household Paper Products	71.	Health Insurance
35.	Stationery & Writing Supplies	72.	Private Education & Research
36.	Drug Preparations	73.	Religious & Welfare Activities
37.	Magazines, Newspapers, Etc	74.	Foreign Travel by U.S. Residents
		75.	Expenditures in U.S. by Foreigners.

Table E-1. Continued

Final
Demand
Categories Category Description

Residential Investment

76. Residential Single-Family Housing
77. Residential Multi-Family Housing
78. Mobile Homes
79. Residential Additions & Alterations
80. Residential Nonhousekeeping
81. Residential Broker Commissions and Net Used

Nonresidential Investment - Structures

82. Industrial Buildings
83. Office Buildings
84. Other Commercial Buildings
85. Religious Buildings
86. Educational Buildings
87. Hospitals & Institutional Buildings
88. Misc. Buildings
89. Hotels & Motels
90. Railroads
91. Telephone & Telegraph Facilities
92. Electric Utility Facilities
93. Gas Utility Facilities
94. Petroleum Pipelines
95. Farm Service Facilities
96. Petroleum & Natural Gas
Exploration & Drilling
97. Other Mining Facilities
98. Other Nonbuildings
99. Broker Commissions & Net Used

Government Construction

100. Gov't Residential Buildings
101. Gov't Industrial Buildings
102. Gov't Educational Buildings
103. Gov't Hospitals
104. Gov't Misc. Buildings
105. Gov't Highways & Streets
106. Gov't Military Facilities
107. Gov't Cons. & Devel. Facilities
108. Gov't Sewer Facilities
109. Gov't Water Supply Facilities
110. Gov't Misc. Nonbuilding
111. Gov't Net Used

Final
Demand
Categories Category Description

Nonresidential Investment - Equipment

112. Furniture & Fixtures
113. Fabricated Metal Products
114. Engines & Turbines
115. Tractors
116. Agricultural Machinery
117. Construction Machinery
118. Mining & Oilfield Machinery
119. Metalworking Machinery
120. Special Industry Machinery, N.E.C.
121. General Industry Machinery
122. Office Equipment
123. Service Industry Machinery
124. Electrical Transmission Equipment
125. Communication Equipment
126. Misc. Electrical Equipment
127. Trucks & Buses
128. Autos - New
129. Aircraft
130. Ships & Boats
131. Railroad Equipment
132. Instruments
133. Photographic Equipment
134. Other Nonresidential Producer's Durable Equipment
Scrap, Auto (Net Used)
135. Scrap, Exc. Auto
136. Residential Producer's Durable
137. Equipment

Government, Excluding Construction

138. Federal Defense, Ex. Construction
139. Federal Nondefense - Compensation
140. Federal Nondefense - Purchases, Ex. Construction
141. State & Local Education - Compensation
142. State & Local Education - Purchases, Ex. Construction

Table E-1. Concluded

Final Demand Categories	Category Description
143.	State & Local Other - Compensation
144.	State & Local Other - Purchases, Ex. Construction

Exports

145.	Foods, Feeds & Beverages
146.	Industrial Supplies & Materials
147.	Capital Goods, Ex. Automotive
148.	Automotive Vehicles, Parts, Etc.
149.	Consumer Goods, Ex. Food & Auto
150.	Misc. Services
151.	Factor Income

Final Demand Categories	Category Description
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Imports

152.	Foods, Feeds & Beverages
153.	Supplies & Materials Ex. Fuels
154.	Fuels & Lubricants
155.	Capital Goods, Ex. Automotive
156.	Automotive Vehicles, Parts, Etc.
157.	Consumer Goods, Ex. Food & Auto
158.	Misc. Services
159.	Factor Income

Inventory Change

160.	Agriculture
161.	Nonmanufacturing
162.	Manufacturing
163.	Allocated Raw Materials
164.	Allocated Wholesale Trade
165.	Allocated Retail Trade

APPENDIX F

SENSITIVITY ANALYSES

SENSITIVITY ANALYSES

This appendix describes the structure and results of 15 separate analyses of the sensitivity of the 1989 National Defense Stockpile Base Case estimates to changes in potentially important planning assumptions. The information presented here includes a description of each case as well as a discussion of the tier-by-tier composition of the estimated shortfalls. Further details on the material-by-material shortfall estimates are contained in [10].

A. APPROACH

The 15 excursions explore the effects on strategic and critical material (SCM) requirements that occur as a result of modifying individual variables used in the calculation of the requirements. Thirteen cases examine the effect of changes to a single variable. Two excursions look at the effect of changing to multiple variables. The assumptions modified in the excursions include U.S. military production requirements, shipping losses, reliability of foreign suppliers, civilian austerity, U.S. SCM production capability, economic conditions and SCM requirement demands.

The cases are defined as follows:¹

2. Increase U.S. military production requirements for SCMs by 25 percent over Base Case estimates.
3. Reduce U.S. military production requirements for SCMs by 25 percent below Base Case estimates.
4. Double the expected shipping losses to twice the level of the Base Case estimates.
5. Reduce expected shipping losses to zero.
6. Use Department of State political reliability estimates for foreign suppliers from the 1982 Stockpile Study.
7. Change the political reliability assessment of one additional country to unreliable.

¹ The structure of Case 1, an oil disruption variant, is still being developed.

8. Reduce civilian austerity, particularly for motor vehicle expenditures and residential investment.
9. Assume no civilian austerity.
10. Slightly increase economic growth relative to the Base Case. Growth rates are equal to the Reagan administration economic projections as of the beginning of fiscal year 1989.
11. Reduce economic growth relative to the Base Case. This case assumes that growth rates in the early years of the scenario are lower due to a recession in 1990, but recover by the end of the three-year period examined.
12. Expand U.S. SCM production capability to include current facilities as well as restarts of shutdown facilities and new facilities.
13. Reduce U.S. SCM production capability to 85 percent of the Base Case estimates.
14. Increase SCM requirements demands for all tiers--military, investment and civilian--to 115 percent of the Base Case estimates.
15. Change multiple factors resulting in a situation of relatively high demand with relatively low supply. Changes include 25 percent increase in U.S. military production requirements, doubled shipping losses, one additional country assumed unreliable, less civilian austerity, 15 percent reduction in current U.S. SCM production capability and 15 percent increase in SCM requirements demands.
16. Change multiple factors resulting in a situation of relatively low demand with relatively high supply. Changes include 25 percent reduction in U.S. military production requirements, shipping losses are nearly eliminated, both assured and fairly reliable foreign suppliers are viable sources of supply for all tiers of demand, weaker economic conditions, U.S. SCM production capability includes current facilities, restarts of shutdown facilities and new facilities.

B . RESULTS

Table F-1 provides a summary of the results of each excursion, including a breakdown of SCM stockpile requirements into defense, investment and civilian requirements. Within the ranges examined, these results give some insight as to which tier is principally affected by changes in individual assumptions and also illustrate the significant non-linearities and threshold effects in the model. One cannot assume that changes to defense-related assumptions affect only the defense tier, or that broader changes to production capability or economic conditions, for example, affect both defense and

civilian tiers equally. In fact, where significant differences in SCM requirements are observed, the civilian tier is often more greatly affected than the defense tier.

Table F-1. 1989 Sensitivity Cases

Case	Shortfall (\$M)			
	Defense	Investment	Civilian	Total
Base case	3,715	273	306	4,294
2. 25% larger military requirement	5,281	382	2,812	8,475
3. 25% smaller military requirement	2,184	207	297	2,688
4. Double the shipping losses	3,718	273	958	4,949
5. No shipping losses	3,712	273	272	4,257
6. 1982 State Dept reliability estimates	3,693	272	272	4,237
7. One more country assumed unreliable	3,737	342	2,141	6,220
8. Less civilian austerity	3,705	202	1,472	5,379
9. No civilian austerity	3,724	226	10,557	14,507
10. Slightly stronger economic growth ²	3,696	201	357	4,254
11. Weaker economic growth	3,669	185	276	4,130
12. Greater U.S. SCM production capability	1,913	75	228	2,216
13. 85% of base case U.S. SCM production	4,051	363	5,912	10,326
14. 115% of base case SCM req. demand	4,672	452	10,421	15,545
15. Combines Cases 2, 4, 7, 8, 13, 14	7,047	4,088	24,044	35,179
16. Combines Cases 3, 5, 11, 12, with reliable foreign supply usable in all tiers	705	10	883	1,598

For instance, Case 2 shows the effect of a 25 percent increase in military production requirements. As expected, this change in demand resulted in larger SCM stockpile requirement estimates than in the Base Case, an increase of nearly two fold. The interesting fact about this result is not the direction or the magnitude of the increase in SCM stockpile requirements, but the fact that the greatest increase occurred in the civilian tier. While requirements for the defense tier increased 42 percent, requirements for the civilian tier were more than 8 times higher than in the Base Case. A closer examination at the individual material level reveals that the increase in defense requirements is distributed across the entire range of materials in which shortfalls occurred in the Base Case, but the

² An update to the investment function in the JIMPP Macroeconomic Module was conducted after preparing the Base Case results, and reduced investment requirements--thus the slightly counter-intuitive total shortfall as compared to the Base Case. In Case 10 this does not change the effect of the increase in economic growth on civilian sector requirement demands.

increase in civilian requirements results principally from a new shortfall for one material only--aluminum metal.

On the other hand, Case 3, which assumes a 25 percent reduction in military production requirements, has a very different effect on SCM stockpile requirements as compared to Case 2. In Case 3, the stockpile requirement is reduced by 37 percent overall--41 percent in the defense tier but only 3 percent in the civilian tier.

Other cases, such as those concerning changes in civilian austerity (Cases 8 and 9), principally affect one tier. In these cases, an increase in civilian production demands results in increased SCM stockpile requirements mainly in the civilian tier--nearly 5 times larger in Case 8 and 35 times larger in Case 9 than Base Case civilian tier shortfalls.

C. DISCUSSION

The estimates presented here illustrate the sensitivity of the various tiers to changes in planning factors. In general, within the range of assumptions examined, SCM requirements for the civilian tier tend to be affected more significantly by changes in various assumptions than the defense tier. In many cases, however, the effect on the civilian tier can be traced to significant changes in only a few individual materials. Even so, these results highlight the importance of considering essential civilian demands in addition to military demands in estimating SCM stockpile requirements.

APPENDIX G

**DETAILED ASSESSMENTS FOR THE ADVANCED
MATERIALS**

DETAILED ASSESSMENTS FOR THE ADVANCED MATERIALS

A. INTRODUCTION

This appendix presents IDA's interim assessments of the following advanced materials studied in this project: gallium, rhenium, hafnium, tellurium, zirconium, yttrium and boron. Analysis of indium, rhodium, ruthenium and aerospace rayon fiber will be forwarded separately in a paper that is classified company proprietary.

Military application of these materials is recent in most cases and consumption remains small. For several materials, the defense-critical application technologies and/or processing methods are still under development. These materials are produced by few firms and information about them is limited.

For each of the candidate materials, the methodology adopted for this study required completion of the following steps:

- Technical characterization of the material.
- Assessment of the resource base and determination of the degree of import dependence.
- Quantification of key variables, where possible.
- Determination or estimation of defense sector requirements and comparison with secure availabilities.
- Description of the industry structure and isolation of potential production bottlenecks.
- Development of recommendations regarding National Defense Stockpile actions.

B. ASSESSMENTS

This section presents IDA's interim assessments for each of the candidate materials.

Table G-1 summarizes the production and consumption data. Most of these data were provided by the United States Bureau of Mines.

Table G-1. Advanced Materials Production and Consumption¹

Material	Unit	1988 Production	1988 Military Consumption	1988 Civilian Consumption	1988 Total Consumption	Net Import Reliance (%)
Gallium	MT	0.0 ²	10.0	.75	10.70	100
Hafnium	MT	68.0	30.0 ³	38.00	68.00	Neg.
Rhenium	1,000 Lb	6.0	4.0	13.00	17.00	65
Tellurium	MT	60.0	2.0 ⁴	107.00	109.00	45
Yttrium	MT	N/A	30.0	N/A	N/A	N/A
Zirconium	Thous. MT	105.0	Neg. ⁵	155.00	155.00	35
Boron	ST Boric Acid Equivalent	624.0	30.0 ⁶	435.00	465.00	0

¹ U.S. Bureau of Mines, data summaries prepared for this study.

² Primary metal only. Does not include gallium contained in imported consumer electronics. Consumption data are based on assumption of average yield in processing of 20 percent.

³ Measures total consumption of hafnium in production of superalloys, which are assumed to go 100 percent into military end use. Estimate was developed by ASM International Panel on zirconium and hafnium, 1988.

⁴ Based on estimates developed by IDA engineering staff. Refers mainly to tellurium content of mercury-cadmium-telluride consumed by focal plane array manufacturers. Overstates essential military demands by a wide margin.

⁵ Military demand for zirconium is very small compared with traditional applications in refractories and metallurgy.

⁶ Estimate of boron consumption in fibers (very small) and carbide, refractories, etc., developed during this study.

1. Gallium

Gallium is a semiconductor used in optoelectronic devices (ODs) and integrated circuits (ICs). ODs exploit gallium's ability to convert electrical energy to optical energy or the reverse. ICs make use of the fact that high-purity gallium arsenide integrated circuitry is much faster than comparable silicon circuitry and is more tolerant of heat and radiation.

Most military applications of the material are still being tested in pilot projects and many remain in research and development stages, especially in IC technology. Moreover, gallium devices are fragile and vulnerable to single event upsets: a single shock can render a system made with gallium devices inoperable. Silicon devices are less delicate. The fragility of gallium devices coupled with low yields in fabrication and very high quality requirements account for the fact that commercialization of gallium to date has disappointed the expectations of a decade ago.

Potential military applications of gallium include: phased-array radar and signal jammers, night vision equipment, electronic warfare systems, expendable decoys,

navigational systems for missiles and satellites, laser rangefinders, short-range fiber-optic communications systems, solar cells for satellites, and high-speed computers. Civilian applications to date are found primarily in consumer electronics and consist mainly of optoelectronic devices, in which the Japanese are said to have 70 percent of the world market. There is very little consumption of gallium in the United States in the manufacture of civilian goods.

The principal source of primary gallium is bauxite. The United States possesses modest reserves of this mineral but has over 18 million tons in the NDS inventory. In addition, major bauxite deposits are found in the Caribbean Basin: Jamaica, Haiti, the Dominican Republic, Guyana, Suriname and Venezuela. The Jamaican bauxite reserves alone contain approximately 48,000 metric tons of gallium--enough gallium to meet total Free World requirements at current levels for over a thousand years. Bauxite deposits in the United States, which are rich in gallium, contain sufficient gallium to satisfy current Free World requirements for nearly a century. Moreover, zinc ores in the United States contain an estimated 1,050 metric tons (MT) of recoverable gallium--about 27 percent as much gallium as is estimated to be contained in domestic bauxite resources. There is also a substantial amount of gallium contained in NDS bauxite inventories located at domestic alumina plants. As a rough estimate, these inventories contain approximately 4,000 metric tons of recoverable gallium. Finally, the red mud wastes that have accumulated over the years near the major U.S. alumina plants contain most of the gallium that entered the alumina plants with the bauxite. Assuming these red mud accumulations to total 50,000,000 metric tons, the amount of potentially recoverable gallium contained in them could be as much as 15,000 metric tons, given the fact that the concentration of gallium in red mud should be roughly twice as high as its concentration in bauxite.

Not all of these resources are currently in production, of course, nor is it likely that all of the gallium contained in them will ever be recovered. Furthermore, the technology for recovering gallium from red mud may not yet exist. Nevertheless, it is clear that there is an enormous amount of gallium available relative to current and probable future requirements. This is true even if attention is focused exclusively upon gallium resources in the continental United States. With respect to primary resources, therefore, there is no scarcity of gallium.

No primary gallium has been produced domestically for several years and production in Canada was terminated in 1988 because of unfavorable market conditions. Hecla Mining, however, commenced by-product gallium recovery at its germanium mine in

Utah in January 1990.¹ This facility, the only mine in the world exploited primarily for its germanium and gallium resources, will achieve a gallium production rate of six to seven MT per year by mid-summer 1990 and nine MT by the end of the year. There are several ore bodies at the mine and production could be expanded beyond nine MT per year in three years or less. ALCOA has indicated plans to resume gallium production in the United States at its Point Comfort, Texas, alumina facility when the business becomes profitable again. According to ALCOA officials, such a facility could be brought into production in approximately 18 months.²

IDA concludes, therefore, that there is no shortage of primary gallium source material.

Modern electronic applications require extremely pure gallium. The most important military applications require material that is at least 99.99999 percent pure, referred to in industry as "7N" gallium. This requirement is so stringent that a shipment of material is not certified as satisfying specifications until a device has been made from it that performs satisfactorily. The refining of crude gallium to 7N high-purity metal is thus a critical operation as well as a potential supply bottleneck in the domestic industry.

Two domestic firms produce 7N gallium: Eagle-Picher and Recapture Metals, Inc. Eagle-Picher has a 7N capacity of two MT per year, expandable to five MT in four months. According to Eagle-Picher executives, capacity could be increased by a factor of four or five within one year assuming required construction materials are available.³ Recapture Metals has a current refining capacity of three MT expandable to six MT per year in 60 days.⁴

¹ Telephone interview with Ms. Sherald Maher, Product Manager for Germanium and Gallium, Hecla Mining Co., September 29, 1989. Hecla has a contract with Eagle-Picher (EP) Industries to ship its germanium output to EP for refining. Gallium production will be exported to Japan. According to EP, shipments of germanium will commence in late March 1990, and of gallium in April 1990. Telephone interview with Mr. Jack Adams, Vice President, Eagle-Picher Industries, Inc., February 22, 1990.

² G. Barthold, ALCOA, during ASM International advisory panel meeting on gallium. Confirmed in telephone communication with Mr. Barthold on September 29, 1989.

³ Telephone interview with Mr. Jack Adams, Vice President, Eagle-Picher Industries, Inc., October 13, 1989.

⁴ Mr. Peter Black, Plant Manager, Recapture Metals, Inc. Telephone interview October 13, 1989.

Analysis of the adequacy of the domestic gallium industry is complicated by the fact that several critical variables are involved, including the primary reserves and refining capacity issues addressed above. These include:

- Essential military and civilian gallium requirements.
- Yield rates in the processing of gallium materials.
- Gallium scrap recovery rates.

These variables are interrelated in such a way as to require careful analysis based on reasonable estimates for these variables.

With respect to requirements, the Bureau of Mines has estimated that total U.S. consumption of gallium in 1988 was 10.7 MT. This does not include gallium contained in various consumer electronics items imported from the Far East which are considered non-essential in this study. According to Dr. Howard Lessoff of the Naval Research Laboratory, a gallium expert and a member of the ASM Panel on gallium, total U.S. military consumption of gallium does not exceed two MT per year.⁵ Dr. Lessoff also estimates that military consumption will not exceed five MT per year under emergency conditions, given the present state of the art in gallium processing and application technologies. Very little gallium is currently being processed in the private sector for civilian consumption in the United States.

Dr. Lessoff's estimates are for end-use gallium content, not for the gallium processed to produce military end-use items. The distinction is important because yields in gallium processing are low: about 20 percent at present. This means that considerable 7N material must be processed to yield a small volume of end-use product. It also means that the processing of gallium generates more scrap than usable final product.

Major efforts are underway in industry and government to increase yields and reduce the fragility of gallium devices. These efforts focus on improving the yield efficiency of current technologies and on developing new utilization technologies that will be less vulnerable to breakage and to uncontrollable deviations from performance specifications. For example, very promising research is underway on the use of silicon substrates for gallium-containing devices, in effect wedding the electronic advantages of gallium to the durability advantages of silicon. As this research progresses, yields will

⁵ ASM International panel on gallium, Final Report, March 1988.

improve and requirements per unit of final output will decline: i.e., it will take less gallium to make the devices required by the military.⁶

IDA's analysis of gallium availability is based on Dr. Lessoff's estimates of military end-use requirements and on conservative estimates of the critical variables listed above. Briefly, the method employed involves estimation, first, of primary gallium production plus initial scrap availability. Second, essential requirements are estimated. Third, the implications of reasonable assumptions for yields and scrap recovery rates are estimated as they relate to total metallics demand, on the one hand, and scrap generation on the other. This procedure, an example of what economists call "period" analysis, permits the gallium supply and demand assessment summarized in Table G-2.⁷

⁶ According to Dr. Michael Ehman, General Manager of Morgan Semiconductor, IC fabricators are now getting 50% yields from wafers already. Assuming the wafer makers get 50% yields from purchased high purity gallium, which is also reasonable, this means that overall yields would be in the vicinity of 25%. It is unlikely that yields at the wafer stage, however, are currently this high.

⁷ The following algebra indicates the reasoning on which Table G-2 is based.

Requirements:

D_t = defense end-use requirement yr t
 C_t = civilian end-use requirement yr t
 $E_t = D_t + C_t$ = total end-use requirement year t
 Y_t = processing yield rate yr t
 $R_t = \text{Gross Metal Requirement yr } t = (E_t) (1/y_t)$

Supply:

V_t = virgin production yr t
 A_t = total supply
 M_t = metal carryforward from yr $t-1$ (scrap recovered plus unused refined metal)
 $A_t = V_t + M_t$

Implications:

- 1) If $A_t > R_t$, there is a surplus;
- 2) If $A_t < R_t$, requirements cannot be met;
- 3) In year I, $E_t = 5.77$ for $A_t = R_t$
In year II, $E_t = 6.15$ for $A_{t+1} = R_{t+1}$
In year III, $E_t = 6.40$ for $A_{t+2} = R_{t+2}$

Table G-2. Gallium Supply and Demand Estimates (Metric Tons)

	Warning Year	WAR YEARS			
		I	II	III	Total
REQUIREMENTS					
Military End use (D_t)	2.00	5.00	5.00	5.00	15.00
Civilian End use (C_t)	0.15	0.15	0.15	0.15	0.45
Total End use (E_t)	2.15	5.15	5.15	5.15	15.45
Process Yield Rate (Y_t)	0.22	0.25	0.25	0.25	
Gross Metal Required (R_t) (E_t)(1/ y_t)	9.77	20.60	20.60	20.60	61.80
SUPPLY					
Virgin Metal Prod. (V_t)	9.00	9.00	9.00	9.00	27.00
Metal Carryforward ¹ from Previous Year (M_t)	8.00	14.09	16.39	18.69	
Total Metal Supply (A_t)	17.00	23.09	25.39	27.69	76.17
PERIOD SUPPLY OR DEFICIT ($A_t - R_t$)					
Metal Carryforward					
Non-Scrap Recovery (S_t) ($R_t - E_t$)(r) ²	6.86	13.90	13.90	13.90	
Unused Refined Metal ($A_t - R_t$)	7.23	2.49	4.79	7.09	
Carryforward (M_t)	14.09	16.39	18.69	20.99	
Deficit		0.00	0.00	0.00	
¹ Assumed scrap + virgin metal inventory at beginning of first period. ² r = scrap recovery rate assumed to be 0.9.					

Table G-2 assumes that processing yields will be about 22 percent in the Warning Year and 25 percent in the War Years. These assumptions allow for modest progress in yield improvement and are reasonable in the context of current industry practice but may be excessively conservative for outyears. An average scrap recovery rate of 90 percent is assumed in the table, which is also conservative. Industry sources indicate that a

95 percent recovery rate is probably more accurate as a measure of current practice. Gallium is expensive (\$400 per kilogram) and can be recycled from all of its commercially significant applications.

The final crucial assumption is that the scrap recovered in year "t" becomes part of the total metal supply in year "t + 1." This is a reasonable simplification of industry practice. In Table G-2, the scrap recovered in year "t" is added to whatever refined metal is left over at the end of the year and reported as "Metal Carryforward from Previous Year" in year "t + 1." Note that the initial Metal Carryforward in Table G-2 (Warning Year) is 8 MT. This is an assumption reflecting the fact that inventories of gallium intermediates and scrap are known to be large, probably in excess of 10 MT.

Analysis of the algebra in footnote 7 reveals that the "bottom line" is sensitive to changes in all of the key variables. A virtue of the approach is that the implications of changes in the basic assumptions made in Table G-2 can be worked out easily. For example, suppose it would be useful to know how much total end-use requirements can rise without necessitating supplies of gallium from outside the system (e.g., from the NDS). This can be calculated easily by setting Total Supply equal to Gross Metal Requirements and solving for Total End Use. The results of this operation are: in War Year I, Total End Use can reach 5.77 MT; in War Year II, Total End Use can reach 6.15 MT; and in War Year III, Total End Use can reach 6.40 MT.

This is a useful exercise because it demonstrates that there is not much flexibility in the system for unexpected military end-use requirements. For example, the assumptions in Table G-2 would permit only a 15 percent increase in War Year I total end-use gallium consumption without additional supplies of metal from outside the system. It also shows, however, that the system permits relatively large increases in end use for modest increases in either virgin metal supply or stockpiles. For example, a 5 MT NDS inventory assumed to be in place in the Warning Year would permit a 36 percent increase in the total end-use consumption of gallium in War Year I.

Under the assumptions of Table G-2, a stockpile inventory of at least 9 MT would be necessary to satisfy the 5.15 MT end-use requirement in War Year I if Hecla's Utah germanium-gallium mine goes out of business. Presumably, efforts would be initiated during the Warning Year to install a gallium recovery circuit at one of the major alumina plants, possibly ALCOA's plant in Texas. Under the best of circumstances, it would take 18 to 24 months to bring such a facility into production. At the earliest, output from the new capacity would not make itself felt until toward the end of War Year II. Should NDS

planners decide to stockpile gallium as insurance against this contingency, a stockpile inventory of at least 18 MT would be needed. At present prices, this would cost about \$7 million. A larger inventory would be necessary if it is assumed that a new gallium recovery circuit would not be initiated promptly during the Warning Year.

Obviously, different assumptions regarding processing yields and scrap recovery rates could also significantly affect the outcomes reported above. The implications of changes in these assumptions can be worked out easily using the algebra presented in footnote 7.

Many of the variables in IDA's analysis are likely to change in the future in predictable directions, especially under emergency conditions. Scrap recovery rates would certainly rise. Yield rates are already showing slow improvement. Positive changes in these variables reduce the virgin metallics required to achieve self-sufficiency in gallium. They do not, however, reduce the requirement for 7N refining capacity, which remains a critical potential bottleneck in gallium supply.

Table G-2 shows that gallium supply is always at least equal to requirements, provided the Utah mine achieves and maintains its planned gallium production rate and provided the high-purity refining capacity reported in this study remains available. IDA concludes, therefore, that there is no urgent need at this time to stockpile gallium. However, the inflexibility of the system with respect to unexpected increases in military end-use requirements and the small number of domestic producers indicate that NDS planners may want to consider a small NDS inventory of gallium. The question of what form such an inventory might take will be discussed in a separate paper which is classified company proprietary.

2. Rhenium

The principal defense-related application of rhenium is in manufacture of superalloy jet engine turbine blades. It is also used as a catalyst in the oil refinery industry. In 1988, domestic rhenium output was 6,000 pounds, while total consumption was approximately 17,000 pounds. Two-thirds of the United States rhenium supply is imported, most of it from Chile.

Rhenium is extracted from molybdenite separated from porphyric copper ores during the concentration process. To recover the molybdenum values, the molybdenite is roasted, volatilizing the rhenium with the roaster offgas. Environmental regulations require

that the offgas be treated in a scrubber, where the rhenium collects in the scrubber liquor. Recently, it was discovered that considerable rhenium can also be recovered from domestic gold and silver ores, but no one is doing this as yet.

Because rhenium is a by-product of a by-product, its price elasticity of supply is very low. The availability of rhenium depends primarily on the level of demand for copper and molybdenum. Apart from the toll recycling of oil refinery catalysts, there is little secondary recovery of rhenium.⁸

The United States has substantial rhenium reserves, but they are found in copper ores that are poor in copper compared with ores in Chile and Peru.

Several copper mines in the United States currently produce molybdenite containing rhenium. Kennecott's mine in Utah produces 2,000 to 3,000 pounds annually of recoverable rhenium.⁹ MAGMA's mine in Arizona yields 4,000 to 6,000 pounds of recoverable rhenium per year as does the Cyprus Mines mine at Sierrita, Arizona. Total domestically available primary rhenium is thus somewhere between 10,000 and 15,000 pounds per year. In wartime, expanded domestic copper production would increase these figures to 12,000 and 18,000 pounds, respectively, according to U.S. Bureau of Mines estimates based on projected expansion of primary copper production. The data presented in this paragraph are reproduced in Table G-3 later in the text.

Additional quantities of domestic rhenium would be available if copper concentrator and molybdenite roaster losses of the material were reduced significantly. Progress in this area, however, is difficult to forecast.

In addition to domestic rhenium resources, Utah International (UI) in British Columbia, Canada, produces 5,000 to 9,000 pounds annually of contained rhenium. Despite earlier optimism with regard to this mine, however, IDA has learned that UI's mine

⁸ Substantial rhenium will enter the in-service pool soon via jet engine turbine blades. This material will be relatively easy to recycle as the blades are worn out. But military aviation authorities expect rhenium superalloy blade life to average at least eight years. This means that significant scrap recovery of rhenium will not occur until towards the end of this century.

There is interest in industry circles in the possible recovery of rhenium from used X-ray targets. T. Millensifer of POWMET, Inc., believes that 1,000 pounds of rhenium per year could be recovered from this scrap stream.

Note also that most of the rhenium contained in native copper ores is not recovered. Losses are especially high with current technology during the concentration process.

⁹ Rhenium content data are presented in ranges because the natural occurrence of the element in copper ores varies from one batch of ore to the next. This accounts for the low-side/high-side estimates of wartime supply presented later in this section.

reserves will last for only three to five years at current levels of production. A recent assessment of potential ore bodies adjacent to the mine revealed that only traces of rhenium are present, far less than would be necessary to justify recovery operations even under wartime conditions. There are no other known mineral deposits in Canada with sufficient rhenium content to justify a rhenium circuit. This means that Canada will not be a source of rhenium unless new mineral deposits are found containing significant rhenium.

There is also some rhenium-bearing molybdenite produced in Mexico and exported to the United States for processing. The Mexican rhenium potential was not explored in this study.

At present, Kennecott's rhenium-bearing molybdenite is exported to West Germany for processing. Half of MAGMA's production also goes to West Germany while the remainder is sold to AMAX, an American firm with roaster facilities in Pennsylvania. AMAX has never recovered rhenium at its roaster and there may be considerable recoverable rhenium in its tailings piles.

The above discussion indicates that between 4,000 and 6,000 of the 10,000 to 15,000 pounds of potentially available annual domestic rhenium production are exported to West Germany. Some of this material may soon be diverted to U.S. roasters since both Molycorp and AMAX are considering adding rhenium recovery circuits to their existing roaster facilities. According to industry sources, Molycorp has been discussing a possible molybdenite supply contract with Kennecott. In the event of an emergency, of course, Defense Production Act and Export Administration Act authorities could be utilized to divert these exports to domestic refining facilities.¹⁰ It is reasonable, therefore, to consider all exports to West Germany as reliable rhenium supplies in the event of an emergency.

Rhenium values are recovered from molybdenite in rhenium refining circuits co-located with molybdenite roasters. At present, there is only one such facility in the United States, located at the Sierrita, Arizona, mine of Cyprus Mines, Inc. This facility has an annual rhenium recovery capacity of approximately 23,000 pounds. The Sierrita mine, however, yields only sufficient molybdenite to exhaust a fraction of this capacity. Cyprus buys molybdenite from other mines but still operates at well below capacity. Nevertheless, the plant has the capacity to recover all of the rhenium contained in domestically produced

¹⁰ Over half of the rhenium values exported from the U.S. to West Germany return to the U.S. after refining. It is worth noting, in this context, that private contracts are superseded by governmental actions under both the Defense Production Act and the Export Administration Act.

molybdenite. Additional rhenium recovery circuits could be installed at other roasters in less than a year at a cost of \$2 million to \$3 million per plant depending on plant specifics.

IDA concludes that the North American rhenium supply in the event of an emergency would be as follows:

**Table G-3. Estimated North American Rhenium Supply
(Pounds/Year)**

Warning Year	6,000 to 7,000
War Year I	12,000 to 18,000
War Year II	12,000 to 18,000
War Year III	12,000 to 18,000
Total War Years	36,000 to 54,000

The Warning Year estimate assumes that no domestic capacity expansion comes on line in that year and that exports continue. In War Year I, exports are terminated and domestic production increases by 2,000 to 3,000 pounds because of copper industry expansion at existing facilities projected by the U.S. Bureau of Mines. In War Years II and III, rhenium availability does not change.

The rhenium output of molybdenite roasters with rhenium circuits takes the form of either ammonium perrhenate or perrhenic acid. Many rhenium consumers can use one or the other of these compounds directly; others, however, require refined metal. The rhenium used in jet engine superalloys, for example, must be 4N pure rhenium metal or metal powder. This means that the relative importance of rhenium metal refining is likely to grow in the future as the jet engine market becomes more important.

At the present time, there is only one domestic producer of volume metallic rhenium: Rhenium Alloys, Inc., located in Elyria, Ohio. A second plant, Metec in Winslow, New Jersey, has not been refining metal in recent years but is said to be tooling up to re-enter the market as a significant producer. Metec belongs to Cyprus Mines, the domestic producer of primary rhenium feedstocks. Rhenium Alloys was acquired a year ago by Sandvik, a large Swedish steel company which also owns a molybdenite roaster. It is not clear yet what Sandvik intends to do with the Rhenium Alloys plant. It is possible that the company may ship feedstocks from its Swedish roaster to Rhenium Alloy for

refining and subsequent sale in the United States. This would increase U.S. dependence on foreign produced and processed rhenium. Unless Metec does become a significant factor in the rhenium metal market, it could mean that the military jet engine producers would become dependent on a foreign-owned firm for virtually all of their high-purity rhenium supply.

Historically, at least 80 percent of the rhenium consumed in this country has been used by the oil industry as a reforming catalyst in the production of unleaded gasoline. It is used in the form of a bi-metallic alloy with platinum (commonly 90 percent platinum and 10 percent rhenium). Recently, the major aircraft engine manufacturers have discovered that adding rhenium to the superalloy used to make jet engine turbine blades increases engine life and permits higher operating temperatures.

Alloys ranging from 3 percent to 5 percent rhenium have been studied for use in making turbine blades. According to the ASM Panel on rhenium, the engine makers are favoring a 5 percent alloy but they could shift to a lower rhenium content if the price of rhenium were to increase significantly. Should the manufacturers decide on a 5 percent rhenium superalloy for turbine blades, the 4-year emergency scenario rhenium requirements, based on IDA projections of the number of military aircraft that would be demanded, can be estimated as follows:

Number of engines (approximate)	6,500
Average rhenium content per engine	9 Lbs ¹¹
Total rhenium required $9 \times 6,500 =$	58,500 Lbs
Oil Industry Make-up catalyst demand $4 \times 1,000 =$	4,000 Lbs ¹²

Thus total four-year emergency requirements are approximately 62,500 pounds or 15,625 pounds per year. Comparison of estimated annual wartime requirements, 15,625

¹¹ T.A. Millensifer, *Rhenium Background and Markets*, 1987. Also *Rhenium, An Update*. Paper presented by Mr. Millensifer at the Metals Week Mo, Ni and Co conference in Tucson, AZ, October 27, 1988. Millensifer is Vice President of POWMET, Inc., a metals trading firm that represents Cyprus Mines in the marketing of its rhenium output. He was a member of the ASM International Panel on rhenium.

¹² According to Mr. Mark Osborne of TASC, oil industry executives have informed him that the industry could survive in an emergency with 1,000 pounds of make-up rhenium per year. Telephone conversation, October 23, 1989. This could be achieved, in part, by increasing the recovery of rhenium during recycling. Make-up demand is the quantity of new rhenium required to replace what is lost during the recycling process. This loss averages about 15 percent, but would be reduced substantially at higher rhenium prices.

pounds, with the estimates in Table G-3 of wartime rhenium availabilities indicates that North American rhenium supplies will fall short of requirements. North American supplies are nearly sufficient to meet requirements only if the high-side rhenium production estimates are achieved. If the low-side production estimates are assumed, a three-year war scenario deficit of approximately 11,000 pounds of rhenium emerges from the analysis:

Three-year Low-Side Rhenium Supply:	36,000 Lb
Three-year War Scenario Requirements:	<u>46,875 Lb</u>
Deficit	10,875 Lb

The high-side rhenium supply estimates yield a small three-year war scenario surplus:

Three-year High-Side Rhenium Supply	54,000 Lb
Three-year War Scenario Requirements:	<u>46,875 Lb</u>
Surplus	7,125 Lb

NDS planners may conclude from this analysis that it would be prudent to add a small inventory of rhenium to the NDS. There are, however, some complications that must be taken into consideration in making this decision and in determining how much rhenium should be purchased for the stockpile.

First, according to industry sources, the jet engine builders hold rhenium inventories of 7,000 to 10,000 pounds of metal. One of the reasons for this is that the engine builders supply the superalloys to the investment castings manufacturers who produce single-crystal turbine blades and other jet engine components. There are also inventories of approximately 3,000 pounds of rhenium in the catalyst supply pipeline. Taken together, these inventories eliminate all or most of the three-year war scenario rhenium deficit generated by the low-side rhenium production estimates in Table G-3.

Second, it is not clear yet whether the jet engine builders will opt for a three or a five percent rhenium superalloy or some intermediate percentage. Use of a three percent rhenium superalloy would reduce wartime rhenium requirements to only about 10,000 pounds per year. In this case, IDA's low-side rhenium supply estimates indicate that there would be sufficient rhenium available to meet essential military and civilian requirements even without taking into consideration the substantial inventories discussed in the previous paragraph.

It is important to recognize that there is no technologically essential level of rhenium consumption in the jet engine. If the price and availability of rhenium permit, the engine builders will use it throughout the hot sections of their engines. On the other hand, if the price is high and it is difficult to obtain the metal, the builders will confine utilization of rhenium to those sections of the jet engine where it yields the greatest performance payoffs. In other words, the percentage of rhenium which will be used in jet engine components is a variable which will be influenced by the price and availability of the metal. Rhenium is to some extent a metallurgical luxury in the engine business, one which yields significant performance benefits but which can be done without if necessary.

It is, however, dangerous to base NDS decisions on speculative projections regarding superalloy compositions or on corporate inventories. The jet engine builders could find, at some point, that utilization of a high-rhenium superalloy yields decisive performance advantages in military jet aircraft engines. Or they might also decide that tying up \$6 million to \$10 million in rhenium inventories is a luxury they are no longer able to justify financially. This could happen if the price of rhenium rises sharply or the aircraft industry enters a period of serious recession. Furthermore, even IDA's low-side rhenium supply estimates are vulnerable to unexpected adverse developments in the domestic copper industry. Retirement of a single copper mine (e.g., Bingham or Sierrita) would undermine IDA's low-side rhenium supply estimates.

IDA concludes that a modest NDS inventory of rhenium may be advisable. Approximately 10,000 to 15,000 pounds of 4N metal powder should be sufficient to provide insurance against unexpected shortfalls of North American rhenium production. At current rhenium prices, this inventory would cost between \$7 million and \$12 million.

It must be remembered, however, that the elasticity of supply of rhenium is low. Moreover, at the present time, the supply and demand situation in the rhenium market is in delicate equilibrium. An effort to build a significant NDS inventory of rhenium quickly would almost certainly result in shortages and sharp price increases. IDA recommends, therefore, that if the decision is made to stockpile rhenium, stockpile purchases should be timed so as to avoid market disruptions.

There is a special situation in rhenium which needs to be brought to the attention of NDS planners. According to industry experts, the oil refinery industry has commenced shifting to a new continuous reforming technology that uses a platinum/tin catalyst rather

than the current platinum/rhenium catalyst.¹³ Four domestic refineries are reported to have made the conversion already. Conversions are likely to gather momentum towards the end of the next decade.

This development is important because the oil refinery industry has an estimated in-service rhenium inventory ranging from 50,000 to 70,000 pounds. As the new technology is introduced, the refineries will send the displaced platinum/rhenium catalysts to recycling plants for recovery of the platinum (the catalyst is a 90/10 platinum/rhenium alloy). The rhenium values contained in this material are 95 percent recoverable. IDA recommends that this matter be studied in depth, especially with respect to the timing of platinum/rhenium catalyst replacement and the possible need for contingency policies to ensure that this rare natural resource will not be lost.

3. Hafnium

Hafnium is a refractory metal recovered as a by-product during production of zirconium metal. The United States possesses substantial reserves contained in zirconium-bearing titanium sands and is potentially self-sufficient in this material.¹⁴ Hafnium metal capacity in the United States is estimated to be about 120 MT per year.¹⁵ Two firms produce the metal and current production is well below capacity. Only about 5 percent of total United States zircon production is converted to metal. Metallic hafnium is removed from this zirconium.

Hafnium is used in naval nuclear reactors and in turbine engine superalloys. The Department of Energy maintains inventories of hafnium materials for nuclear applications, but not in the forms and grades required for superalloys used in aircraft rotors. According to ASM Panel estimates, about 20 to 40 MT per year of high-purity crystal bar are required for aircraft superalloys. The ASM Panel estimates U.S. domestic capacity for this grade of material at approximately 55 MT per year. All of the material used in turbine engines is regarded as defense-related. Essential civilian requirements are estimated by IDA at approximately 5.0 MT per year.

¹³ Telephone interview with Dr. Arthur Neal, Exxon Corp., September 1, 1989.

¹⁴ Most zircon is imported from Australia at the present time for price and quality reasons. Domestic zircon can be substituted for imports in an emergency.

¹⁵ ASM advisory panel final report, *Assessment of Quality and Material Form of Minor Metals for the National Defense Stockpile, Zirconium, Hafnium and Zirconium Materials*. (Metals Park: ASM International, December 1988).

While the United States has ample reserves and extractive capacity for hafnium, there is concern that the declining consumption of metallic zirconium in nuclear applications may eventually reduce the availability of hafnium metal, causing shortages of hafnium metal to emerge. This assumes that zirconium metal would not be produced in order to permit extraction of the required hafnium, which is unlikely to be true if the availability of hafnium for high priority applications is threatened by declining demand for zirconium.

Assuming that superalloy demand is 30 MT per year in peacetime and emergency requirements would be 50 percent higher, or 45 MT per year, available supplies of 55 MT are more than adequate.¹⁶ Department of Energy inventories are considered adequate to meet emergency nuclear reactor requirements in the military sector. IDA concurs with the ASM advisory panel in its recommendation that hafnium not be added to the NDS at this time.

4. Tellurium

Like rhenium, tellurium is a by-product of copper production. It is recovered from the residues that fall to the bottom of the electrolytic refining pot lines during the refining of copper. Tellurium supply is constrained, therefore, by the level of production in the primary copper industry.

At the present time, only one copper producer in the United States is recovering tellurium: ASARCO.¹⁷ The slimes from other refineries are exported, mainly to Western Europe. A considerable amount of the tellurium contained in these exported slimes subsequently returns to the United States in imports. Total U.S. consumption in 1988 was about 109 metric tons, according to the U.S. Bureau of Mines; about 70 MT of this was domestically produced. There was substantial production in Canada as well, approximately 12 MT of which was exported to the United States. The balance of U.S. demand was satisfied by imports from the United Kingdom, the Philippines and various other countries.

The Bureau of Mines estimates that, in an emergency, an additional 40 MT of tellurium per year could be produced at existing copper refining facilities in the United States. A concerted effort to expand copper production over and above the expansion

¹⁶ Domestic consumption and production of zirconium materials are both increasing. See section 7 of this appendix.

¹⁷ U.S. Bureau of Mines, *Mineral Commodity Summaries*, 1988.

potential of existing facilities would permit recovery of an additional 20 to 40 MT per year of tellurium. The expansion potential in Canada is unknown.¹⁸

Considering only the expansion potential of existing facilities, total wartime domestic tellurium capacity thus comes to about 110 MT. Assuming the continued availability of 12 MT per year of tellurium from Canada, total wartime tellurium supply would be approximately 122 MT.

By far the most important civilian sector application of tellurium is in the manufacture of free-machining low-carbon steels and in non-ferrous alloys. These markets normally account for 85 percent of U.S. tellurium consumption. But consumption in steelmaking has been declining in recent years and will continue to decline in the future. Inland Steel Co., which dominates the free-machining steels market, recently installed continuous casting equipment for these steels. According to Inland Steel executives, bismuth is superior to tellurium as an additive for the steels to be continuously cast.¹⁹ Although not all free-machining steels will be continuously cast, the economics of the process are such that an increasing percentage of total output will be accounted for by this process. Consequently, a secular decline in tellurium consumption in the steel industry is to be anticipated. As Inland's Research Director put it, tellurium has seen its peak demand in the U.S. steel industry.

Tellurium is also used in producing various non-ferrous metals. The only additional market of any consequence is in chemicals, where tellurium is used in the manufacture of certain types of rubber and for other purposes. There is, however, little growth in the tellurium demand in these markets.

In the defense sector, tellurium is used primarily in production of focal-plane arrays for night vision applications. These applications are new and generate very modest tellurium requirements: less than 2 metric tons per year. Most of the tellurium consumed in this high-technology application is imported from Canada (COMINCO) for quality reasons. U.S. electronics firms, however, re-refine even the material they buy from COMINCO and

¹⁸ COMINCO executives, however, indicate that Canadian tellurium capacity is easily expandable. Although they were unable or unwilling to give estimates, the implication is that additional supplies would be available from Canada in the event of a war.

¹⁹ Telephone interview with Dr. Ian Hughes, Director of Metallurgy, Inland Steel Co., December 6, 1989.

could increase their use of domestically produced tellurium if necessary.²⁰ Some Canadian tellurium is also imported for consumption in the steel and other industries.

Estimation of wartime defense tellurium requirements is complicated by the fact that focal-plane array manufacturers have just shifted to epitaxial deposition of mercury-cadmium-telluride (MCT), the principal form in which tellurium is used in military applications. Taking into consideration this fact as well as the modest levels of current requirements, IDA projects a wartime requirement of approximately 4 metric tons per year. This is likely to be a high-side estimate. Like the situation in gallium, little tellurium actually leaves the factory shipping dock in the form of field-usable military equipment.

IDA estimates that about 80 percent of tellurium consumption in steel, non-ferrous metals, chemicals, and rubber constitutes essential civilian consumption from the mobilization planning perspective. Table G-4 presents IDA's estimates of wartime civilian sector tellurium requirements based on 1988 consumption levels.

Table G-4. Wartime Essential Civilian Tellurium Requirements (Metric Tons)

Steel Industry	40
Non-Ferrous Metals	22
Chemicals	10
Rubber	16
Total	88

Note that the steel sector estimate is somewhat "soft" because bismuth and lead can be substituted satisfactorily for tellurium with some resulting loss in production rates in those industries using free-machining steels.

Table G-5 summarizes IDA's analysis of the tellurium supply and demand situation during wartime.

²⁰ Telephone interviews with Mr. Louis Fitzgerald, tellurium product manager, ASARCO, October 13, 1989, and with Dr. Carlos Castro, senior research staff, Texas Instruments, October 17, 1989.

Table G-5. Estimated Wartime Tellurium Supply and Demand (Metric Tons)

	1988	Warning Year	War Years			
			I	II	III	Total
U.S. Production	70	90	110	110	110	330
Imports from Canada	12	12	12	12	12	36
Total N. American Supply	82	102	122	122	122	366
Military Requirements	2	4	4	4	4	12
Essential Civilian Requirements			88	88	88	264
Total Requirements			92	92	92	276
Surplus/Shortage			+ 30	+ 30	+ 30	+ 90

Table G-5 assumes no expansion in tellurium supplies from Canada and that domestic expansion is based solely on existing facilities. From the supply side, therefore, it is a conservative assessment. The estimates show that at no time is there a shortfall in the availability of tellurium for essential civilian and military requirements. On the contrary, the surplus in all years is sufficient to cover any requirements underestimates that may have been made in IDA's analysis.

In reality, Canada is likely to divert tellurium exports from Western Europe to the United States and also to expand production in the event of a war. The implication is that substantially more tellurium would be available to the United States than has been assumed for the purposes of Table G-5.

As in the case of gallium, however, primary tellurium must be refined to high-purity material before it can be used in the manufacture of electronic-grade MCT. This means that high-purity refining capacity could be a supply bottleneck in the event of an emergency.

At the present time, most high-purity MCT consumed by American manufacturers of MCT-containing devices is imported from COMINCO, which has a high-purity refining capacity of about 10 MT per year. ASARCO has an annual capacity of about 5 MT of refining capacity for a product that is not quite as pure as the material obtained from Canada. But, as noted above, the electronics companies all maintain refining capacity

themselves and regularly remelt all the tellurium-bearing materials they buy, including those from COMINCO. Clearly, there is no shortage of high-purity refining capacity.

IDA concludes from this analysis that there is no need to stockpile tellurium at this time.

5. Zirconium

Zirconium is a refractory material extracted as a by-product from titanium-bearing sands. The United States has substantial reserves of these sands and is considered to be self-sufficient for emergency planning purposes except with respect to a very high purity form of zirconium oxide called baddeleyite, found only in the Republic of South Africa.²¹ This material is essential for foundries producing investment-cast turbine blades and other parts for military jet aircraft; no satisfactory substitutes exist.²²

While the world market for zircon is very tight, and the United States depends on imports for approximately 44 percent of its requirements, many of the traditional foundry and refractory applications can use substitutes. While imported zircons are preferred in many of these applications for economic reasons, domestic materials would serve adequately in an emergency.

The density, purity and grain structure of baddeleyite are ideal for investment casting purposes and for making crucibles for melting superalloys.²³ These grains cannot, with present technology, be reproduced artificially. The principal consumer of baddeleyite for these purposes is HOWMET, Inc. According to the ASM Panel, HOWMET requires from 135 to 180 MT of the material each year.

IDA concurs with the ASM advisory panel that consideration should be given to adding sufficient baddeleyite to the NDS to meet U.S. emergency requirements. While data on requirements are regarded as proprietary by the industry, they are estimated at approximately 200 MT per year under emergency conditions.²⁴ Since there is no

²¹ Molycorp, Inc., has initiated development of a mine near Muscalero, New Mexico, which will produce both zirconium and yttrium. The mine and associated processing facilities are scheduled to commence production in mid- to late-1991.

²² ASM International Panel on zirconium and hafnium, Final Report, 1988.

²³ Yields in the investment casting of single-crystal superalloy turbine blades are low--in the neighborhood of 20 percent. The necessity to shift to a less satisfactory mold material during an emergency would reduce yields still further in the process, effectively reducing capacity.

²⁴ This estimate was confirmed by Mr. Clayton Butzer, HOWMET, Inc., in a telephone interview, October 20, 1989.

substitute or alternative North American source of supply and the United States has no reserves of this material, it is recommended that consideration be given to stockpiling three years of defense requirements or approximately 600 MT of baddeleyite. The acquisition cost of this material would be approximately \$600,000.

6. Yttrium

Yttrium is a rare earth metal with applications in superalloy metallurgy, electronics, ceramics and refractories. Despite its classification as a rare earth, it is not rare. The United States and Canada possess substantial yttrium resources which are not yet reflected in official reserves data. U.S. reserves, for example, do not include the yttrium resources in Molycorp's new mine in New Mexico. The same is true of the Strange Lake deposit in Canada, which may be the largest rare-earth deposit in the world.

Historically, almost all of the yttrium consumed in the U.S. has been imported. Australia currently accounts for 90 percent of U.S. imports. This situation is in the process of changing drastically as a result of recent developments in the industry. Molycorp, for example, is estimated by industry experts to be producing about 10 MT per year at its California rare earth mine and processing plant. Molycorp will also soon commence shipping yttrium oxide from its new mine near Muscalero, New Mexico.

The company estimates that this mine will yield approximately 25 MT per year of yttrium oxide when it achieves full production in about a year. Finally, Molycorp is also involved in the Elliot Lake project in Canada which will soon commence shipping about 150 MT of yttrium oxide per year. Molycorp's contractual share of the output of this mine is 75 MT of yttrium oxide per year.

Therefore, it can be shown that there is ample yttrium available to meet emergency requirements.

Associated Minerals, an Australian-owned mining company operating in a variety of U.S. locations, produces 25 or 30 MT of yttrium oxide per year in rare earth concentrates, all of which is exported to France. Molycorp, Inc., produces yttrium oxide at its California mine and processing plant. Industry sources estimate output at about 10 MT per year.²⁵ More than half of the output of this mine is currently exported but could be retained in the United States in the event of an emergency. Molycorp also receives 75 MT

²⁵ Molycorp's mine at Mountain Pass, California, is the second largest and the highest quality rare-earth mine in the world.

per year from its participation in the Canadian Elliot Lake project. Most of the rest of Elliot Lake's production, about 75 MT, is exported but would be available to the United States in the event of an emergency. In about 18 months, according to Molycorp executives, production will commence at the company's new zirconium-yttrium mine in New Mexico, capacity of which has been estimated at 25 MT per year. Hecla Mining Co. has a 50 percent interest in the Thor Lake mine (Canada), which could also produce considerable yttrium oxide. This project is still under evaluation, however, and is four years away from production, assuming a decision is made to proceed with mine development. Hecla is also involved in the Strange Lake project in northern Canada. This is an enormous rare earth deposit with sufficient verified reserves to meet total Free World yttrium requirements, if it is developed. There are many problems to be overcome, however, not the least of which is the severe weather conditions in which the mine would operate for seven months of the year. Putting aside resources which may or may not be developed in the future, these sources generate the following primary yttrium supply picture:

Molycorp/California	10 MT/yr (est.)
Molycorp/Canada	75
Molycorp/Muscalero	25
<u>Associated/Florida</u>	<u>25</u>
TOTAL	135

If it is assumed that about 75 percent of the Elliot Lake output not controlled by Molycorp (75 metric tons) would also be available to the United States in an emergency, total supply, assuming no additional resource development, would exceed 190 MT per year of yttrium oxide.

In reality, domestic yttrium oxide production could be expanded substantially in an emergency: according to Molycorp executives, Molycorp alone could double U.S. yttrium oxide supplies within six months, based on existing mine and extraction facilities. The rare earths are not really rare and U.S. production could be larger today were it not for the fact that less expensive supplies are available abroad. In an emergency, however, domestic production would be expanded to displace foreign supplies. Moreover, production in excess of 150 MT per year could also be achieved at the Elliot Lake mine in an emergency.

With respect to the processing of concentrates, there appears to be ample domestic capacity in place. Molycorp officials indicate that the company's current capacity for extracting pure yttrium oxide from concentrates is more than twice total domestic

consumption.²⁶ The Davison Chemical Division of W.R. Grace, which extracts yttrium oxide from imported monazite concentrates, also has substantial capacity as does Associated Minerals. With respect to metallic yttrium, Molycorp has a plant in Colorado with a capacity in excess of current total U.S. demand, estimated at 2 to 3 MT/yr. Rhone-Poulenc, a French company, also has substantial metallic yttrium extraction capacity in the United States, located at Freeport, Texas. The demand for metallic yttrium is not growing rapidly, however, and it is unlikely that there will be a serious supply problem in the near future. It is used primarily as a superalloy additive. According to Molycorp officials, current metal capacity could be expanded 50 percent in less than nine months by installing an additional vacuum induction furnace in its plant at Louviers, Colorado.²⁷

There are, unfortunately, no official data on the consumption of yttrium in either the civilian or military sectors. Most trade data on yttrium are aggregated with the other rare earths. Defense sector requirements, however, were estimated by the ASM International advisory panel on yttrium. These were supplemented by IDA research and are reported below.

In the private sector, the largest market for yttrium is in the petroleum and chemicals industries, where it is used as a catalyst. Some yttrium is also used in automotive catalytic converters, permanent magnets, misch metal, iron and steel making, polishing compounds for optical lenses, cathode ray and TV tubes, glass, phosphors and fluorescent materials, traveling wave tubes, and various electronic devices.

Although there are no data on yttrium consumption in the civilian sector, Molycorp's representative at the ASM advisory panel meeting stated that very little civilian sector yttrium consumption can be regarded as essential in time of war apart from the small amount of material used in oil refinery catalysts.

In the defense sector, yttrium is used in metallic form as a superalloy additive and in coatings for rotor blades and stator vanes, where it provides protection against oxidation and corrosion at high temperatures. Yttrium oxide has innumerable defense sector applications, though generally those applications require insignificant quantities of the material. These include: ceramic coatings and abradable seals, laser crystals and other

²⁶ Presentation by T. Wilson, Senior Vice President, Molycorp, Inc., at the 1987 ASM International advisory panel meeting on yttrium.

²⁷ Telephone interview with Mr. Thomas Wilson, Senior Vice President, Molycorp, Inc., October 25, 1989. According to Mr. Wilson, nearly all of current U.S. metallic yttrium consumption is in the production of superalloys.

electronic devices, sonar devices, and various chemicals. One of the most important defense applications is the investment casting of single-crystal turbine blades where high-purity oxide is added to the zirconia used for making the crucibles and molds.

Yttrium in considerable quantities is likely to be required in high-temperature superconductors, especially for thin film applications in electronics and instrumentation. This is not a commercialized market as yet, but should be monitored from time to time by NDS planners.

The defense sector applications of greatest importance are the following:

- Yttrium-Iron Garnets (YIGs)--used in wave guide devices in AEGIS and other radar systems. Current annual consumption is approximately 5 MT of high-purity yttrium oxide.²⁸
- Yttrium-Aluminum Garnets (YAGs)--used in laser crystals. Current annual consumption is also about 5 MT.²⁹
- Superalloy Additives--account for approximately 2 MT per year of metallic yttrium, most of it for aerospace applications.³⁰ Note that it takes about 2 MT tons of yttrium oxide to produce 1 MT of metal.
- Zirconium Crucibles--use high-purity yttrium oxide for melting aircraft superalloys. Annual consumption is approximately 5 MT.³¹
- Turbine Blade Coatings--yttrium oxide used as a stabilizer in a zirconium compound applied to the blades as a thermal barrier. Annual yttrium oxide consumption in this application is estimated at approximately 1 MT.³²
- Advanced Ceramics--use yttrium oxide as a stabilizer. Annual yttrium oxide consumption in this application is less than 10 MT in current military applications.³³

These peacetime military requirements account for approximately 30 MT per year of yttrium oxide. No estimates of wartime yttrium requirements have been made. Accurate

²⁸ Mr. L. Belz, KBI-Cabot, Inc., during ASM International advisory panel meeting on yttrium. Mr. Belz indicated that this is a stable figure and has not changed since the ASM meeting. Telephone interview with Mr. Belz, October 29, 1989.

²⁹ Also estimated by Mr L. Belz.

³⁰ Estimated By Mr. Thomas Wilson, Molycorp, Inc., during telephone interview, October 25, 1989.

³¹ Telephone interview with Mr. Clayton Butzer, HOWMET, Inc., October 20, 1989. HOWMET is the largest of the firms in the turbine blade business.

³² Telephone interview, Mr. L. Belz, October 29, 1989.

³³ Telephone interview, Mr. L. Belz, October 30, 1989.

estimation is impossible because so many of the relevant technologies are undergoing rapid change. For present purposes, IDA assumes simply that wartime requirements will be double peacetime consumption, or about 60 MT. Note that this exhausts only about 80 percent of Molycorp's share of the yttrium oxide output from Elliot Lake. Since there are substantial additional yttrium availabilities coming on line in the near future--in particular from the Molycorp project in New Mexico--it is clear that North American yttrium supplies, estimated above at approximately 190 MT per year, are more than adequate to meet defense sector emergency requirements.³⁴ Even assuming no increase in North American supply, there would be a surplus of more than 100 MT per year available for civilian needs.

IDA concludes that there is no need to stockpile yttrium at this time. This conclusion is in agreement with the 1987 ASM advisory panel recommendation on yttrium.

7. Boron

Boron, a transition element with the properties of both metals and non metals, is relatively abundant and has been a commercially significant material for many years. Its major markets are in glass products, soaps and detergents, and metallurgy. The United States is the world's largest producer and exporter of primary boron products and is self-sufficient in the basic raw material. The bulk of U.S. reserves and mine production, however, are controlled by a British-owned company.

Recently, new applications for boron intermediates have emerged in the defense sector and others are under development. Small amounts of boron are used in these applications and they generally have few commercial markets as yet. Consequently, most of the strategically significant boron intermediates are produced in sole-source industries.

Boron Carbide

Notwithstanding its importance as a producer of primary boron, the United States is 90 percent or more dependent on imported boron carbide, a material with applications in many defense-related industries. Sintered boron carbide parts have applications in scores of defense systems, including aircraft (e.g., helicopters and the Advanced Tactical Fighter),

³⁴ The New Mexico yttrium-zirconium deposit lies close to the surface, which facilitates both mining and accurate estimation of reserves. According to UNOCAL, which owns Molycorp, this mine contains over 9,000 MT of recoverable yttrium and is associated with ore bodies that have not been evaluated as yet. UNOCAL's president, Richard Stegemeier, recently wrote, "The New Mexico deposit contains sufficient quantities of yttrium to supply America's requirements for many decades." R.J. Stegemeier, *Letter to Employees*, August 1989.

missiles, tanks and nuclear power plants. Various advanced abrasives are made with boron carbide. Moreover, this material is the principal feedstock used to manufacture several intermediate boron products of importance to the production of military hardware:

- Boron trichloride, the principal precursor for boron filaments used in the F111 and F14 fighters
- Elemental boron, the precursor for boron nitride used in the Stealth aircraft, metallurgical boats for refining high-purity gallium arsenide, and anti-missile armor plating.

Boron carbide products also have critical applications in the industrial sector, including advanced abrasives. Many of these applications exploit the fact that boron carbide is the hardest of all synthetic materials.

A single West German firm, Elektroschmelzwerk Kempten GMBH (ESK), controls all U.S. imports of boron carbide and is also a dominant supplier of many boron carbide and boron nitride parts. This firm's dominance of the U.S. market is said to result from production economies of scale (it is the world's largest carbide producer), access to low-cost electric power, reputation for quality and service, and aggressive marketing strategy. The technologies it employs are well-known and non-proprietary for the most part. There are several American companies that make small quantities of boron carbide, in particular Eagle-Picher Industries (EP) and KBI Cabot, which make high-purity material for laboratory and nuclear power use. There are also several domestic electro-metallurgical plants that could tool up to manufacture boron carbide. For example, plants making silicon carbide can be shifted to boron carbide quickly, although not as efficiently as plants designed expressly for production of boron carbide.³⁵ There is, however, only one surviving silicon carbide plant in the United States and it is owned by ESK.

According to industry experts, ESK's market dominance rests on an aggressive marketing strategy coupled with a pricing policy that discourages the entry of American suppliers.³⁶ ESK does not market "crude" boron carbide alone but rather a full line of carbide and nitride products adapted to the requirements of many different industries. It is

³⁵ Telephone interview with Mr. James Everitt, manager, Eagle-Picher Industries Boron Division, January 4, 1990.

³⁶ Telephone interviews with Dr. Sam Weaver, Chairman of the Board of Directors, American Matrix, Inc., Mr. Herman Vargas, Kerr-McGee, Mr. James Everitt, EP, and various other industry executives, including officials of Textron and numerous companies that use boron products. These interviews were conducted in the spring and summer of 1988 as part of a study sponsored by the U.S. Department of Commerce.

ESK's domination of these downstream boron carbide markets that enables it to discourage entry at the volume boron carbide level.

ESK's policy of maintaining sufficient capacity to supply virtually the entire Free World market also plays a role in discouraging entry.

Clearly, ESK's dominance of the boron carbide market is not a stockpile problem. To stockpile undifferentiated boron carbide would accomplish little in the absence of an industrial base to fabricate the material into the many specialized products incorporating it. But there are so many specialized applications of boron carbide that stockpiling would not be an efficient policy option for them either.

For the reasons set forth above, IDA does not recommend stockpiling either boron carbide or the specialized products made from it. IDA does recommend consideration of U.S. government strategies for encouraging ESK to build boron carbide capacity in the United States sufficient to satisfy essential defense requirements in the event of war. ESK could do this at its silicon carbide plant in Illinois merely by installing an additional electric arc furnace and a large transformer.³⁷

Boron Filaments

Undifferentiated boron carbide is the feedstock for production of boron trichloride, used principally as the precursor for manufacture of boron filaments. These are threads of nearly pure boron deposited on a core of thin-gauge tungsten wire. The tungsten wire used for making boron filaments is imported exclusively from Japan.³⁸ Boron filaments impart strength to various structural elements of advanced aircraft and are used in such systems as the F111 and F14 fighter series. They permit significant weight economies (up to 30 percent) and also reduce plastic deformation of metal components.

ESK is the sole supplier of boron carbide feedstock to Kerr-McGee, the sole United States producer of boron trichloride. About 80 percent of Kerr-McGee's boron trichloride

³⁷ ESK's U.S. manager, Mr. William Long, indicates that his company has considered installing boron carbide capacity at the Henlopen, Illinois, silicon carbide plant. No action was taken, however, because sales in the U.S. fell off sharply when the decision was made to stretch out production of the Apache helicopter, which uses considerable boron carbide, mainly in seat armor. Total ESK boron carbide exports to the U.S. in 1989 were about 100,000 pounds, about 45 metric tons. This means that total boron carbide sales in the U.S. in 1989 must have been approximately 50 metric tons. Telephone interview, January 5, 1990.

³⁸ According to Textron executives, American tungsten product producers could produce the wire used in making boron filaments but are not interested in this market because of its small size. Some investment in specialized wire drawing equipment would be required.

output is sold to Textron Specialty Materials, the Free World's only producer of boron filaments.

The boron filament manufacturing process is difficult, capital intensive and somewhat hazardous because of the toxicity and explosiveness of some of its basic inputs (e.g., hydrogen and boron trichloride). The finished product, therefore, is expensive: \$500 to \$600 per pound. This discourages commercialization of the product. About 75 percent of United States production goes to the military market while the balance is used in making tennis rackets and golf clubs. Total demand is not growing consistently, although there was a sharp spike in sales to the sporting goods industry in 1989. Textron's total filament production in 1987 was about 28,000 pounds or approximately 13 metric tons. To IDA's knowledge, none of the newer aerospace systems incorporates the material. Accordingly, IDA does not recommend stockpiling boron filaments or boron trichloride.

Boron Whiskers

Some years ago, the U.S. Navy funded an American firm, ARCO, to develop technology for making silicon whiskers, small fibers made from silicon carbide used in many of the same types of applications as boron filaments. ARCO captured the defense market for silicon whiskers and then sold out to TATEO, a Japanese firm which now controls 90 percent of the U.S. market for silicon whiskers, which is almost exclusively military.

Meanwhile, American Matrix (AM), a small U.S. firm in Knoxville, Tennessee, developed a technology for producing boron whiskers, which are competitive with silicon whiskers in nearly all markets. This technology is currently being patented by AM, which is reluctant to discuss process details until the patent is finally approved. Dr. Sam Weaver, AM's Chairman and principal researcher, has revealed that the AM process utilizes "...a readily available, off-the-shelf boron feedstock, not ESK boron carbide."³⁹ This probably means anhydrous boric acid.

The boron whisker market is currently small (about 2 metric tons per year) but could explode. Promising applications include:

- Reactive armor

³⁹ Telephone interview with Dr. Weaver, June 11, 1988. During this interview, Dr. Weaver revealed that his firm would like to penetrate the boron carbide market but cannot compete with ESK's pricing. According to Weaver, ESK has a record of depressing its prices whenever it perceives prospective entrants on the horizon. It was not possible to verify this statement during the present study.

- Ceramics
- Plastic flow inhibitors in aerospace structural components and superalloys.

Applicability of boron whiskers to the tennis racket and golf club markets has not yet been established.

According to Dr. Weaver, AM's current whisker capacity is 1,000 pounds per month, expandable in four months to 10,000 pounds per month. To date, however, shipments have not exceeded 350 pounds per month. Company officials are unwilling to discuss pricing except to indicate that whiskers sell for far less than filaments.

American Matrix will dominate boron whisker production for years to come because prospective entrants will have to lease its technology to achieve entry. Thus this product, too, is likely to remain a sole-source commodity for the foreseeable future. In view of AM's excess capacity and the newness of the market, however, IDA does not recommend stockpiling boron whiskers.

Other Advanced Boron Materials

Boron ores consist of 19.57 percent B10 isotope and 80.43 percent B11 isotope.⁴⁰ The B10 isotope has a number of special applications, including:

- Neutron radiation detectors and retainers used in nuclear reactors; this application requires boron trifluoride with at least 90 percent B10 fluoride
- Catalysts for many organic reactions, especially polymerization as in the production of butyl rubber from isobutane.

The feedstock for B10 fluoride separation is high quality boron fluoride containing both isotopes. The fluoride, produced from ordinary boric acid, is a highly toxic, explosive substance that is difficult to handle and store. Allied Chemical is the sole United States supplier of the feedstock and Eagle-Picher is the sole producer of B10 isotope.

The potential market for B10 fluoride is large because it may be specified by the Nuclear Regulatory Authority as the required quenching material for commercial reactors. In the interim, however, Eagle-Picher's separation plant has ample capacity to service the market. Indeed, current demand is such that this plant is operated only intermittently. If the Nuclear Regulatory Commission specifies B10 fluoride, however, substantial capacity

⁴⁰ Isotopes of an element are atoms the nuclei of which contain the same number of protons but different numbers of neutrons.

expansion will be necessary. Eagle-Picher executives indicate that it would take about two years to replicate their current separation plant.

B10 fluoride has no known military applications outside the nuclear arena. IDA concludes, therefore, that there is no need to stockpile this material. Current EP consumption of boron trifluoride feedstock in the production of B10 fluoride is in the neighborhood of 3 metric tons per year.

Considerable research has been devoted to development of a class of boron chemicals called "boranes" which exhibit promise as rocket fuels. None of these chemicals is near application, however, and IDA therefore sees no reason to consider them for NDS purposes at this time.

Summary

As the above analysis indicates, total consumption of advanced boron products in 1987-88 was somewhere in the neighborhood of 65 metric tons. The boric acid equivalent of this is difficult to estimate with precision but must have been of about the same magnitude. In 1988 U.S. primary boron production on a boric acid basis was 566,000 metric tons. Even if all of the products involved had been produced utilizing domestic feedstocks, the advanced boron products sector would have been an insignificant market for the boron mining sector. This would remain the case if the production of any or all of these products should expand by several orders of magnitude, which is unlikely even under war conditions. This underscores IDA's conclusion that there is no resource problem in this sector.

While most of these products have promising futures, only boron carbide is currently of sufficient importance to the defense sector to warrant NDS consideration. With respect to this product, IDA's recommendation is to seek a more fundamental solution to the foreign dependency problem, not to stockpile.

APPENDIX H

SUBSTITUTION FOR STOCKPILED MATERIALS IN THE CIVILIAN SECTOR

SUBSTITUTION FOR STOCKPILED MATERIALS IN THE CIVILIAN SECTOR

This Appendix reports the progress and research plan for Current Initiative (13)--Emergency Substitution Possibilities in the Civilian Sector. Resource economics and metallurgical engineering literature dealing with substitution were examined, with the objective of determining feasible and suitable methodologies for developing civilian sector substitution rates for future reports to the Congress. Approaches to emergency substitution rate analysis and substitution rates used in previous stockpile reports were researched in order to determine current availability and quality of government substitution data. A proposed Fiscal Year 1990 research plan for developing feasible and acceptable near-term material substitution policies was then developed.

FINDINGS

- Analysis of substitution falls into two broad categories: studies having to do with resource depletion, on the one hand, and those concerned with sudden interruption of supply, on the other. Resource depletion is a long-term effect. We are interested in the short-run effect of a change in supply. Of the methodologies examined in our initial review, extrapolation, econometric analyses, expert judgement and engineering studies appear to be the most promising for analysis of the short run .
- We assume that manufacturers are using processes and materials which minimize cost. Any substitution away from the assumed economic optimum results in additional costs. These costs may be in terms of more costly materials, required investment--retooling, retraining, etc.--or in some cases an inferior product. Substitution in an emergency which results in an inferior product may represent a perceived infinite cost in many military hardware applications.
- Replacement over the long term of one material by another is the product of technological change. Once such replacement has begun, the investment in manufacturing processes, plant and equipment which accompany technological change cannot necessarily be recovered in order to reverse the process in the short run. Technological change may not be reversible except at great cost.

Therefore, we should concentrate our efforts on substitutes which are still competitive in at least some applications, i.e., where industrial capacity is still in place and can be expanded in an emergency.

- It appears that the last large-scale, government-sponsored study of substitution rates was completed in 1977 and was based on 1968 and 1973 data. The methodology used for initially determining these substitution rates and for updating them was essentially expert judgement. The estimates were reviewed by Bureau of Mines and Commerce analysts in 1978, and the results of this review provided the basis for the substitution rates used in the 1979 stockpile study. The 1979 estimates were updated for twelve commodities by the Department of Commerce with substantive input from the Bureau of Mines. These updated estimates were used, by FEMA, as inputs for the 1984 stockpile study.
- Although the FEMA substitution data used in the 1984 stockpile study are outdated, they are in sufficient detail to serve as a starting point for the analysis of the sensitivity of 1990 stockpile estimates to alternative substitution assumptions.

PROPOSED STUDY PLAN

The purpose of this research is to examine substitution models, available data and substitution rates developed for past stockpile studies in order to discover manageable techniques for determining feasible and acceptable near-term material substitution policies for the civilian sector. We have initially analyzed published reports and the existing metallurgical engineering and resource economics literature, with the objective of evaluating existing substitution rate estimates and methodologies, and determining potential feasible substitutes by industry.

The study on which the 1979 and 1984 stockpile study substitution rates were based concluded that at least one quarter of the current strategic and critical materials either had no satisfactory substitutes or the only substitutes were other stockpiled materials.¹ We have found this to be still true. During our preliminary analysis we have concentrated on the replacement of stockpiled materials with non-stockpile materials. However, replacement of strategic and critical materials by other stockpiled materials which are in excess of goals will be considered as soon as feasible.

¹ Jack Faucett Associates, Inc., *Rates of Substitution for Stockpile Commodities*, Government Services Administration, Washington D.C., June 1977.

The most recent substitution rates and lead-time data used in government-sponsored stockpile studies are based on research which is nearly 15 years old. As with many studies in the field, the available government substitution reports do not lend a great deal of insight into methodology, except that they appear to be based primarily on expert opinion. These studies and data do indicate potential substitutes at the four digit SIC code level. The substitution rates themselves may also be useful as a starting place for sensitivity analyses of the Secretary's 1990 report findings.

Most substitution studies address technological change from a long-term perspective. We are concerned with reversibility and the possibility of reverting to displaced processes in the short run. But studies of technological change, and the long-term substitution effect offer insight into the potential for reversing the process. The time path of technological change is generally "S" shaped (commonly referred to as a "logistic" curve). Replacement of one material by another takes place slowly at first, then increases for a time, and finally tapers off as the process becomes nearly complete.

The "S" shaped substitution path has been modeled by many researchers and it has been shown that the rate of change in the market share of a material which is becoming more competitive is proportional to the remaining market share of the material being displaced. The examination of the past progress of material substitution, using these models, may provide insight into the viability of potential substitutes in an emergency.² Knowledge of the existing market shares of two competing materials, and the predicted time when substitution will be complete provides information on the viability, as a substitute, of the material being displaced. If a non-stockpile material is no longer a competitor, the possibility of expanding its use in an emergency is decreased. Similarly, if the material which is gaining market share is displacing a stockpile material, the model would provide information on the potential for accelerating the process, and hence further substitution in the short run.

² Fisher, J. C. and R. H. Pry. "A Simple Substitution Model of Technological Change," *Technological Forecasting and Social Change*, vol. 3, 1971, (75-88). Fisher and Pry fit logistic curves to seventeen historical examples of substitutions and in each case found the "S" shape to be a consistently good fit. The form of the Logistic function used was:

$$f/(1-f) = \exp\{2a(t-t_m)\}$$

where: f = the market share of the new material at time t .
 a = half the annual fractional growth of the new material's market share in the early years.
 t_m = the time at which the substitution is half complete.

A problem common to any substitution methodology is how to treat investment in the industries providing the substitute. In our proposed approach, stockpile requirements would first be calculated with existing material input coefficients--without substitution.³ Then modified material input coefficients would be calculated using the estimated time-phased substitution rates. Note that substitution would in reality increase production demands for the substitutes in the planning scenario, potentially requiring investment to produce the substitutes themselves. Procedures to assess the scope of this complication will be developed as part of a test of the sensitivity of the 1990 stockpile findings to different substitution assumptions.

Although material substitution tends to lag or not react to price changes in the short run, there is at least one notable exception to this--cobalt in 1978--and possibly others. We will therefore also record total historical consumption and prices for each strategic and critical material, and consumption by SIC code for selected years.

During our initial investigation substitutes are being catalogued by specific characteristics. The purpose is to gain insight into the potential for substitution in various applications. These characteristics are:

- Degree of substitutability (perfect, partial).
- Technical feasibility.
- Cost factors.
- Rate of substitution.
- Substitution of one SCM for another.
- Energy considerations and substitution of petrochemical-based plastics.
- Availability of substitutes.

Once a data base has been developed, the work will turn to estimates of substitution rates and civilian tier stockpile requirements for future reports to the Congress on National Defense Stockpile requirements.

RESEARCH TASKS

This work has been divided into four tasks:

(1) Determining the availability of current estimates of substitution possibilities and rates of substitution. This task includes two sub-tasks: Sub-task (1.a) is a literature review

³ See Appendix C for a discussion of material input coefficients.

and interviews with experts in the field. Initial work on this task includes summarizing potential substitutes by industry classification to assist in focusing on those materials and industries with the greatest potential for substitution in the civilian sector. This summary, which has been completed, will also be useful in evaluating existing substitution data. Sub-task (1.b) is an evaluation of current substitution rates and the potential effect of substitution analyses on proposed stockpile goals. This sub-task will include an analysis of the sensitivity of the 1990 stockpile requirements to different substitution rate assumptions.

(2) Determining the applicability of specific methodological approaches to this research. An important part of this task is determining the availability of data to support candidate models. This has been started in conjunction with Task 1. We propose that it be continued and conclude with selection of a research plan for estimating substitution rates and civilian tier stockpile requirements for the *1991 Report to the Congress on National Defense Stockpile Requirements*.

(3) Estimating substitution rates and civilian tier stockpile requirements for the 1991 Report to the Congress on National Defense Stockpile Requirements. In addition to the models evaluated in Task (2), expert judgement of BoM and DoC analysts is expected to be relied on in this phase. This phase will be accomplished in conjunction with work being conducted by these agencies and the Institute for Defense Analyses.

(4) Devising a plan for improving the estimates for the 1992 report. This task will include a closer look at mid- and long-range substitution models. The potential for replacing strategic and critical materials with stockpile materials which are in excess of goals will also be examined in more detail.

APPENDIX I

A MICRO-DATABASE DECISION AID FOR STRATEGIC MATERIALS

A MICRO-DATABASE DECISION AID FOR STRATEGIC MATERIALS

A. INTRODUCTION

Several areas have been identified during IDA's Phase One NDS effort as promising candidates for collection of more refined data and design of systematic policy decision aids.

Three key areas are the following:

- development of procedures and data bases to more clearly distinguish anticipated emergency SCM supplies and production bottlenecks according to the forms of the material that domestic and foreign producers could provide to the U.S., e.g., ore, refined product, etc.;
- analyses of the architecture of current and anticipated emergency inter-nation (and inter-firm where possible) flows of SCMs in the mining/refining process to provide NDS decision-makers with credible evidence and options to minimize potential "Third-Country-Problems"¹ in NDS requirements planning;
- articulation of systematic decision-criteria and evidence to assist NDS planners in making form/grade recommendations for the National Defense Stockpile.

Today, individual U.S. material experts within the U.S. federal government and the private sector possess a wealth of detailed evidence and informal decision-criteria in these areas. Unfortunately, these data and decision-logics are not integrated in a form that is readily accessible to NDS planners and policy-makers. Preliminary discussions with officials in DoD, the Department of Interior and selected private-sector firms suggest that a

¹ The term "Third-Country-Problem" is a convenient label for two problems which stem from the fact that ores from one country may be processed in a second country before being shipped to the United States. The first problem is a double-counting error on the supply side. The second problem is inaccurate supplier country reliability assessments. The worst form of the double counting error would consist in assuming that two countries' production of a material are both fully available to the U.S. when in reality the total output of one of those countries would require the SCM output of the other country as a feedstock. Minimizing such potential double counting in the NDS Requirements estimates demands a clear articulation of inter-nation SCM flows on a material-by-material basis as well as a systematic decision-logic to avoid the problem.

management information system drawing together basic background information on SCMs as well as key evidence in each of these three areas could be of considerable value in overall NDS requirements planning processes. On the other hand, to be realistic, such a system would need to be focused very sharply on collection/integration of the highest value evidence for planners in each of these areas. Without very close, continuing attention to the relevance of the evidence being compiled, management information systems can easily grow like topsy, turning into endless fishing expeditions with little or no attention to the law of diminishing returns.

B. THE STRATEGIC AND CRITICAL MATERIALS DATABASE (MATBASE)

IDA has initiated development of a micro-database methodology (MATBASE) for application to the strategic and critical materials of interest to the Department of Defense. The information for each material contained in the MATBASE will be organized to address the following tasks:

1. Construction of a Capacity, Production, Consumption and Trade Profile

- Collection of time-series data for each U.S. supplier country on:
 - Raw material reserves, mining and/or refining capacity and annual production;
 - Domestic consumption of the material in downstream processing;
 - Exports and imports of the material and its derivatives.
- Identification of normal trade patterns and supply dependencies.
- Determination of mine or plant ownership and foreign control relationships.
- Graphic display of key trends.

2. Assembly of a U.S. Foreign Supply Dependency Profile

- Quantification of U.S. imports by country of origin and level of processing.
- Identification of third-country sole-source supplier dependencies.
- Evaluation of the nature of the U.S. dependency: e.g., natural resource scarcity, possession of proprietary technology by foreign producers, market imperfections (e.g., cartels); etc.

3. Assessment of U.S. Industrial Vulnerability

- Identification of the material's key civilian and military applications.
- Evaluation of U.S. vulnerability in the event of specific foreign supply denials:
 - Elasticity of supply from alternative sources of supply;
 - Civilian and military sector consequences of specific foreign supply denials;
 - Substitution possibilities and tradeoffs;
 - Identification of U.S. processing bottlenecks that would become of strategic importance in the event of specific foreign supply denials.

4. Summary of Policy History

- Past assessments of dependencies on the material and actions taken;
- National Defense Stockpile history:
 - Assessments of the material for NDS acquisition;
 - Stockpiling constraints (cost, storage stability, availability of domestic processing capabilities, etc.).

5. Economic and Technological Assessment

- Summary of technological trends in the production and utilization of the material and implications for:
 - Future patterns of production and consumption;
 - Future U.S. supply vulnerabilities;
 - Policy options (e.g., stockpiling constraints);
 - Substitution options.
- Evaluation of trends in civilian and military demands for the material:
 - Future civilian sector demand;
 - Weapons systems requirements under specific national strategy scenarios.
- Net vulnerability assessment.

The initial focus of this project is on the first task outlined above: assembly of data on reserves, mine capacities and production, smelting/refining capacities and production, and foreign trade. In this phase of the project, the emphasis for each material is on

quantifying the current structure of world capacity, production and trade as it relates to U.S. supply dependency, especially in relation to third-country suppliers.

IDA has already assembled data on reserves, production and trade for approximately 45 materials, relying wherever possible on official U.S. Bureau of Mines statistics. In many cases, however, completion of this phase of the project will require access to non-official sources of information because of gaps in the official data sources. Such gaps are especially common for the rarer advanced materials for which strategically important military requirements have recently emerged: e.g., gallium, germanium, rhenium, indium, tellurium, etc. For these materials, IDA will rely on its access to key industry and academic specialists in order to develop reliable estimates for the project. These specialists will also be valuable resources for later stages of the project.

Two types of flowcharts are central to IDA's concept of the MATBASE. The first of these flowcharts (see Figures I-1 and I-3) displays the various production stages for each material as well as the inputs and outputs at each stage. The chart displays the current technological structure of production for the material, and highlights the key factors affecting and constraining its flow through the stages of its economic and geographic structure. This flowchart, therefore, is essential as the MATBASE user's introduction to the industry producing the material. In the flowchart for rhenium, for example, note the relationship between rhenium, on the one hand, and the copper and molybdenum industries on the other. Note also that the flowchart reveals the key technological stages of production that structure the real-world rhenium industry: copper mining, copper ore concentration and molybdenite separation, molybdenite roasting and rhenium recovery, rhenium refining and production of rhenium intermediates, and consumption. An examination of several other materials will display graphically the interrelationships of various industries in the materials production processes--this is one of the important outputs of the MATBASE methodology.

The second type of flowchart (Figures I-2 and I-4) maps out the international structure of a material's current production and displays graphically the flow of product to the United States. This flowchart and its corresponding data illustrate the magnitude of U.S. dependency on foreign sources of supply, the identity of those sources, and potential U.S. supply vulnerabilities in the event of war. IDA's work on these flowcharts is still incomplete, with the result that there are some important data omissions in these figures.

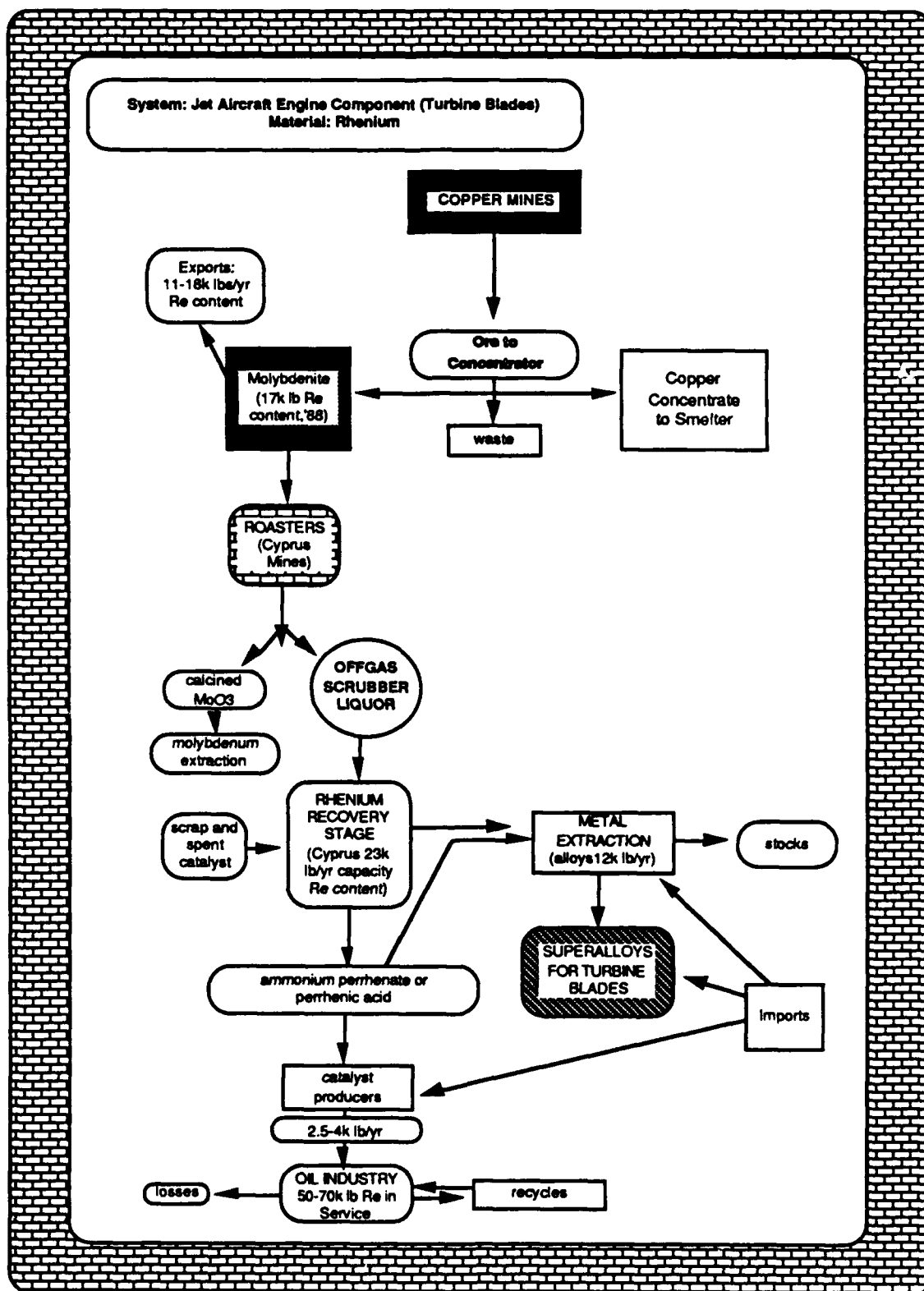


Figure I-1. First-Order Processing Flowchart for Rhenium

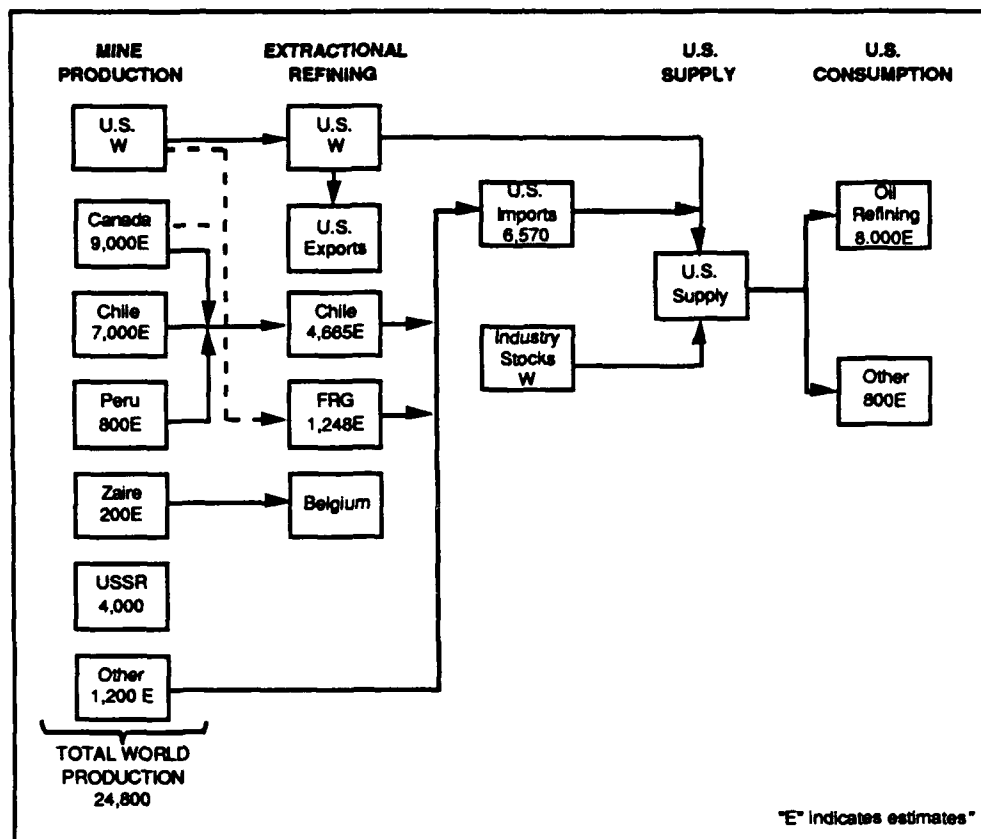


Figure I-2. Structure of World Rhenium Production and U.S. Imports, 1983 (Pounds Re Metal Content)

IDA's work on aluminum is highly preliminary at this time, but Figure I-5 is included at the end of this chapter to indicate the MATBASE potential for a more traditional material.

In practice, the MATBASE for a specific material will consist of a family of standardized support files defined with reference to the flowcharts. For example, there is in the second type of flowchart described above a "cell" for U.S. imports. The MATBASE will contain files presenting time-series data for:

- U.S. imports by commodity and country of origin;
- U.S. exports by commodity and country of destination;
- Imports as a percentage of U.S. civilian and military requirements.

Similarly, there will be a "cell" in the flowchart for refining activity if the material is refined at some stage. The MATBASE for the material will have support files for refining activities containing country data on:

- Refining capacity and production;
- Ownership and nationality of facilities;
- Origin of feedstocks;
- Destination of output.

Support files for the technological flowchart will contain information on:

- Key conversion ratios (e.g., how much feedstock is required, with current technology, to yield a unit of refined product) and input requirements;
- Substitution possibilities and the tradeoffs involved;
- Technology options at each stage of production (e.g., electrowinning vice traditional smelting in the copper industry);
- Sources of information on the material (e.g., trade associations, producing and supplying companies, consultants, government experts).

A typical MATBASE user interested in rhenium for possible NDS action would proceed in the following manner:

- First, the disk containing information on rhenium is loaded into a computer. This disk has a directory listing all the files in the MATBASE for rhenium, including information on file location. The user selects files incorporating Figures I-1 and I-2 in order to view first the structure of the industry and then the extent of U.S. import dependence.
- Second, the file with data on U.S. civilian and military consumption is selected. This file displays the uses of the material and its relative importance to various U.S. industries and to the defense sector.
- Third, the user may select the file containing information on any previous NDS assessments of the material.
- Fourth, the requirements for updates are noted in another file. The directory is selected in order to locate files containing the required information.
- A Search Directory with the names, addresses and telephone numbers of individuals and organizations that are sources of information on the material is available. The Search Directory for rhenium, for example, contains telephone numbers for the Rhenium Corporation, Inc., and for the U.S. Bureau of Mines rhenium specialist.

An important consideration for IDA is that the MATBASE be structured in such a way as to permit easy access both for non-technical users and database specialists responsible for periodic updating.

The next stage of this project includes the following tasks:

- Preparation of a prioritized list of materials for which MATBASEs will be developed.
- Development of a schedule for delivery of future products.
- Determination of manpower requirements.
- Development of a computer protocol and formulation of an information acquisition plan and schedule.
- Development of a prototype decision-making matrix or spreadsheet for NDS assessment purposes. This will assist in determining the types of information required in the MATBASEs.
- Assembly of the prototype MATBASEs for rhenium, tellurium and aluminum has already been initiated. These prototypes will assist in refining the methodology and in determining the full menu of MATBASE files that needs to be put together for each material.
- Graphic display of key trends.
- Development of a data update plan.

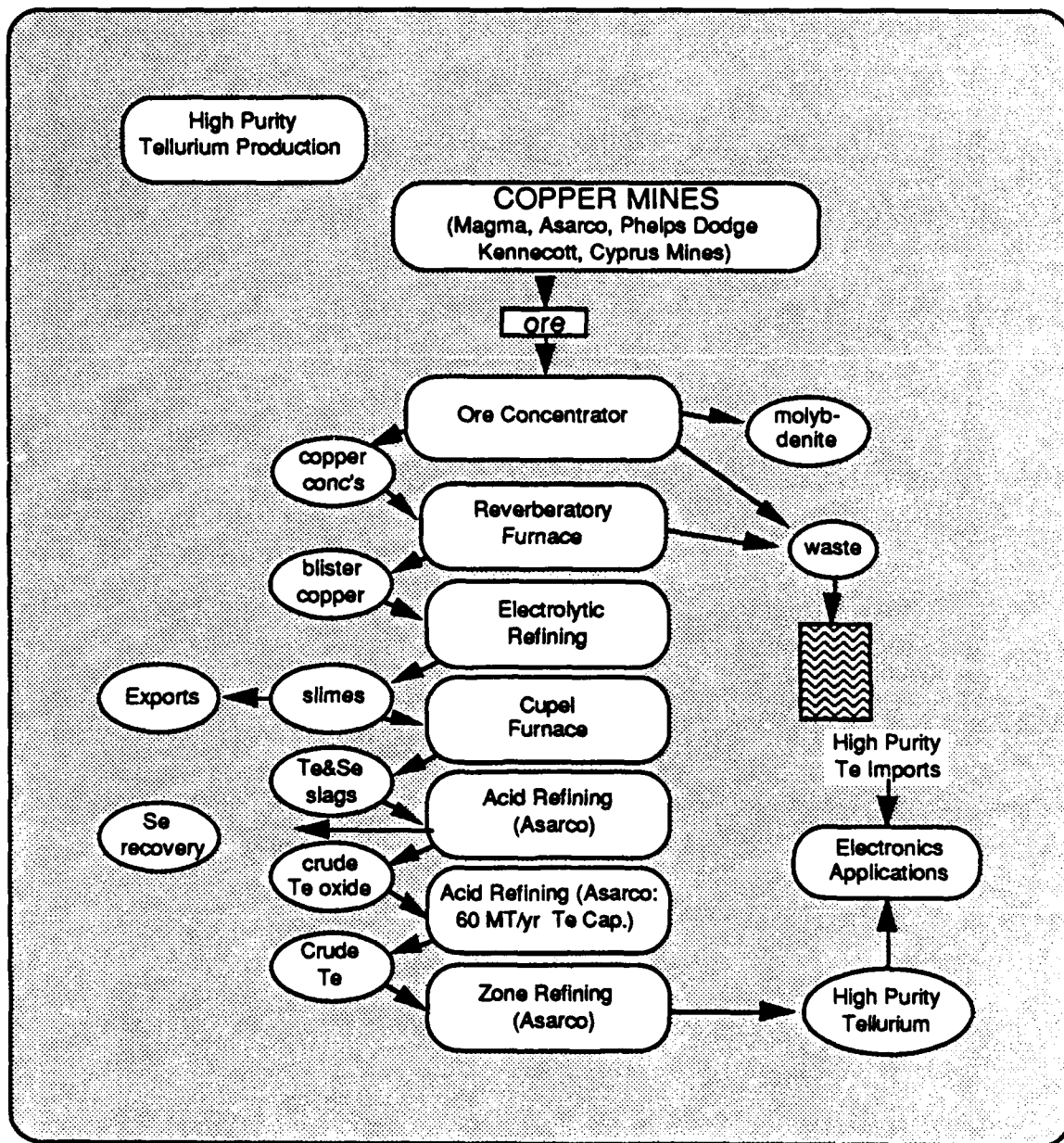


Figure I-3. First-Order Processing Flowchart for Tellurium

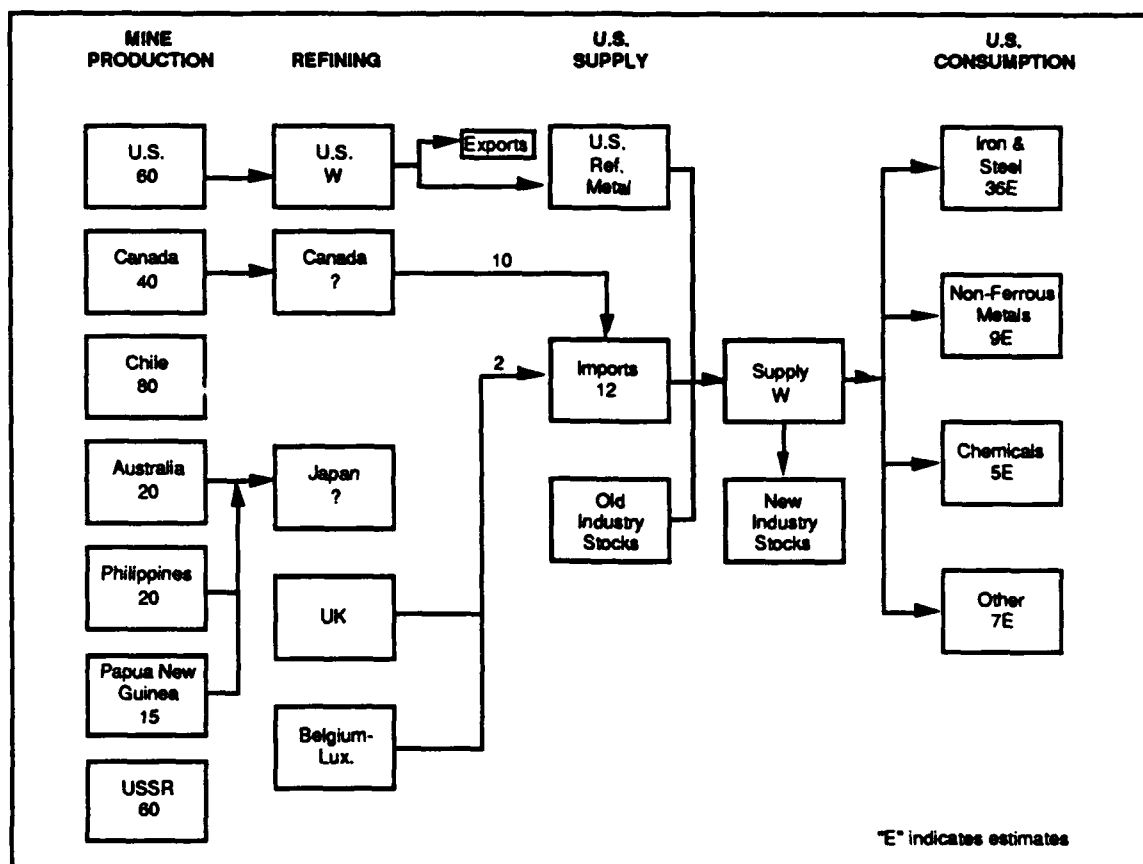


Figure I-4. Structure of World Tellurium Production and U.S. Imports, 1983 (MT Te Metal)

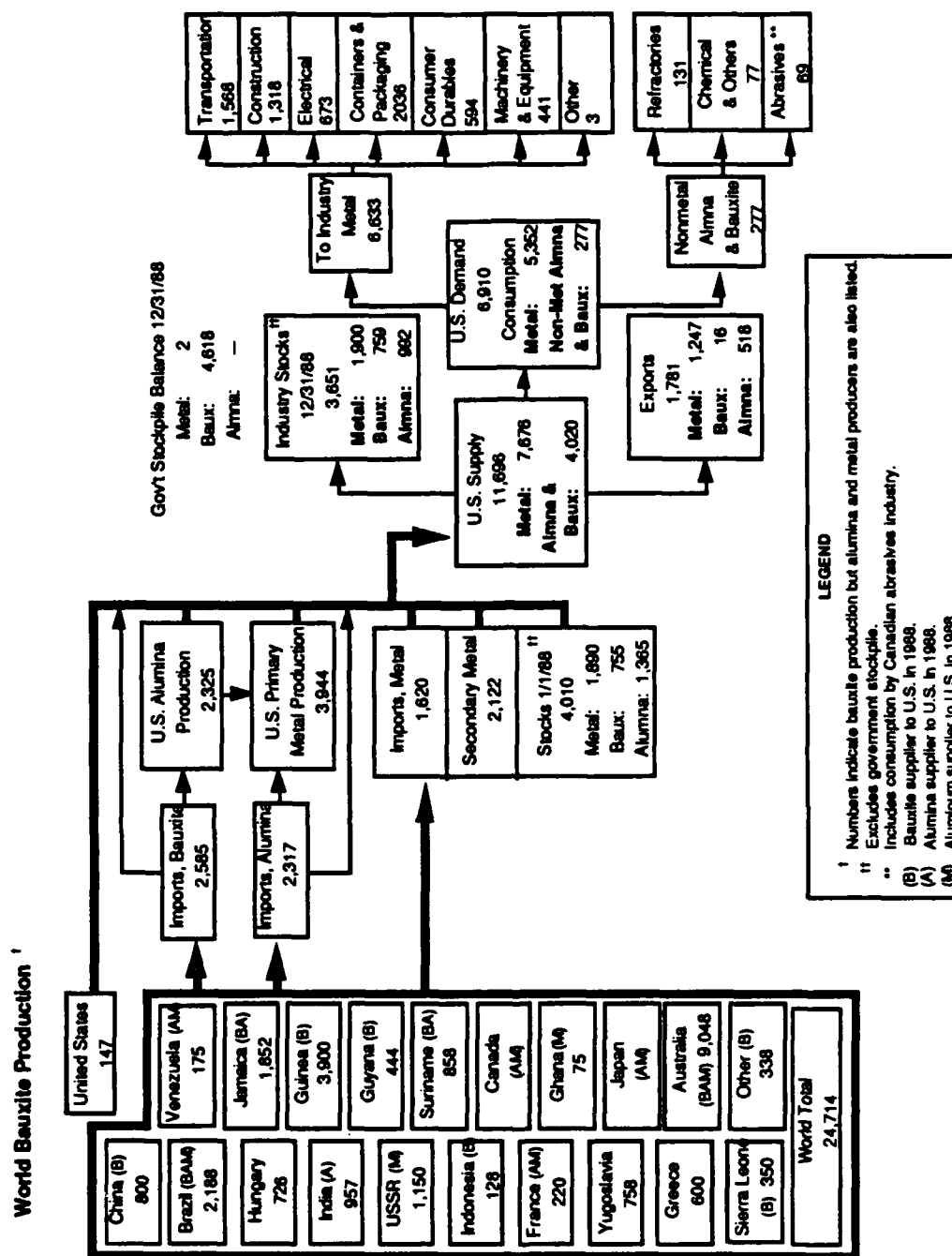


Figure I-5. Structure of World Aluminum Group Production and U.S. Imports, 1988 (Thousand MT Al Metal)²

² All quantities converted to aluminum metal equivalent; bauxite quantities divided by 4; alumina divided by 2. Because of rounding and simple division by whole numbers quantities may vary from actual aluminum content.

Source: Bureau of Mines, Minerals Yearbook.

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