Appendixes

Appendix A

Review of Previous Lists and Methods of Selection

Most lists of strategic materials are based, implicitly at least, on the two strands of criticality and vulnerability. A 1981 report by the Congressional Research Service listed the following criteria for defining a materials import "vulnerability" (as distinguished from import "dependency "):[1]

1. Critical need for the material.
2. Lack of adequate domestic resources (including both a total lack and an insufficiency).
3. Limited potential for substitution.
4. Lack of alternative sources of supply (including politically stable sources and geographically close sources).

It will be noted that factors (1) and (3) have to do with criticality of use, and factors (2) and (4) with vulnerability of supply. On the basis of these factors, the Congressional Research Service defined the following as "materials of particular concern":

Bauxite/aluminum
Cobalt
Chromium
Columbium
Manganese
Platinum-Group Metals
Tantalum
Titanium

A "semiquantitative" index for rating strategic materials on the basis of vulnerability was devised by the Strategic Studies Institute (SSI) of the U.S. Army War College in 1974.[2] The index was based primarily on five factors affecting vulnerability to "coercive pressures from foreign suppliers, " as follows:

1. Availability of domestic reserves.
2. Availability of substitutes,
3. Number and location of foreign suppliers.
4. Ideology of foreign suppliers.
5. U.S. stockpile objectives (based, at that time, on 1 year's wartime needs).

Materials selected for the SSI assessment were the 20 minerals for which the United States imported half or more of its requirements, plus tungsten. The authors included tungsten, even though U.S. import dependency for tungsten was below 50 percent, because the ratio of U.S. production to consumption was "rapidly decreasing" and because of "the unusual circumstances that the Communist countries possess about 75 percent of world reserves."[3]

Of the 21 materials, 10 were eliminated "because of favorable combinations of such factors as adequate U.S. reserves, declining domestic demand, available substitute materials, availability of technology to process low-grade ores, and proximity of foreign supplies."[4] The other 11 minerals were assigned index numbers and ranked by relative vulnerability, as shown in table A-1.

The SSI does not describe exactly how the index numbers for each material were derived. The text implies that the index numbers are the sum of numerical values assigned (on the basis of the authors' judgment) to each of the five principal factors mentioned above. The selection of these factors gives far more weight to vulnerability of supply than to criticality of use. However, it is evident from the text that factors other than those five entered into the ratings. For example, the authors' discussion of individual materials refers to the essential uses of each, as well as the availability of substitutes. In any case, as the authors state, the numbers do not refer to anything quantitative but were based on "qualitative assessment, " that is, their own judgment.

In 1977, one of the authors of the SSI study revised the vulnerability index in an attempt to refine it and make it more quantitative.[5] The 1977 version of the SSI Index included 27 factors, each rated for the importance of its influence on economic, political, and military vulnerability of materials. Table A-2 shows the factors and their ratings.

Of the 27 factors on the list, no more than 5 are related to criticality. Not one explicitly mentions the essential uses of particular materials. Yet one must assume that essential uses are implicit in the rating scheme, at least in the selection of materials to rate and in assessing the availability of substitute materials.

A further complication in the rating scheme is that each of the 27 factors is also assessed for the

[1] Congressional Research Service, *A Congressional Handbook on U.S. Materials Import Dependency/Vulnerability,* cited in note 2, p. 341 ff.

[2] Alwyn H. King and John R. Cameron, *Materials and the New Dimensions of Conflict,* Strategic Studies Institute, U.S. Army War College (Carlisle Barracks, PA: 1974) available from National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22151 (AD/A-004263).

[3] Ibid., p. 5. 1981 estimates indicate that China holds 47 percent of the world reserve base of tungsten, and another 11 percent is in the Soviet Union and North Korea. Both Canada and the United States have large reserve bases of tungsten; Canada's is 15 percent of the world trade.

[4] Ibid.

[5] Alwyn H. King, Materials Vulnerability of the United States—An Update, Strategic Studies Institute, U.S. Army War College (Carlisle Barracks, PA: 1977), available from the Defense Technical Information Center, Defense Logistics Agency, Cameron Station, Alexandria, VA 22314,

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Table A-1.—Strategic Studies Institute Index of Relative Vulnerability: 1974 Ranking

Material	Vulnerability index	Principal or major exporters
Chromium	34	Soviet Union, South Africa
Platinum metals	32	Soviet Union, Canada, South Africa
Tungsten	27	Canada, Peru
Manganese	23	Brazil, Gabon
Aluminum	22	Jamaica, Canada
Titanium	20	Australia, Canada
Cobalt	20	Canada, Zaire
Tantalum	16	Canada, Brazil, Zaire
Nickel	14	Canada, Norway
Mercury	11	Canada, Mexico, Spain
Tin	6	Malaysia, Thailand

SOURCE: Alwyn H. King and John R. Cameron, *Mater/a/s arrd the New Dimensions of Conflict,* Strategic Studies Institute, U.S. Army War College (Carlisle Barracks, PA, 1974)

Table A-2.—Factors Affecting Materials Vulnerability Index: 1977 List

Factor	Effect on Vulnerability		
	Economic	Political	Military
Domestic reserves:			
Availability	L	L	L
Cost of developing	L	L	s
Domestic production industry:			
Present capability	L	L	L
Cost of augmenting	L	L	S
Substitute materials:			
Present availability	L	L	L
Cost of research to develop	L	L	S
Time required to develop	L	L	L
Additional domestic resources:			
Present availability	L	L	L
Cost to develop suitable processes	L	M	M
Time to develop suitable processes	M	M	M
Probability of discovery if not available	M	M	s
Cost of additional exploration	M	M	s
Foreign suppliers:			
Number of controlling companies	L	s	M
Number of supplier countries	M	M	M
Political stability of supplier countries	M	L	M
Ideology of supplier countries	M	L	M
Productive capacity of supplier countries	L	L	L
Economic sufficiency of supplier countries	L	L	s
History of political relations with U.S.	s	M	s
U.S. dollar involvement in supplier country	M	M	s
Accessibility of supplier countries (supply routes)	s	s	L
U.S. stockpile:			
Present U.S. stockpile objective	L	L	L
Actual quantity in U.S. stockpile	M	M	M
Customary industry stockpile	M	M	M
Trend in usage of critical material	M	M	s
Proportion of national consumption directly related to military requirements	s	s	L
Importance of secondary sources (recycling)	M	M	M

KEY: L = Large
M = Medium
S = Small

SOURCE: Alwyn H. King, *Mater/a/s Vulnerability of the United States—An Update,* Strategic Studies Institute, U.S. Army War College (Carlisle Barracks, PA: 1977).

direction of its influence on vulnerability; that is, whether it currently contributes to a significant increase, a moderate increase, or a decrease in the vulnerability of material supplies. All these factors, including their importance and direction, are given numerical values, the sum of which is the "relative vulnerability index" number of each material. Figure A-1 shows the results for four materials.

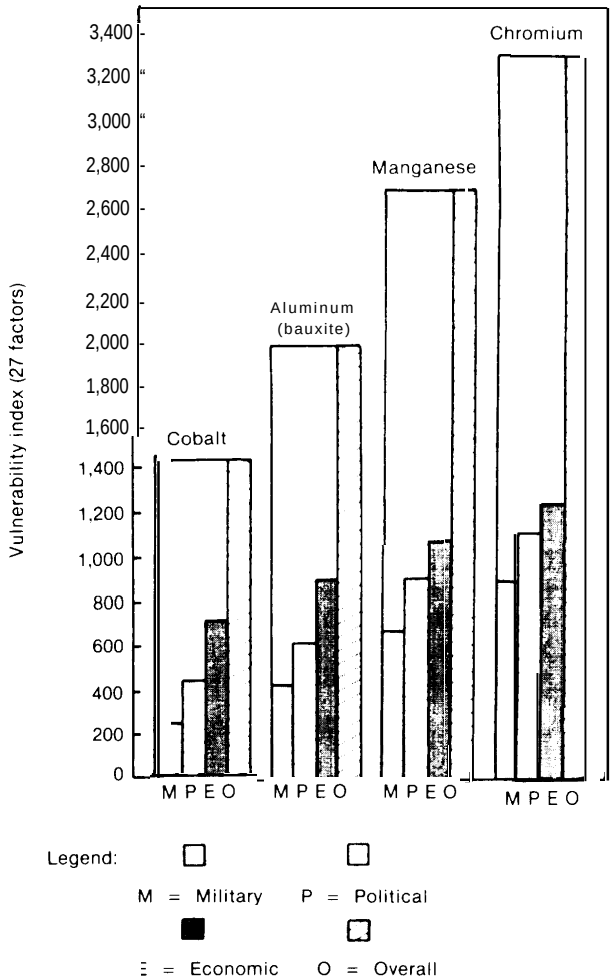
The authors suggested using this numerical index to help set priorities for stockpiling, allocation of funds to research and development, and other such decisions. A pitfall in using this index, or others like it,[6] for such purposes is that it may convey a misleading impression of certainty or objectivity. The use of index numbers to show "relative vulnerability" may be a convenience but does not at all evade the necessity of applying subjective judgment—as the authors of the index recognized. Judgment is involved at every step: in deciding what factors to include, how much importance each should be given, how to rate a material in relation to a specific factor (e. g., "political stability of supplier countries"), and so on.

Another attempt to construct a systematic rating system for strategic materials was the Critical Minerals Index pilot study done by the U.S. Department of the Interior's Office of Minerals Policy and Research Analysis in 1979.[7] Designed to be used as warning of potential problems, the index included two components: one to measure the likelihood of disruption of supply (i.e., vulnerability) and the other to measure the cost of disruption or, conversely, the importance of the minerals to the U.S. economy (including factors of vulnerability and criticality). The scheme proposed to use the subjective judgment of a panel of experts to assign index numbers for both components to specific minerals.

Examples of events considered possibly disruptive to supply were:

- Collusive price agreements (cartels).
- Shifts in demand.
- Embargoes.
- Labor strife.
- Transportation bottlenecks.
- Violent conflicts, including local rebellion, regional war, riots, border skirmishes, blockades, and sabotage.

Figure A-1.—Strategic Studies Institute Relative Vulnerability Index: 1977 Ranking



NOTE: Overall Index number is the sum of military, political, and economic index numbers

SOURCE: Alwyn H King, *Materials Vulnerability of the United States — Arr Update*, Strategic Studies Institute, U S Army War College, (Carlisle Barracks PA: 1977)

Factors suggested for inclusion on the cost side were:

- The magnitude and duration of the disruption.
- Total annual U.S. demand for the mineral.
- Availability of alternative sources of supply; e.g., domestic or other foreign sources.
- Time required to deliver alternate supplies.
- Availability of substitutes.
- Time required to adopt substitutes.
- Expectations of those controlling investment about the future of alternative supplies and of substitute technologies.

[6] An index with some similarities to the Strategic Studies Index, with a clearer description of how it is constituted, is in Bohdan O. Szuprowicz, *How to Avoid Strategic Materials Shortages (New* York: John Wiley & Sons, 1981), p. 8ff and p. 285 ff.

[7] Robert L. Adams, Barbara A. White, and James S. Crichar, ***Developing a Critical Minerals Index: A Pilot Study,*** Office of Minerals Policy and Research Analysis, U.S. Department of the Interior, July 1979.

The Critical Minerals Index was simply proposed in a pilot study. Its authors did not apply it to produce a list of minerals.

A different approach to a rating system for strategic materials, making no attempt to produce overall index numbers, was proposed by the British Institute of Geological Sciences (IGS) in a 1982 Memorandum to a Committee of the House of Lords in Parliament.[8] Dividing the factors that define a strategic material into the vulnerability and criticality strands, the institute's vulnerability list included:

1. Import dependence (besides net import dependence, this factor included total import dependence, recognizing that some of Britain's minerals processing and export industry relies entirely on the import of raw materials).
2. Concentration of supplies to Great Britain.
3. Concentration of world production.
4. Indirect import dependence, involving a long, complex chain of supply.
5. Concentration of world reserves (or "economic resources").
6. Reliability of producer countries.
7. Market mechanisms, which include:
   - Ž the lead time to develop new productive capacity.
   - • the proportion of materials tied up in long-term contracts, compared to the amount available on the "free" market.
   - • the potential for cartel formation, on the basis of shared interests and values of producers.
8. The potential for recycling.
9. The adequacy and security of supply links on land and sea.

The IGS memorandum pointed out that many of the measures for vulnerability can be quantified, some quite simply. To show the concentration of suppliers to Great Britain, the IGS devised an index based on the total number of supplying countries and the share they supply; the same kind of index was used to denote concentration of world production, Reliability of supply, on the other hand, cannot be quantified because it depends on such considerations as political stability, ideology, or "excessive economic nationalism, " which are matters of qualitative judgment.

On the criticality side, the institute mentioned the range of uses, the availability of substitutes, the nature of British industries consuming the material, and a number of measures of the economic importance of the material, all of which, the IGS conceded, were difficult to analyze and apply.

Altogether, the IGS concluded that criticality cannot be quantified readily. The quantitative pointers are either crude or trivial. The more important questions—defining the national interest, judging the importance of one manufacture in relation to another, determining whether substitutions for a material are possible and how long it would take to effect substitutions— are all matters of judgment. However, it is possible to combine judgments about these factors into a subjective criticality rating of high, medium, or low for each material.

Overall, the IGS rating scheme separated the vulnerability and criticality strands; disentangled factors which can be quantified from those which cannot; quantified different factors, each in its own terms; and gave subjective ratings to factors that cannot be measured adequately by quantitative indicators. No effort was made in the scheme to combine all these unlike "apples and oranges" into a common index number.

In their statement to the House of Lords, the authors concentrated on describing their rating scheme rather than applying it to produce a list of strategic materials. They did select 15 materials to illustrate how the scheme would work. Two of the 15 materials were selected to show the independence of vulnerability and criticality. Fluorspar is critical for the production of aluminum and steel, but is mined in Great Britain and thus is not regarded as vulnerable. Vermiculite has high vulnerability because Great Britain is entirely dependent on imports from one dominant supplier (South Africa), but it is not critical because substitutes are readily available. Of the 13 other materials used to illustrate the IGS rating scheme, the authors said that most "are likely to manifest high degrees of both vulnerability and criticality, and would therefore be identified as strategically important." They are:

Aluminum	Nickel
Columbium	Phosphate rock
Chromium	Platinum-group metals
Cobalt	Tantalum
Manganese	Tin
Molybdenum	Tungsten
	Vanadium

The materials selected are strategic to Great Britain but not necessarily to the United States, Molybdenum, for example, would not appear on a list of U.S. strategic materials because the United States is the world's largest producer and exporter and holds more than half of the world's resource base—a great deal more than any other country.

[8] Institute of Geological Sciences, *Strategic Minerals,* Memorandum submitted to the Parliament, House of Lords. Select Committee on the European Community (Subcommittee F), Feb. 18, 1982.

A simpler scheme, based on the aggregate judgment of an expert panel, was used by the British Materials Forum on Strategic Materials.' Applying the concepts of degree of criticality and degree of vulnerability to the metals used by British industry, the forum reported that "the following group of eight metals emerged as meriting the highest priority in the newly defined strategic sense'':[10]

Chromium	Manganese
Cobalt	Vanadium
Columbium	Molybdenum
Tungsten	Platinum-group metals

All members of the forum agreed on the rating, and all the metals were thought to merit equal rating. Again, the materials listed are strategic from the British point of view,

For each metal on the Materials Forum list, the criticality aspect was brought out by examining the metal's more important uses in key industries. To help assess vulnerability, the forum members looked at the ratio of reserves to production in each of the major producer countries of the world to estimate which countries are likely to become dominant in the future. The group recognized that the reserves-to-production ratio is a "static" indicator of reserve life (and could very well change as new reserves are discovered or as countries' rates of production change). The members used qualitative judgment, as well, in estimating probable future diversity of supply and in evaluating the political factors involved in vulnerability of supply.

The flavor of the forum's evaluation is suggested by the following excerpt from its discussion of chromium:[11]

> Although the physical long-term supply situation for the world as a whole looks reasonable. . nevertheless, 97 percent of the presently known reserves of chromium are located in South Africa and adjacent Zimbabwe. The relatively small reserves located in other countries indicates that their present levels of production are unlikely to be maintained for more than 10 to 20 years (unless new reserves on a very substantial scale are found and then developed commercially within this time scale). Thus, along with many other consumer countries, the U.K. could steadily shift towards a greater dependence on South Africa and Zimbabwe for chromium supplies, whatever countries are supplying us at present. Since these two countries are surrounded by political uncertainties, or at least such is the generally accepted view by most Western countries, then imports to the U.K. need to be regarded as becoming increasingly "vulnerable" in the future.

[9] The Materials Forum, ***Strategic Metals and the United Kingdom,*** cited in note 3.

10 Ibid., p. 3.

[11] Ibid., p. 6.