NUCLEAR FUEL ASSURANCE:
ORIGINS, TRENDS, AND POLICY ISSUES

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ABSTRACT

The economic, technical and political issues which bear on the security of nuclear fuel supply internationally are addressed. The structure of international markets for nuclear fuel is delineated; this includes an analysis of the political constraints on fuel availability, especially the connection to supplier nonproliferation policies. The historical development of nuclear fuel assurance problems is explored and and assessment is made of future trends in supply and demand and in the political context in which fuel trade will take place in the future. Finally, key events and policies which will affect future assurance are identified.

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1. INTRODUCTION

The security of nuclear fuel supply is a source of economic and political concern to many countries. These worries result in part from a heightened awareness of the role of energy in national economic health and security in the wake of the 1973-74 oil crisis and an increased sensitivity to the vulnerability of foreign sources of energy supply. However, other issues and events specific to nuclear fuel have exacerbated this general assurance problem. The oil crisis increased the importance of nuclear power to Western Europe and Japan, and the resulting large capital-intensive reactor commitments have created their own fuel supply imperatives. The nuclear fuel supply system is also complex, requiring a sequence of processing steps, several of which are highly concentrated in a few supplier countries. Historically, nuclear fuel supply has experienced serious market and political problems, including substantial variations in market conditions, market failures and changes in policies of key suppliers. All of these have contributed to intense concern about the security of fuel supplies in the future.

Nuclear fuel assurance concerns also interact strongly with nuclear technology development plans and with international security considerations associated with nuclear weapons proliferation. The perceived insecurity of supplies of the low-enriched uranium fuel used in today's light-water reactors creates an incentive for some countries to build their own fuel cycle facilities and to move more rapidly toward new technologies which use less uranium and thereby reduce dependence on others. This desire creates a pressure to commit to commercial development of new technologies earlier than would otherwise be necessary -- perhaps with results less satisfactory from an economic or technical perspective. But the most serious implication of this drive for independence is its effect on the achievement of nonproliferation goals.

Accelerated commitments to enrichment facilities, to spent fuel reprocessing and plutonium recycle, or to plutonium breeders -- all of which could make weapons-usable material more immediately available to more countries -- are now viewed, in the United States and elsewhere, as straining the capabilities of the existing nonproliferation regime. Assurance of low-enriched uranium fuel supply is thus regarded as playing a key role in retarding such proliferation-sensitive commitments. However, this relationship is complicated by supplier imposition of new nonproliferation conditions on access to nuclear fuel that, from a consumer perspective, may lead to a perception of reduced rather than improved assurance.

As a result of these complex interrelated concerns, the issue of nuclear fuel assurance has assumed a central role in U.S. nuclear policies. It is also central to the discussions of the International Nuclear Fuel Cycle Evaluation (INFCE) in which 50 nations are now participating. In this paper we explore the web of technical, economic and political issues which underlie the reality and the perceptions of fuel assurance:

- What are the primary fuel assurance problems and how bad are they now?
- What are the major factors and historical events which have led to the present situation, and current perceptions of it?
- What are the trends in the evolving system, and what are their implications for future conditions of fuel supply and demand?
- How would alternative national and international policies, events and mechanisms affect future fuel assurance, and perceptions of it?

In the sections that follow, we analyze the origins of the fuel assurance problem, and attempt to identify the current trends and policy actions that will determine future supply conditions. We begin, in Chapter 2, with a definition of what the assurance problem is. Difficulties in fuel supply are divided into short, medium and long term aspects. The short term issues arise out of the possiblility of temporary interruptions in supply; the long term is a matter of resources and reserves, and their relation to expected growth in reactor developments. In the medium term--the next one to two decades--fuel assurance involves the ability of a nation to contract for fuel supplies under acceptable terms and conditions, and with a degree of certainty that delivery will occur. It is this medium-term aspect of fuel assurance that is the primary focus of our analysis.

The investigation begins, in Chapter 3, with a description of the structure of the nuclear fuel industry. This material provides the groundwork for discussion in subsequent sections; it also makes evident that some assurance problems are inherent in the industry structure itself, due to technical complexity, the high level of concentration of supply, and the necessary overlay of national and international rules and regulations arising out of proliferation concerns.

Based on this discussion of the structure of the fuel cycle, Chapter 4 looks at the events that have shaped the industry over the past thirty years. Civilian nuclear development is seen in terms of three eras: a period (following WW II) of gradual emergence from military programs; a time (from the mid-1960s to early 1970s) of rapid commercial expansion; and a recent period (since around 1973) of disruption, confusion and contention. The events of this last era are usually identified with the fuel assurance issue, though the historical review indicates that the seeds of trouble were planted much earlier. The problems of fuel supply are historically complex, involving issues of supply concentration, increasingly strenuous competition in international markets for nuclear equipment, and a very important set of political developments, driven mainly by proliferation concerns.

Chapter 5 presents an analysis of current trends in the fuel supply system, and identifies their effects on fuel assurance. The argument made there is that future directions in fuel assurance depend heavily on the resolution of current international disagreement about nuclear export policies and their relationship to nonproliferation goals. If current discussions lead to a uniform set of conditions for international trade, then trends elsewhere in the supply system lead to optimism about fuel assurance in the medium term. If, on the other hand, current political differences are not resolved, then there is cause for concern about both fuel assurance and the success of current nonproliferation strategies.

The implications of all this for current policy formation are drawn out in Chapter 6, which also presents an overview of the preceding analysis. Resolution of problems and differences in attitudes toward the connection between nonproliferation and low-enriched fuel supply head the list of issues, but there also are other actions which will affect the health of the system, whatever the resolution of current differences.

2. WHAT IS "FUEL ASSURANCE?"

The term "fuel assurance" is a catch-all for a host of issues in nuclear fuel supply, and it is useful to distinguish different categories of concerns. Assurance issues may differ according to

- The decision unit,
- The purpose for which assurance is required, or
- The time horizon of interest.

Regarding the first of these, our focus is on the nation. Where intra-national divergences of interest are significant (say, among utilities, reactor manufacturers, and government agencies) we will try to take them into account. Intra-governmental disputes about nuclear fuel policy play a significant role in the history of particular parts of the fuel cycle (particularly enrichment in the United States) and must be considered. With the exception of particular circumstances, however, most of the issues are usefully discussed in terms of the views and actions of national units.

Regarding the purpose for which assurance is sought, most of the discussion can take place on the assumption that the concern is with security of national electric supply. In some cases this is not the whole story. Assurance of fuel supply may also be desired in order to bolster the commercial interests of nuclear equipment and supply industries, and on occasion this factor will be brought into the analysis.

The third basic division of assurance issues is by time horizon. We divide the future, somewhat abritrarily, into a short, a medium, and a long term.

2.1 The Short Term: Resilience to Crisis

In the short run, the assurance problem results from the possibility that previously arranged fuel supplies may be cut off or delayed. An interruption might result from a plant accident or some other result of nature or commerce, but the main fear is of political change, either within the supplier country or between supplier and purchaser. The withholding by Canada in 1977 of U_3O_8 under contract with Japan and others is an example. The effects of such events depend on several factors. It matters a great deal where in the supply chain an interruption occurs. Lead times in the nuclear fuel cycle are long* compared to those associated with fossil fuels and interruption early in the process (e.g., U_3O_8 supply) is less serious than a problem with enrichment or, even worse, fuel fabrication. Also, the effects of an interruption depend on the size of available stocks, and on the country's ability to gain access to substitute material in the short run, through spot purchases or loan or swap arrangements. Finally, the consequences depend on the role played by nuclear power in the country, on the extent of self-sufficiency in fuel supply, and on the magnitude of the interruption relative to the total nuclear fuel requirement.

A rough measure of short-term assurance is provided by estimating the time a national nuclear-electric system can operate in the face of a complete supply interruption, assuming no access to supplemental supplies. The numbers are surprising large: for problems of uranium supply they range between three and six years for most major nuclear nations, somewhat lower for countries with small nuclear programs. For interruption of enrichment, the delay before significant effect on power output can still amount to several years. This "flywheel effect" is due to both the long natural lead times (discussed in greater detail in Section 3.1) and the large stocks of fuel now held by many national authorities, processing firms, and utilities.

2.2 The Medium Term: Contract Conditions

Short-term crisis resilience refers to the characteristics of a reactor fuel system under the stress of major interruption. Medium-term assurance has to do with the ability of a country to contract for future supplies. Utilities must commit large amounts of capital to nuclear reactor construction, and insecurity of fuel supply threatens both this investment and the reliability of electricity supply. As a result, fuel

*See figure 3.1, next chapter.

insecurity can be a hindrance to nuclear programs in the competition with other forms of electric generation, and can adversely affect national economic health and security. In addition, the ability to arrange fuel supplies can be important in the international competition for reactor sales. Thus the medium-term fuel assurance concerns of small nations may affect the export interests of reactor vendors and supplier nations.

There is no simple index of medium-term assurance, but it can be set out in concept: it is the likelihood that a purchaser can contract for fuel cycle services, under a set of acceptable conditions, and with reasonable certainty that the contract will be fulfilled as written. Further, it is the prospect that he can diversify any residual risks by spreading purchases over multiple suppliers.

The concept of medium-term assurance takes account not only of the terms and conditions of available uranium and enrichment contracts: it also involves the likelihood that known resources will actually be exploited. Some nations (notably Canada and Australia) loom so large in the uranium picture that the threat of withdrawal from the market (as Australia did from 1972 to 1976 and as Canada did, in effect, in 1977) can create problems of medium-term fuel security. In addition, there is uncertainty about the capability of the uranium industry to expand in the medium term, even if exporter nations are willing and the resources are there. Some observers foresee limitations on the rate of expansion in mining and milling that can be attained.

2.3 The Long Term: Resource Adequacy

In the long term, toward the end of the century and beyond, the issue is the uranium resource base--its cost of exploitation and its size in relation to nuclear power programs. Uncertainty about likely resources and reserves at various cost levels is great, and views of the future vary widely. Some analysts regard uranium as a rapidly depleting resource and argue that competition will soon bid up the economic and political costs of nuclear fuel. Others see uranium as a resource whose exploitation is still in its infancy, and regard present estimates as conservative lower bounds on quantities ultimately available. They cite the lack of incentives for exploration in the past, and recurrently unhealthy markets, as reasons to doubt the value of extrapolations based on currently available information. Perceptions of long-term assurance will depend on how this debate evolves.

The linkages between the medium and long term are strong. Uncertainty about the evolution of the LWR fuel supply system, or its continued disruption, will influence the mix of technologies used over the next few decades, as well as the size of the nuclear-electric sector as a whole. If expectations of fuel availability for present converter reactors (or their somewhat more efficient successors) are low, then nations will accelerate research and development and deployment of technologies which are much more uranium-efficient. While in principle there are many such technologies, those closest to technological maturity, like the breeder reactor stressed in most programs, involve the use of plutonium fuels. Research and development aimed at early deployment of plutonium breeders involves even earlier commitments to pilot plutonium facilities. Since the use of plutonium could provide more immediate access to weapons-usable material, worries about long-term nuclear fuel availability have a considerable impact on contemporary international concerns.

3. STRUCTURE OF THE FUEL SUPPLY SYSTEM

To some degree, issues of fuel security are inherent in the structure of the nuclear industry. Fuel cycle technology is complex and expensive, and many countries lack the capability to develop indigenous facilities in the short or medium term. Moreover, supplies of critical materials and services are concentrated in a few countries, leading to fears that existing sources may be used as a political or economic weapon, or may simply turn out to be undependable. Finally, nuclear fuel is inevitably coupled to the problem of nuclear weapons, and to the fabric of treaties, controls, and safeguards that have been designed to curb the proliferation of weapons capability.

Paradoxically, under current circumstances these system characteristics combine to provide a high degree of short-term fuel security. To a large extent, this is due to the technical structure of the industry, and it is to this aspect of the nuclear cycle that we turn first. Then, we review the market structure, and the fabric of political constraints, which are important aspects of the assurance problem in the medium term.

3.1 Technical Structure

Fuel for a light-water reactor (LWR), the dominant reactor type* worldwide, is the result of a long series of processing steps that begins with the mining of uranium-bearing ores and ends with a batch of fuel assemblies which are used to replace, approximately annually, 1/5 to 1/3 of the total fuel material in a reactor. In processing, the uranium ore is milled to recover the 0.1 percent to 10 percent or more uranium contained in it. The result is yellowcake: U_3O_8 with some impurities.

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*The great majority of reactors now in service, and an even greater fraction of those to be constructed over the next decade will be of this type. A few reactors will use natural uranium, rather than the low-enriched uranium used in LWRs. Most of our discussion focuses on the fuel needs of LWRs, though the analysis of uranium supply clearly applies to those of natural uranium reactors.

The yellowcake is then purified, and the uranium coverted to a new chemical compond, UF_6. At this stage uranium contains only about 0.7% of the fissile isotope U235, the remainder being U238. Of these, only U235 can be fissioned by the low-energy neutrons which mediate the chain reaction.

Since the concentration of U235 in natural uranium is too low to sustain a chain reaction in an LWR, the proportion of this isotope must be increased to about 3% by isotopic enrichment, a technology which has been developed commercially by only a few countries. A fraction of the original U235 -- variable, within limits, by the enricher -- remains as "tails" from the enrichment process. After it leaves the enrichment plant, the enriched UF_6 goes to a fuel fabricator where it is converted to uranium dioxide (UO_2), formed into pellets and fabricated into fuel assemblies. Fuel fabricated for one reactor generally cannot be used in another.

This sequence of processing steps is more complicated than for other energy forms, and it requires more time. An idealized procurement schedule for a pressurized water reactor, one of the two main types of LWR, is shown in Figure 3.1. There is a rectangle for each step in the process, and the first core (or full) loading and several reloads are shown. The height of each rectangle gives a rough indication of the quantity of material or fuel-cycle services involved in that step, and the length represents the time required. Note that the manufacture of the first core requires more inputs than reloads. Roughly three years are required to produce the initial fueling, and reloads take more than twenty months. When there are uncertainties--as when international purchases are involved or renegotiation of contracts may be required--utilities generally allow still more time between fuel cycle steps.

Thus interruption at early stages of the fuel cycle would not have an immediate effect on output. For example, failure of delivery from a natural uranium supplier would not result in an interruption of electric generation for nearly two years. This is very different from the situation with oil where near-term crises develop rapidly: the time

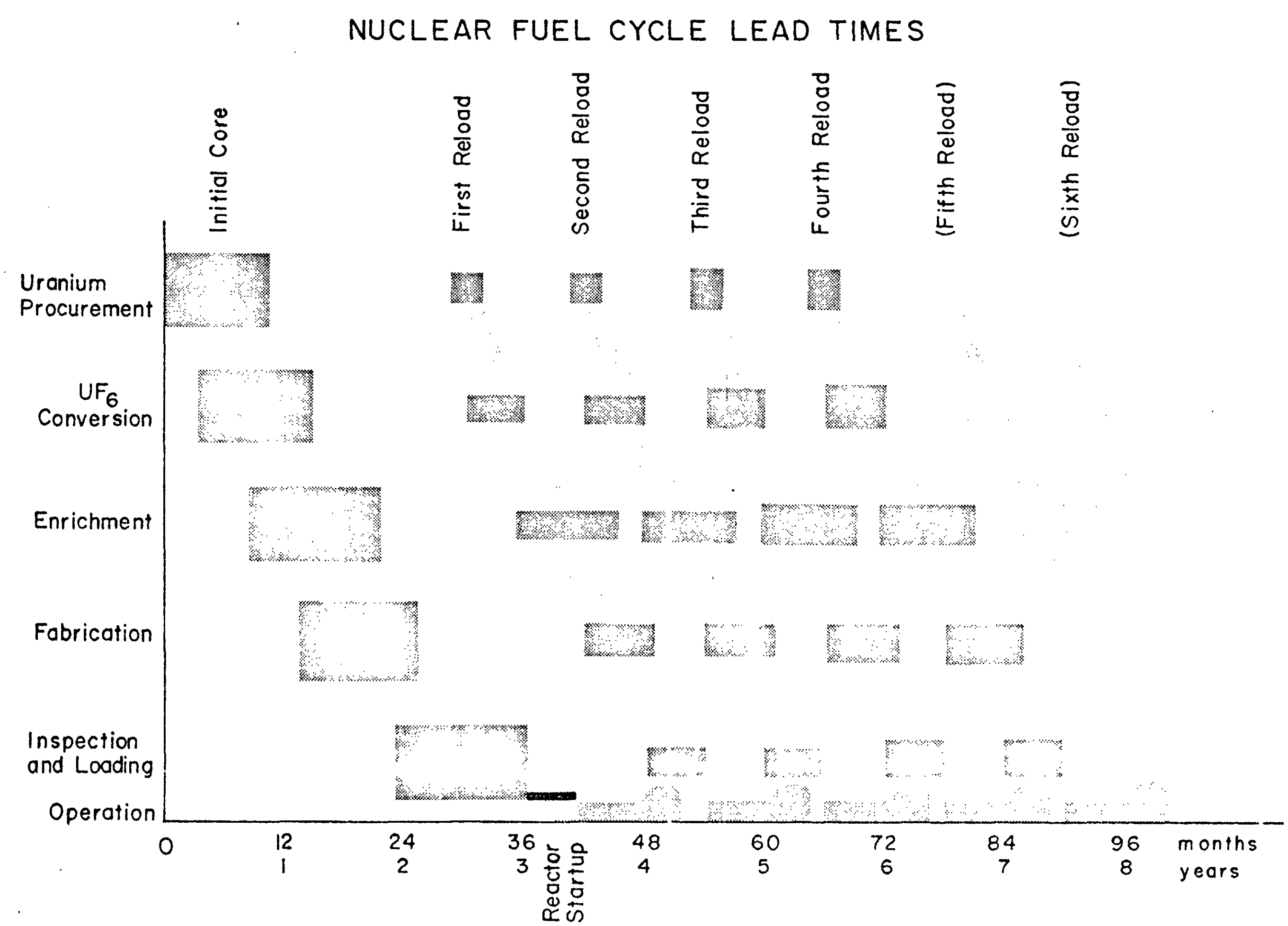

Figure 3.1 Nuclear fuel cycle lead times for a pressurized water reactor. The shaded blocks show the flow of fuel material through the fuel cycle. The length of each block designates the time needed for each process step while the height of the block indicates the quantity of material or services involved. The first fuel loading requires more than three years to produce and considerably more materials and services than do reloads.

between supplier failure and impact on economic activity would rarely exceed three months for oil. For the nuclear fuel cycle, such a short lag time could occur only in the case of interruption following fuel fabrication.

Technical measures may further extend the operation of nuclear plants. Time can be gained by reducing coolant temperature and thus lowering the power output of the plant. Reduction to 75% of full power can add about 4 months operation if initiated early in a burn cycle; reduction to 50% might add 12 months under similar conditions. The extension results both from a reduction in the rate of consumption of fissile material and an increase in reactivity (due to lower temperature) which increases the total fuel burnup possible over the cycle. Late in the burn cycle, only one to three months extension is possible.

The natural flywheel effect of the nuclear supply system is enhanced by the conservative planning of some consumers and suppliers. Utilities usually order fuel on the assumption that the reactor will operate at a 75-80% capacity factor. In practice, reactors have been operating at average capacity factors ranging from 42% (Japan, 1977) to 67% (West Germany, 1976). If a supply interruption were to occur, a reactor running at such a lower capacity factor usually could continue operation for a number of months (perhaps 2 to 10) beyond its usual scheduled refueling date.

The mismatch between plans and performance in the past has also resulted in stockpiles of fuel materials. Where it is possible to extend operation of a reactor beyond its refueling date, the stock is held as fresh fuel material; when it proves desirable to refuel on schedule (e.g., between seasonal demand peaks) the stock may be held in reactor cooling ponds as irradiated fuel which has not reached design burnup. In principle, it is possible to reinsert this fuel in the reactor, though safety regulations inhibit such use.

The fact that fuel supply planning is more conservative than actual operations (a practice that is justified by the large magnitude of reactor capital relative to fuel cycle costs) means that other forms of flexibility are available as well. The reduced urgency of some consumers' needs may allow rescheduling, or even reassignment, of material by a fabricator, enricher or other supplier in order to meet the needs of consumers whose fuel has been delayed or damaged. Suppliers also are conservative in their production planning. For example, the U.S. has required enrichment customers to enter into contracts well in advance of reactor startup. Similar commitments have been required of participants in fuel cycle ventures in Europe. Since actual deployment of reactors has not kept pace with the plans on which fuel commitments were made, surpluses of fuel have been accumulating. Many utilities in industrialized countries now hold one, two or more years forward supply of nuclear fuel; inventories are somewhat smaller in developing countries.

Thus, the overall trend in countries with large nuclear programs has been toward large domestic stockpiles of fuel. For example, Italy is entitled to a 25% share of the output of the new EURODIF enrichment venture (discussed below). This share would be enough to provide initial cores for 5000 megawatts-electric (MWe) annually or to sustain 23,000 MWe of nuclear capacity; during the early to mid 1980s total Italian nuclear capacity will be at most 4000 MWE. The surplus material could be stockpiled, or sold, thus contributing to security of supply for Italy or opening alternate sources of supply or stockpiles for other countries.

Such near-term technical flexibility in the nuclear power industry protects countries from serious consequences in the case of brief, occasional interruptions in the supply of fuel. However, it will do little to increase actual assurance if the fuel supply is chronically unstable, or is perceived as being so. The likelihood of interruption and the ability of consumers to deal with fuel supply problems depend crucially on conditions within the markets where these goods are traded. The number of possible points of interruption, the concentration of supply in a few nations, the problems of restarting fuel cycle flows after a disturbance, and the relatively high level of institutional intervention tend to undermine fuel assurance, particularly in the medium term.

3.2 Market Conditions

Each of the supply stages in Figure 3.1 is part of a set of interlinked markets in nuclear materials and associated processing services. Figure 3.2 shows the distribution (as of 1977) among nations of uranium production capacity, enrichment capacity, UF_6 conversion facilities, and fuel fabrication. Also shown is the (1977) distribution of reactors about the world and the demands they put on the fuel system, stage by stage. The various fuel cycle steps are interdependent; for example, enrichment contracts often determine quantities of uranium procured and the timetable for fabrication. In addition, spot transactions, swaps, and sharing arrangements often are worked out by UF_6 conversion firms and fabricators. However, assurance concerns lead to a focus on two parts of the system: uranium supply and enrichment.

Enrichment

The international market for enrichment services is highly concentrated, as Figure 3.2 shows. Currently, the only significant suppliers are the United States and the Soviet Union. The United States has long held a virtual monopoly in commercial enrichment, and contracts with the U.S. Department of Energy currently serve roughly 90 percent of the demand of non-centrally-planned countries.

Sales to European nations by the Soviet Union were the first step in the erosion of the U.S. monopoly position; over the next few years the USSR will provide enrichment services to Western Europe comparable to those from the U.S. European enrichment consortia have also entered, or will soon enter. URENCO, a tri-national consortium of British, Dutch, and West German interests, made its first commercial deliveries in 1976 and has plans to expand its enrichment capacity through the 1980s. EURODIF, a consortium involving France, Belgium, Spain, Italy, and Iran, will make its first commercial deliveries in 1979 and quickly increase its capacity to about half that of the United States.

In addition to these ventures, a number of others were announced in the mid-1970s when it appeared that enrichment capacity might be inadequate in the next decade. The Eurodif partners planned a new venture, Coredif, a 10.8 million SWU plant with ownership shares somewhat different than those of Eurodif. Reduced demand pressure has delayed incentives to build Coredif, though plans have not been formally terminated. South Africa's Uranium Enrichment Corporation (UCOR) has

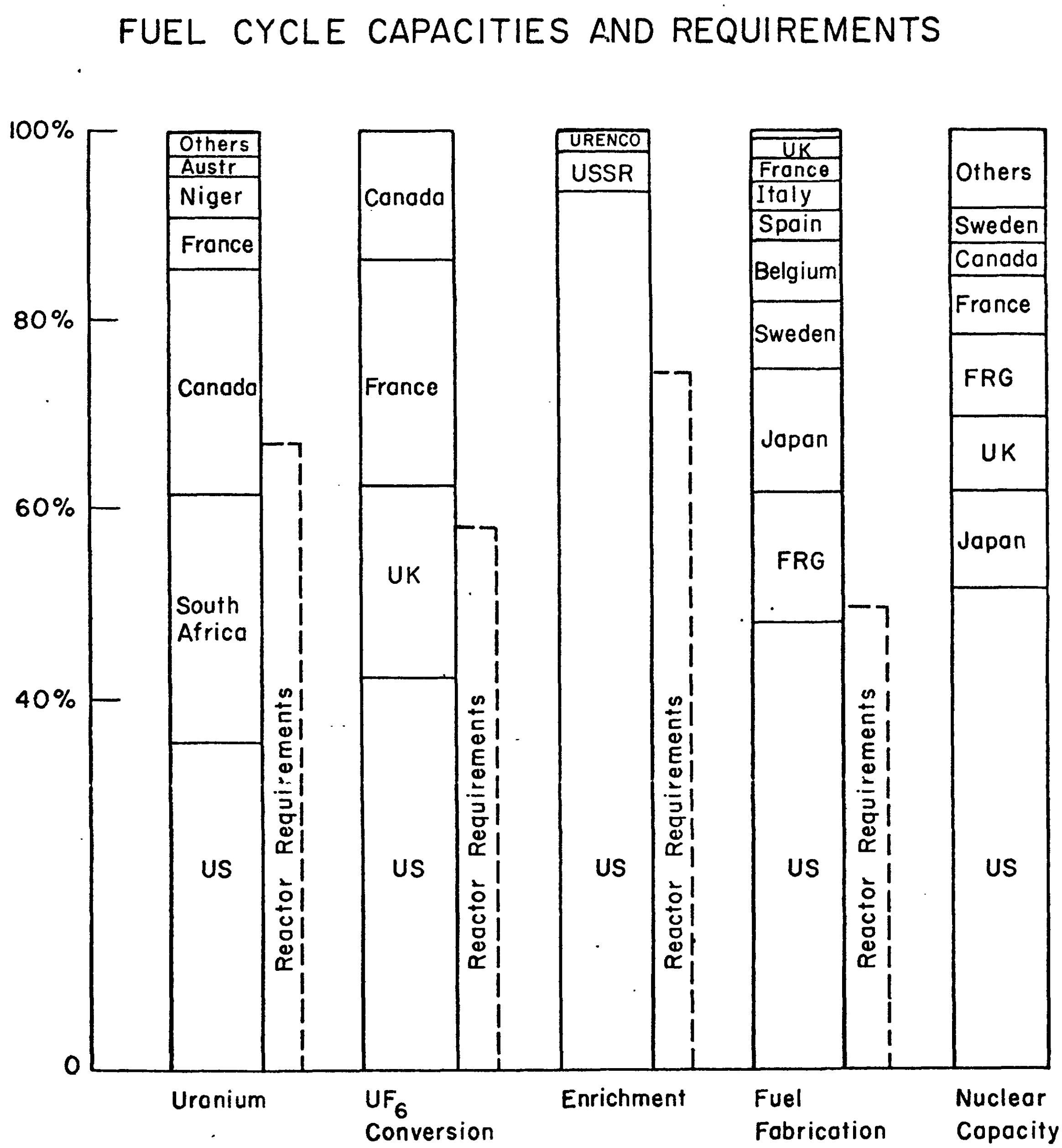

Figure 3.2 Nuclear fuel cycle capacity distributions and reactor requirements in 1977. The solid histograms show production capabilities for each fuel cycle step, distributed by country; however, not all of the production capacity was utilized in 1977, as indicated by the narrow dashed histograms showing actual reactor requirements in that year. Average reactor capacity factor is assumed to be 70% and enrichment tails assay 0.20%. Source: Japan Science and Technology ed., Genshiryoku Poketto Bukku (Atomic Energy Pocket Book), 1977 edition. Tokyo: Japan Atomic Industrial Forum, November, 1977. (In Japanese); OECD Nuclear Energy Agency and the International Atomic Energy Agency. 1977. Uranium Resources, Production and Demand. Paris. 136 pp.; and Nuclear Engineering International. November 1976, Volume 21 No. 251.

announced plans to build a commercial facility using a stationary wall centrifuge process. South African sources indicate that a 5 million SWU facility could come on line by the mid- to late 1980s. Brazil's Nuclebras, with the assistance of West Germany, plans a 0.2 million SWU demonstration facility in the mid-1980s using German Becker nozzle technology. Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC) is considering expansion from a current pilot centrifuge plant up to a one million SWU or larger facility by the mid- to late 1980s. At various times, interest in acquiring enrichment capability has been expressed by Australia, India, Iran, Portugal, Sweden and Zaire. Of all these plans, only the Japanese and South African ventures are at all likely to make a significant contribution to enrichment supply in the next decade.

Although commercial enrichers do make short-term spot sales of enrichment services under emergency circumstances, virtually all current and future enrichment sales are under long-term contracts. Current DOE long-term contracts are of two basic types. In the early years of the U.S. industry, a form known as a Requirements Contract was used. Under these contracts, which are still in effect, enrichment services are supplied to meet the actual requirements of a particular reactor. The contract holder firms-up the enrichment delivery schedule six months ahead of the time when the product is needed. The Requirements contract was replaced in 1973 by Long-Term Fixed Commitment (LTFC) contracts. Under this contract customers are required to firm-up the enrichment delivery schedule on a rolling ten-year basis. The U.S. has recently introduced a third contract form, the Adjustable Fixed Commitment (AFC) contract which involves a shorter firm-up period and greater flexibility; those holding LTFC contracts will be able to convert to the new contract form. Major adjustments cannot be made without incurring penalty charges. Most current and potential foreign enrichers offer some variant of these contract forms. URENCO offers a Requirements-type contract, while EURODIF negotiates contracts more like the AFC contract form. Both set price on a cost-recovery basis, with prices significantly in excess of those charged by DOE. The Soviet Union's Techsnabexport offers contracts for fixed quantities of enrichment services for delivery at specified times; prices are reported to be slightly below those of the U.S.

The international enrichment market is currently undergoing major changes. The first change is structural: the entry of new suppliers will replace monopoly with oligopoly and create opportunities for consumers to diversify risks by contracting with several sources. Moreover, the existence of excess capacity (discussed below) will create even more fluid market conditions, with consumers potentially able to alter their traditional supply patterns more rapidly than if new capacity additions were just adequate to serve new demand. Finally, enrichment contract terms are becoming much more flexible in terms of lead-times, commitment periods, delivery schedules and specification of enrichment tails assay. The latter will increase the elasticity of uranium demand, allowing enrichment services and uranium to be substituted, within a small range, for each other at consumer initiative.

Uranium

The production of uranium is concentrated in a handful of countries. As shown in Figure 3.2, the U.S., South Africa, Canada, France and Niger accounted for 97% of non-Communist output in 1977. Resources are similarly concentrated. Australia, Canada, Niger, South Africa and the U.S. together have 88% of "resources" as estimated by the OECD [1]. Expanding the OECD definition to include higher-cost or less-certain deposits would not appreciably alter the overall level of concentration, though the shares of some countries would differ significantly.

The U.S. and France are net importers of uranium, and will continue so in the future. However, since they both import and export (with a net import balance) they represent opportunities for diversification of supply, and can thus improve short-term assurance against the failure of supply from any one country. On the other hand, if the concern is power over market price, it is more informative to look at the level of concentration among net exporters. Here the concentration is no less great: if one sets aside the U.S. and France, then South Africa, Canada and Niger account for 95% of remaining production.

We also can make a crude estimate of the concentration of reserves available for export in the medium-term future. For this purpose, one should subtract from the OECD total the entire U.S. and French reserves, and 21% of Canadian reserves (the allotment required under Canada's domestic allocation program). South Africa, Australia, Niger and Canada then turn out to have 84% of the remaining reserves, and therefore groups of these countries have the possibility of cartel-like control of the world price of U_3O_8.

A variety of firms and agencies participate in uranium production. First, producer country governments are directly involved in resource exploitation. In Canada, for example, Eldorado Nuclear Ltd., a Canadian crown corporation, owns the Beaverlodge mine in Northern Saskatchewan and has bought into a development at Key Lake. Canadian provincial governments are part owners of several mining ventures. The South African government owns 25% of the Rossing operation in Namibia through its Industrial Development Corporation (though the continuation of this relationship is an issue in the independence struggle). France, Niger, Gabon, and Australia all have significant governmental interests in their domestic uranium industries.

A second group of participants consists of consumers who began in the mid-1970s to acquire direct interest in uranium production. In a recent Department of Energy survey [2], 30 of 65 responding U.S. utilities reported some direct involvement in uranium production. Countries with major import requirements are moving aggressively to acquire interests in foreign uranium production ventures. This is especially true of Japan, West Germany, and France. The means of foreign involvement is through government corporations or private corporations acting with official backing. Examples would be Germany's Urangesellschaft or France's AMOK.* In the case of companies like these it is often difficult to separate national interest from commercial motivations.

The third major group consists of private companies which are commercially motivated. Production is dominated by large companies but,

*A detailed description of these ventures is provided in a study by NUS Corporation [3].

especially in the U.S., there is an important fringe of smaller producers. Because of the large scale ard high risks, joint ventures are common.

For a rough idea of the relative importance of the three groups, one can calculate the shares of production and reserves attributable to each. In Australia, Canada, Niger and South Africa, 14% of production (and 13% of reserves) are directly controlled by producer country governments. Importer country governments, and private companies which appear to have strong ties to these governments, account for 17% of production (and 9% of reserves). Other private companies account for 66% of production and 77% of reserves [4]. (These figures do not total to 100% because the ownership of a small amount of production and reserves could not be identified.) Special mention should be made of Rio-Tinto Zinc, a U.K. based multi-national conglomerate with important holdings in Canada, Australia, and South Africa. Through various affiliates, this firm controls approximately 25% of total industry production and 24% of reserves worldwide.

These figures only give the roughest impression of control over production and reserves. However, they are sufficient to indicate that consumer country governments do not have a dominant influence in the market through direct involvement of government agencies or their proxies. To the extent that is possible to separate public and private motivations, commercially-motivated companies appear to play a strong role at this stage of the fuel cycle. However, this activity often must take place within the constraints of the export policies of producer governments which have substantial economic or political interests in uranium and are in a position to exercise considerable market power.

Long-term contracting is predominant in this industry, and a typical contract seems to be between 10 and 20 years. The U.S. market is the best documented. According to a recent FTC study [4], long-term contracts currently account for about 75% of sales by U.S. producers, and this percentage has been increasing. For Canada, as of the beginning of 1978 there were export contracts approved totalling some 76,000 STU_3O_8,* with delivery scheduled in some cases into the 1990s. By comparison, Canada's production in 1977 was about 6,100 STU_3O_8. Australia has about 11,000 tons in outstanding commitments but its production level is only about 1,000 tons per year at present [3]. The contract situation in South Africa is not well known because of secrecy laws.

Current contracts generally specify a base price with provision for escalation. The escalation clauses are tied either to the specific costs of the supplier or to general inflation indices. Many contracts include so called "market price" provisions which provide that if the spot price at time of delivery exceeds the escalated base price then some specified percentage of the difference (sometimes 100%) will be added to the base price. Another common contract provision calls for the purchaser to provide a portion of project financing, sometimes on an interest-free basis.

The spot market is thin, and there is no organized market on the order of the London Metals Exchange or the Commodity Exchange of New York. However, there are brokers who are in the business of arranging uranium transactions.

3.3 Institutional Framework

Nuclear trade takes place within a number of unilateral, bilateral, and multilateral constraints. Although international commodity trade is often subject to political controls, the rules governing nuclear fuel are particularly complex. Each fuel cycle step can occur in a different country, under different legal and political conditions. Moreover, governments have a long history of involvement in the nuclear industry and often are responsible for research and development, finance, and export promotion. The result is a set of political restraints and

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*Different units are used to quantify uranium output. In the U.S., quantities are usually stated in short tons of U_3O_8 (STU_3O_8). In Europe, quantities may be given in metric tons of uranium metal (MTU). Elsewhere, other units such as metric tons of U_3O_8 (MTU_3O_8) may be used. The conversion factors are: 1 MTU equals 1.3 STU_3O_8 equals 1.18 MTU_3O_8.

interventions which have a considerable effect on the supply of nuclear fuel.

Since supplies of uranium and enrichment are concentrated in a few countries, the current enrichers (U.S. and USSR) and the large uranium exporters (Australia, Canada and South Africa) are in a position to impose political as well as market conditions on the export of fuel. Below, in a section on the history of the assurance problem, we review the development of the policies of these governments in recent years. To prepare for that discussion, it is useful to look briefly at the international structure within which nations with nuclear power programs or industries operate, with special attention to the International Atomic Energy Agency, the Non-Proliferation Treaty, and Euratom.

IAEA Safeguards. The International Atomic Energy Agency serves a number of functions, including research, education, and nuclear promotion. But for the purposes of this discussion, the most important aspect of the Agency is the nuclear safeguards system which it administers. The IAEA system interfaces with a number of national control systems, and with the internal system of the Euratom nations.

The objective of the safeguards system is to provide "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons...and deterrence of such diversion by the risk of early detection." [5] The safeguards are based on a system of materials accountancy which attempts to strike materials balances for various facilities, accountancy regions, and for international flows. The accountancy system is backed up by on-site inspection of a nation's accounting records, and of the safeguarded facilities themselves. Also, the IAEA is taking an increasing role in advising governments on procedures for physical security of nuclear materials.

The detailed arrangements for participation in the system by a nation, or by a group such as Euratom, are negotiated case by case with the IAEA [6]. It is important to note that national safeguards systems vary considerably and that some of a nation's facilities may be under safeguards while others are not. For example, almost all major commercial nuclear power plants fall under the system (some at the insistence of the supplier country), but such involvement in the system does not necessarily imply a commitment to subject all nuclear facilities to international surveillance.

The Nuclear Non-Proliferation Treaty. The NPT contains two basic obligations, one attaching to nuclear-weapon states and the other to non-nuclear-weapon states. Each nuclear-weapon state undertakes not to transfer nuclear weapons, or control over those weapons, directly or indirectly, and not to assist, encourage, or induce any non-nuclear-weapon state to manufacture or otherwise acquire nuclear weapons or control over them (Article I). Each non-nuclear-weapon state undertakes not to receive nuclear weapons or control over them, not to manufacture or otherwise acquire nuclear weapons, and not to seek or receive any assistance in their manufacture (Article II).

Under the safeguards provisions of Article III, each non-nuclear-weapons party to the Treaty is obligated to apply IAEA safeguards to all nuclear facilities. Each party to the Treaty also undertakes not to export fissionable material--or equipment for the use, processing or production of fissionable material--unless IAEA safeguards are applied.

In complement to these commitments, all parties to the NPT "undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy." (Article IV) This obligation has generally been interpreted as flowing from the nuclear-weapons states to the non-nuclear weapons states. However, there has been difficulty in agreeing on which materials and technologies are appropriate to the "peaceful uses" criterion. It has generally been the policy of the U.S. -- and more recently of other suppliers -- that proliferation-sensitive technologies, such as reprocessing or enrichment, or material such as plutonium, are not included under the NPT obligation.

With the exception of France and Spain, all major industrial countries have signed or ratified the NPT. A number of other countries have not done so--among them are Argentina, Bangladesh, Brazil, Chile, India, Israel, South Korea, Pakistan, and South Africa. As noted earlier, however, even in these countries many civilian nuclear power facilities are under IAEA safeguards. In return for assistance in meeting nuclear energy needs, the customer state accepts the intrusion of safeguards on its sovereignty.

Euratom. Established by the Treaty of Rome in 1957, Euratom was designed to serve the collective interests of European nations* in competition with the U.S. Originally, the treaty called for a supply agency with exclusive rights to contract for nuclear materials within and outside the European community. Drafted in the atmosphere of the Suez crisis, the exclusive trade provision was meant to prevent discrimination in access to fuel supplies (enrichment or uranium) which might occur with separate bilateral arrangements or any advantage to particular countries in a supply crisis.

The exclusive trade function was brought into question in the mid 1960s when France sought nuclear fuel supplies outside the Euratom supply channels. In 1971, France unilaterally arranged the purchase of enrichment services from the Soviet Union, an action ruled against by the European Court of Justice but with little effect. The function of the Supply Agency has remained an issue within the Community; however, it generally appears to act as a supply channel (for example, U.S. enrichment contracts for German reactors are between the U.S. and Euratom) rather than as a supply agent, a rather different market role.

From the beginning, the Euratom agreement provided for a free flow of material and information among members. Also, Euratom has had its own internal safeguards system, which is now in the process of being coordinated with the accountancy framework of the IAEA. In recent years, difficulties have arisen because some supplier states have insisted on acceptance of IAEA safeguards or other conditions on individual Euratom

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*At the outset, Euratom included Belgium, the Netherlands, Luxembourg, France, Italy and the Federal Republic of Germany. In the late 1960s, the Commissions of Euratom, the European Economic Community, and the European Coal Commission were combined in the European Communities; the U.K., Ireland and Denmark became EC members in 1973.

nations, resulting in conflicting safeguards requirements and European resistance to this intrusion on regional sovereignty arrangements. In particular the Euratom principle of free flows of material among members also clashes with "prior approval" clauses for retransfers in some supplier contracts (discussed below). At this point some Euratom agreements with major suppliers are interim in nature, and the characteristics of ultimate fuel supply arrangements are not clear.

Urenco. There appears to be tension between the Netherlands and its two partners over Urenco's export controls. The Netherlands advocates tighter safeguards than the others on exports to Brazil, scheduled to begin in 1981. The Dutch parliament has requested that deliveries of low-enriched uranium (LEU) to countries that have not adhered to the NPT be subject to tight safeguards based on IAEA rules covering plutonium storage. If such rules cannot be established before the first deliveries to Brazil, the Dutch have asked for an ad hoc agreement with Brazil. Dutch approval also appears to be conditioned on Brazilian adherence to the NPT, although full-facility on-site inspections of all nuclear operations will not be required.

It is reported that Germany and Britain are not in favor of extending the tripartite Urenco agreement for 10 more years, nor are they anxious to negotiate an ad hoc agreement for tightening safeguards rules. Thus, while safeguards rules have been established, they are subject to political processes both within and among the participating states. Terms of current Urenco bilateral enrichment contracts (with West Germany and Switzerland) include: Urenco's right to terminate a contract in the event of a customer default or bankruptcy; government(s) approval of retransfers; and dispute settlement by arbitration.

Eurodif. This French-led consortium originally planned to market most of its services to the members of the group. To the extent that there will be an excess, however, Eurodif has been designated as the selling agent. Criteria in Eurodif contracts with Japan, Switzerland and West Germany include a provision reserving the right of approval over retransfer.

National Policies and Procedures

As noted above, the two key stages in the fuel cycle, uranium and enrichment, are highly concentrated in a few nations that thereby have the power to impose political conditions on the export of fuel.*

The United States. U.S. procedures for the export of nuclear material are set out in the 1978 Nuclear Non-Proliferation Act. In order to qualify for American-supplied fuel, an importer must have an Agreement for Cooperation, negotiated by the Secretary of State with participation by other governmental entities. In addition, specific shipments of nuclear fuel require an export license provided by the NRC. The 1978 Act specifies new requirements to be included in Agreements for Cooperation (existing agreements must be renegotiated) and designates similar criteria to be applied by the NRC when considering an export license application.

The requirements for Agreements for Cooperation are set out in an amended Section 123 of the 1954 Atomic Energy Act. They include: 1) safeguards on all exports and material produced with exports, ii) full scope IAEA safeguards--safeguards on all the peaceful nuclear activities of the recipient country, iii) a pledge not to use any material or equipment exported for research into or detonation of an explosive device, or for any other military purpose, iv) the U.S. right to require return of any exported material in the event of an explosion or abrogation of an IAEA safeguards agreement, v) U.S. prior consent before retransfer, reprocessing, enrichment, or storage of any exported material, vi) adequate physical security measures, and vii) a guarantee that any facility built using technology transferred under the agreement would be subject to similar conditions.

Many of these conditions can be exempted by the President for foreign policy or security reasons, though the President is directed to

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*A variety of suppliers of fuel fabrication have arisen in recent years. Suppliers at earlier stages in the fuel cycle often have control over or right of approval for fabrication, but these facilities are more widespread than those for enrichment. Hence this step has tended to be less burdened by political and legal considerations.

renegotiate all existing Agreements for Cooperation to incorporate the new antiproliferation restrictions. Various committees of the Congress then have the opportunity to review the Agreements.

The 1978 Act also adds two other amendments to the 1954 Atomic Energy Act, containing criteria governing U.S. nuclear exports. These criteria -- which are to be applied to each specific export license by the NRC -- are virtually the same as those to be included in the Agreements for Cooperation, except that only the full-scope safeguards requirement (number ii above) can be waived by the President, under special conditions and subject to Congressional disapproval. Thus, while the provisions in the Agreements for Cooperation are subject to negotiation between the U.S. and the recipient party, the criteria governing license application are almost all mandatorily imposed by the U.S., the only exception being the full-scope safeguards requirement. The process of obtaining an export license exemption on the full scopes condition, starting with a Presidential decision, is a laborious one, involving several congressional committees and further consultations with the Departments of State and Energy, ACDA, and the NRC. The entire export procedure has been clarified by the Act, but the strong antiproliferation policy, and the provisions for involvement by disparate parts of the U.S. government, do not necessarily serve to relieve uncertainty about the outcome in particular instances.

The 18 to 24 month phase-in period for the full-scopes condition in the 1978 Act allows some time for adjustment of relationships and renegotiation of agreements, though it is not clear that agreement can be achieved or that the process will be easy. While U.S. export policy has been clarified, it is questionable whether it has yet been significantly streamlined; opportunities for political and bureaucratic complication remain.

Canada. Canadian authorities do not rely solely upon American safeguards on enriched uranium exports (the majority of Canadian uranium passes through U.S. enrichment plants), but work under a set of separate regulations announced in December, 1974 and December, 1976. The 1976 regulations are most restrictive. They require that shipments to non-nuclear weapons states under future contracts be restricted to states ratifying the Nonproliferation Treaty or otherwise accepting safeguards on their entire peaceful nuclear programs. This and Canadian demands for veto power over reprocessing and retransfer of exported uranium, a no Peaceful Nuclear Explosives (PNE) pledge, and implementation of a Euratom-IAEA safeguards agreement led to a confrontation with Japan and the Euratom countries, principal buyers of Canadian uranium, discussed below.

The initiation of the International Nuclear Fuel Cycle Evaluation, (INFCE), provided Canada and its European customers a temporary solution to the impasse. Canada and the EC agreed to an interim safeguards package lasting three years, with the third year designed to allow negotiation of a permanent agreement. Under the temporary accord, the EC will notify Canada prior to reprocessing, enriching, or storing Canadian material transferred after December 20, 1974, and prior to reprocessing material delivered before that date. The two parties will hold consultations to ensure that adequate safeguards are assured. Canada does not have approval rights over retransfer of material within the EC, but no Canadian material will be used in France until that country negotiates a safeguards agreement with the IAEA. There is also a provision concerning physical security measures. It must be emphasized that this is only a three year interim accord designed to head off a serious breach in Canadian-European relations: any more permanent structure awaits further negotiations.

An agreement has also been reached with Japan whereby Canada acquires the right to prior consent for enrichment beyond twenty percent, for reprocessing, and for retransfer. This agreement is more permanent than the interim accord with Europe, being a true amendment to the existing Agreement for Cooperation.

Australia. Australia is now in the process of defining its export criteria after a reappraisal of its role in the uranium market and in the nonproliferation regime. The Australian-Finnish agreement of July 20, 1978, can be seen as a model for subsequent bilaterial arrangements with potential customers such as Euratom, Japan, Iran, the Philippines, Sweden, and Austria. Under the accord, Australia reserves the right to prior consent before re-export of uranium to third countries. The agreement contains a pledge not to divert any Australian material to military purposes. IAEA safeguards are to be applied, and Australian consent is required before re-enrichment or reprocessing of supplied uranium can take place. Australia reserves the right to suspend shipments in the event of a failure to observe the terms of the contract or adhere to IAEA safeguards. Australia's requirements are thus generally in line with current U.S. export conditions.

South Africa. A non-signatory of the NPT, South Africa is the source of one-sixth of free-world uranium supply, and has many years of experience as a stable supplier to the world market. However, the likelihood and effect of potential political changes within South Africa in the future cannot be predicted. Also, the supply of uranium from the giant new Rossing complex (and perhaps other mines) in Namibia, currently controlled by South Africa, will be subject to the settlement eventually achieved there.

South African uranium is available under long-term contracts whose features include provisions for early payment, at or above a floor price, and an option to void the contract if mines are closed due to inadequate gold prices. In the future, buyers may also be expected to help pay for South African conversion and/or enrichment services if they are developed. To the extent known publicly, contracts are subject to IAEA, Euratom, USSR or U.S. bilateral safeguards agreements (the last two applying when South African uranium is enriched in the USSR or the U.S.).

3.4 Concentration, Coupling and Risk

Because of the high degree of concentration noted above, issues of market power are very important in nuclear fuel supply, and in the problems of nuclear fuel assurance. Since a good deal of the subsequent analysis will be concerned with this aspect of the fuel market, it is useful to develop some common language about these phenomena.

There is a purely economic aspect of market power. Usually, a transaction between buyer and seller involves some agreed-upon price in financial terms. Where the market is reasonably competitive, the price attached to the transaction is set by the market itself. In some cases, one party to the transaction (most often the seller) has some monopoly power and can influence the price, stated in financial terms.

Where there is market concentration, there also enters the possibility of a price being charged in "political" as well as economic or financial terms. That is, a buyer may face not only a financial cost for a particular delivery but a "sovereign" cost as well, in the sense that the seller demands some limit on the sovereign power or some concession of the nation doing the purchasing.* Naturally, when a voluntary purchase is involved, there is a limit to the "sovereign" price that can be levied, just as there is a limit to the financial price that a monopolist can charge. On the other hand, the penalty for "doing without" can be quite great if the circumstance arises suddenly, after investments (in this case, in reactors) have been made that depend on the material in question.

Of course, any business involves risks for the buyer and seller, and international transactions have their own special categories of costs and risks. For purposes of future discussion, we may refer to two broad categories of these: (i) market costs and risks, and (ii) sovereign (or political) costs and risks.

The market cost is simply the agreed-upon price under expected conditions. Market risks include the risks normally associated with any commodity: strikes, acts of God, cyclical demand and price fluctuations--along with the risk of market concentration leading to monopoly prices--and technological change. In the case of an uncertain, non-renewable resource there are the additional risks associated with resource depletion and diminishing ore grade. In addition, there are those risks peculiar to a commodity traded on international markets--foreign exchange risks, expropriation risks, possible changes in domestic government policy regarding environmental factors or promotional or protectionist import and export conditions.

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*One can make this argument to apply to buyers coercing sellers, e.g., boycotts of Rhodesia or Cuba.

There is a vast array of contract forms that can be used to share risks among buyer and seller; they vary depending on the nature of the risks, the relative market positions of buyer and seller, and so forth. Any contract is, in effect, an agreement on a price and quantity under some expected set of conditions, coupled with a set of arrangements as to who bears the cost, or reaps the benefit, if conditions are different than planned on. Each party must balance acceptance of risk against price. Any long-term trade arrangement involves an instrument of this type, and in our current era of relatively free trade, the ingenuity of the market system in working out arrangement for sharing these risks is impressive.

All these costs and risks, which are normally taken care of by standard market contracts, we refer to as market cost or price and "market risks". These we distinguish from "sovereign" costs and risks, which present a different, more difficult, set of problems. Sovereign costs may arise whenever one nation trades with another. That is, a country may set political terms and conditions as a prerequisite for trade in a particular commodity. Moreover, there may be sovereign or political risks associated with such trade in that these terms and conditions may be changed by the nation imposing them.

There may be various ways that such sovereign risks can arise, but in the case of nuclear fuel it originates largely in concern over nuclear proliferation. Nations, acting through export control legislation or executive action, may create supply interruptions for reasons which are not founded in the pursuit of economic gain or market power, but which are intended to stop the spread of weapons capability. An example of such unilateral sovereign events, motivated by external proliferation considerations, is the Canadian embargo mentioned above.

International markets are created expressly for the purpose of facilitating the sharing of market risks through bilateral contracts. However, no bilateral agreement among parties can deal with contract abrogation by a foreign sovereign. The nuclear fuel markets have enough problems of straightforward market risk (viz, the Westinghouse short sales discussed below), and a fair share of sovereign risks which are common to all international trade (e.g., possible changes in Soviet export policy). But the fear of proliferation, and the changes in national policies that flow from it, create a set of risks unique to the nuclear fuel industry. Were the various stages of the fuel cycle served by large numbers of producers, the risks could be reduced by diversification. As indicated above, current and future levels of concentration limit this possibility, and this unique risk is likely to continue.

Thus one of the main issues addressed below is the interaction of market institutions and the overriding framework of political constraints. An argument that will be made later (Chapter 5) is that the differing levels of sovereign risk (and associated costs) imposed by major supplier nations is one of the most troubling aspects of the structure of the nuclear fuel supply system, and potentially one of the most damaging to fuel assurance.

4. HISTORICAL DEVELOPMENT OF THE FUEL ASSURANCE PROBLEM

The nuclear fuel assurance problem has deep historical roots. In addition to difficulties originating in the evolving industry structure, fuel assurance has been influenced by the construction--and revision--of international political regimes for managing proliferation risks, and by the commercial ambitions of suppliers of uranium, fuel cycle services and reactors. Changes in domestic policies and political conditions in supplier and consumer countries also have had major effects, as has the struggle toward new forms of economic and political relationships between developing and developed countries. Finally, there have been fundamental changes in attitudes towards energy and its relationship to economic and political security.

In reviewing this history, it is convenient to talk in terms of three eras:

- The emergence from military programs. The late 1940s to about 1960: the initial development of reactor technology and fuel cycle facilities under government sponsorship.
- The surge of commercial and political development. The years 1960 to about 1973: the beginnings of commercial development of nuclear power and the emergence of an international nonproliferation regime.
- The period of conflict and instability. Roughly 1974 to the present: uncertainties, conflicts and market failures, in the context of heightened concerns about energy and security.

The boundaries between eras are not precise and the seeds of one era's problems (and of some of their solutions) can usually be found in preceding periods. Nonetheless, this simple breakdown does help in sorting out the events of the past three decades.

4.1 Emergence from Military Programs

In the United States, the era of commercial nuclear power began with the Atomic Energy Act of 1946; the first proposals for an international regime governing nuclear power were contained in the Baruch Plan of the same year. The U.S. Act legislated civilian exploitation of nuclear-electric power, but with a federal monopoly on nuclear technologies and fuel. The Baruch Plan, presented to the United Nations in June of 1946, called for a similar arrangement internationally--i.e., an International Atomic Development Authority, managing all phases of the development and use of atomic energy, including nuclear fuel. The Baruch Plan eventually failed, and by the early 1950s independent nuclear research and power programs were going ahead in several non-nuclear-weapon states.

In December 1953, President Eisenhower delivered his "Atoms for Peace" speech before the U.N., calling for international cooperation in the development of nuclear power, including assistance in research and development and the provision, by the U.S. and other countries, of nuclear fuel and other materials. Implementation of the 1953 proposal required domestic U.S. legislation--the Atomic Energy Act of 1954--rescinding some of the secrecy provisions of the 1946 Act and authorizing international cooperation.

This cooperation took the form of bilateral Agreements for Cooperation between the U.S. and foreign governments (22 in 1955 alone). The Agreements, which first emphasized research activities but eventually included power reactors and fuel, generally included safeguards and inspection provisions. The United States also reserved the right to approve plans for reprocessing fuel it had supplied, to approve re-transfers to third countries, and to designate storage facilities for excess fissionable material (such as plutonium) or to purchase such excess material. Since all parties foresaw the eventual use of plutonium in nuclear power programs, these provisions were not seen as restricting its use for reactor fuel.

The creation of the International Atomic Energy Agency (IAEA) in 1957, presented opportunities to put safeguards and fuel supply under an international institutional umbrella. But delays in implementing such a regime--combined with the reluctance of some nations to put their nuclear futures in multilateral hands, and Congressional reservations about a possible loss of influence--resulted in bilateral agreements continuing to dominate technology and fuel transfers for many years. Early expectations that the IAEA would function as an international fuel authority, with safeguards following flows of material, were never fulfilled.

One bilateral agreement which was to have major significance many years later was that between the United States and Euratom. The Euratom agreement (which lapses in 1985) provided for supply of reactor fuel and special nuclear material for research; the supply is through the Community,* which also took responsibility for safeguards. The initial agreements with individual member countries were subsequently allowed to lapse.

The 1950s also saw the beginning of power reactor development and deployment, first in the USSR (a five MWe plant in 1954) and then in the United Kingdom (four 50 MWe graphite-moderated natural uranium reactors in 1956). In the United States, development of the more complex pressurized water reactor (PWR) for use in submarines led to the Shippingport nuclear power plant in 1957. The boiling water reactor (BWR) was first utilized commercially at Dresden, Illinois in 1959. Both reactor types made use of the low enriched uranium producible in large quantities in the United States enrichment plants, which had been constructed for weapons purposes in the 1940s and now had excess capacity.

During this period, uranium production was stimulated and sustained by the military procurement programs of the United States and the United Kingdom (and later France). Canadian production began in the early 1940s; a domestic U.S. industry was initiated with AEC encouragement in 1948; and production in Australia and South Africa began in the early 1950s, with purchases by the U.S. and the U.K. In all cases, production was encouraged by a variety of consumer and producer government incentives, including discovery rewards, guaranteed purchase prices and tax concessions. These encouragements were effective, as can be seen in Figure 4.1.

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*Originally, Euratom included Belgium, the Netherlands, Luxembourg, France, Italy and the Federal Republic of Germany. In the late 1960s, the Commissions of Euratom, the European Economic Community, and the European Coal Commission were combined into the European Communities; the U.K., Ireland and Denmark became EC members in 1973.

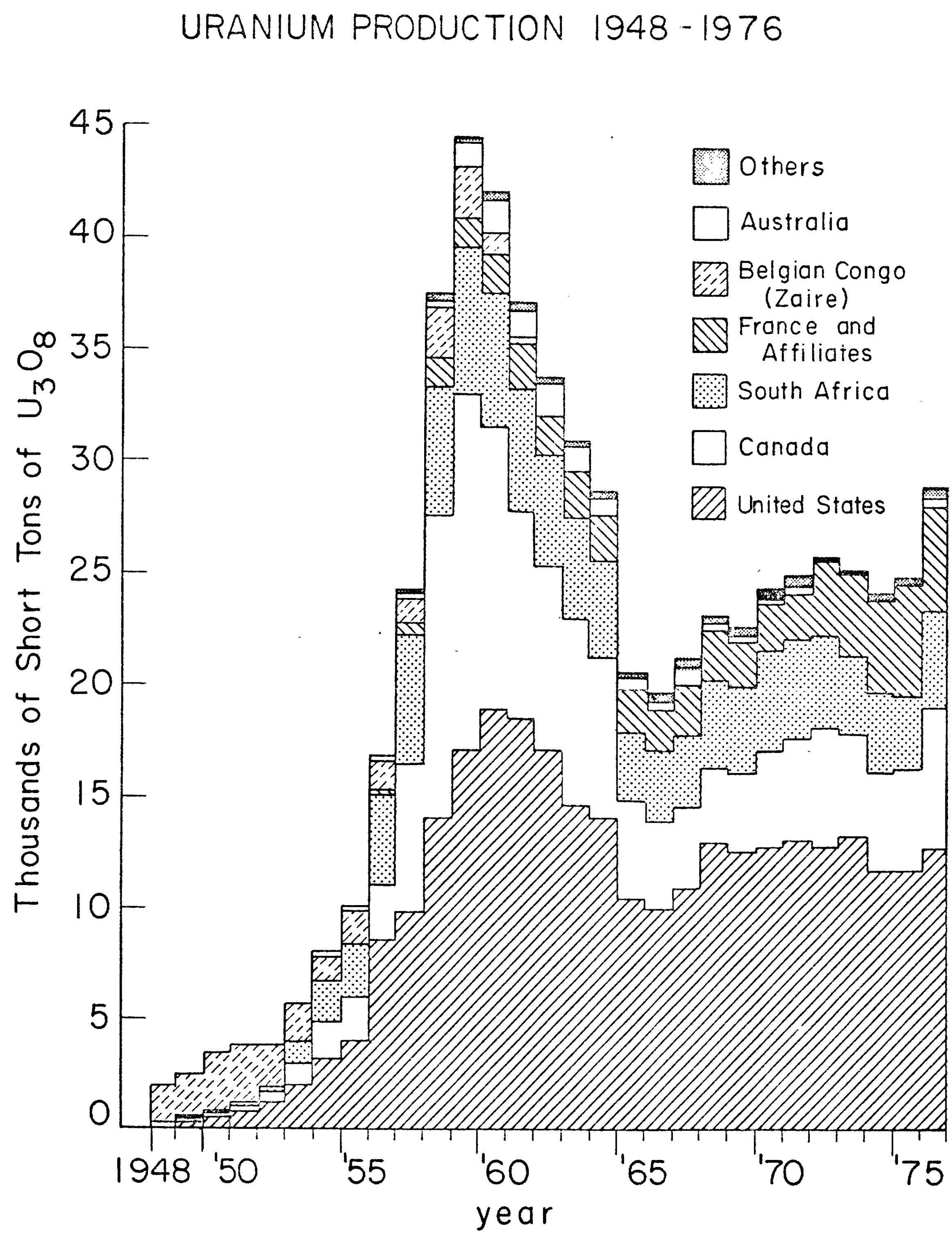

Figure 4.1 Uranium production 1948-1976. Data through 1971 are from U.S. Geological Survey Professional Paper 820, 1973; thereafter from Uranium Resources, Production and Demand, a joint report by the OECD and the IAEA, December 1977.

Throughout this period, the United States played a dominant role, due to its general importance in the post-war world, its leadership in technology, and its monopoly position in nuclear fuel supply. From 1955 until mid-1961, the U.S. government--which had sole domestic control of U.S. uranium and enrichment--sold (or leased) enriched uranium for research and power uses to other countries, under bilateral Agreements for Cooperation. At this time, the material was owned by the U.S. or the recipient government, not by private parties. In 1959, the U.S. Export-Import Bank began to finance sales of power reactors and fuel through loans and financial guarantees, thus signaling a national commercial interest in nuclear power trade.

4.2 The Surge of Commercial and Political Development

The 1960s and early 1970s saw further development of the institutional and political framework, along with the first commercial investments in nuclear power. However, as discussed below, these developments did not deal entirely adequately with political problems, and conditions in the uranium industry were far from healthy. Thus, while the 1960s were an era of major progress, they also contained the seeds of problems which were to bring a crisis in the mid-1970s.

Growth in International Reactor Sales

In the 1960s the first orders were placed for power reactor exports. By 1966, Canada had sold 225 MWe of heavy water reactors to Pakistan and India, and the United Kingdom had sold Magnox reactors to Japan and Spain. Otherwise, the export market was dominated by the United States: Westinghouse sold eight PWRs (2264 MWe) to seven countries, and General Electric sold eleven BWRs (2369 MWe) to eight countries by the end of the decade. During this period, Canada was installing heavy-water reactors and the United Kingdom and France were deploying gas-cooled, graphite-moderated reactors of their own design. In the Federal Republic of Germany, AEG began to sell reactors under license from General Electric. In Japan, three companies began to develop light water reactors for domestic use, under license from U.S. manufacturers.

Major changes came between 1967 and 1969 with the formation of Framatome in France, Kraftwerk Union (KWU) in Germany, and ASEA-Atom in Sweden. Direct government participation was involved in all but KWU. Framatome began to produce PWRs under Westinghouse license for domestic use. ASEA-Atom developed BWRs of its own design, and KWU began to develop its own PWRs. KWU secured its first PWR orders* in 1969 (to the Netherlands), while Framatome did not make export sales until 1974, when it sold four PWRs to Belgium and Iran. As will be seen below, the beginning of competition for international reactor sales put new strains on the nuclear fuel supply system, and on the nonproliferation regime.

Institutional Changes

In the 1950s, efforts to provide a political context for nuclear power development and nuclear fuel supply focused on bilateral agreements and regional integration in Western Europe. In the 1960s increased attention was drawn to the need for a stronger global system. A comprehensive review of the role of the IAEA, as an alternative to bilateral agreements, was undertaken by the United States in 1961. While many recipient countries were happy with their bilaterals with the U.S., the emergence of other suppliers, and the need to provide for universal safeguards in a nondiscriminatory way, provided incentives for bolstering the IAEA regime.

Beginning in 1964 (with intensive negotiations with India), efforts were made to shift bilateral safeguards agreements, old and new, to trilateral agreements including the IAEA. Simultaneously, the IAEA safeguards system was extended to include larger power reactors (1962) and reprocessing plants and other fuel cycle facilities (1965). Enrichment plants were excepted. The IAEA system also was extended to include fissile material (e.g., plutonium) derived from material originally supplied under safeguards. The possible role of the IAEA as manager of fuel cycle flows gave way to a role as administrator of safeguards, except in a few cases where the recipient country wanted the IAEA to act as the supply channel.

*It had sold a pressurized heavy-water reactor to Argentina in 1968.

The major institutional achievement of this era was the Non-Proliferation Treaty (NPT) which was opened for signature in 1968 and which took effect in 1970. As discussed above, the Treaty represents an international compromise between weapons and non-weapons states, involving pledges of peaceful nuclear cooperation in exchange for agreement not to develop nuclear weapons and to accept safeguards on all peaceful nuclear power activities. The interpretation and implementation of these provisions has been a continuing and controversial process, with significant consequences for trade in nuclear fuel. The problem of an independent Euratom safeguards system, originally accomplished through painful political accommodation in Europe, was resolved by an understanding that the Euratom non-nuclear-weapon states would negotiate a safeguards agreement collectively with the IAEA. The fact that Euratom consists of both weapons and non-weapons countries (while the NPT makes a fundamental distinction between them) posed a special problem at the time, and more recently, as noted below. However, from the standpoint of nuclear power development and the stability of fuel supply arrangements, this era was one of increasing optimism about the possibility of separating nuclear power from nuclear weapons.

Developments in the Fuel Cycle

Until the early 1970s nuclear fuel supply was primarily an issue of enrichment services, and the history of enrichment was mostly one of U.S. policy initiatives. From a consumer perspective, uranium supply was not a problem; the production capacities built up in the 1950s were far larger than commercial demand. Moreover, as the principal source of enrichment, the U.S. often provided the uranium from its own stockpiles, which were increasing due to domestic purchase programs. Outside the U.S., the uranium industry picture was one of severe depression, in the trough between military use and buildup of civilian nuclear power.

Uranium. In 1959, the United States, foreseeing a saturation of weapons needs, announced that it would no longer make foreign purchases of uranium; most existing purchase contracts were to expire by the early 1960s. The result, especially in Canada, was the near collapse of the uranium industry. As shown in Figure 4.1, Canadian production dropped from more than 12,000 STU_3O_8 in 1959 to about 3,000 tons in

1965. Even this level was sustained only through a government stretch-out program, a transfer of contracts to low-cost producers, and the buildup of a government stockpile. Only 4 out of 28 producers remained active.

In Australia, the impact was not as great, due to the relatively low level of production and the high degree of government participation and stockpile building. In South Africa, the impact of reductions in exports was small since most uranium production was a by-product of gold mining; the uranium actually produced after 1960 (about half the peak rate) was stockpiled. In 1967, the South African government legislated private ownership of uranium and transferred its calcining facility to the Nuclear Fuels Corporation of South Africa, Ltd. (NUFCOR), which now acts as the uranium marketing agent for the gold-mining companies, subject only to the export controls of the South African Atomic Energy Board.

In the United States, government stimulation of the uranium industry ended with a moratorium on new contracts in 1958. From 1962 to 1966 the AEC carried out a maintenance program in which there was an annual 500 STU_3O_8 limit per property and a fixed price of \$8 per pound. The program sustained the industrial base while limiting the further growth of what was already a large stockpile (about 50,000 STU_3O_8, excluding military stocks). However, the reduction in government demand--from a high of 17,600 STU_3O_8 in 1961 to 10,200 STU_3O_8 in 1966--resulted in considerable contraction in the domestic industry and reduced exploration. When expected power-plant demand failed to materialize, the AEC began to stretch out its contracts; by 1970 prices averaged \$6 per pound. The price history is shown in Table 4.1. Prices of uranium had fallen since the mid-1950s, but the fall in <u>real</u> prices was even more severe, as the table shows.

In 1964, the Atomic Energy Act was amended to allow private ownership of nuclear fuels. In 1966, a year which also saw the first big surge in domestic reactor orders (20 reactors with a total capacity of 16,400 MWe) the United States instituted an embargo on the import of foreign uranium for enrichment for use in domestic reactors. This move isolated foreign producers from the first surge of U.S. demand (only three reactors were ordered outside the U.S. in 1966). The first private purchases of uranium in the U.S. began in 1967 and rose rapidly to

Table 4.1

Uranium Spot Prices in the U.S.

($/lb. U_3O_8)

	Current Dollars[1]	Deflated[2]
1950	$ 9.20	$ 18.90
1955	12.50	22.00
1960	8.80	13.90
1965	8.00	12.10
1970	6.20	7.00
6/73	6.50	6.10
12/73	7.00	6.30
6/74	10.50	8.40
12/74	15.00	10.80
5/75	21.00	14.60
8/75	26.00	17.80
12/75	35.00	23.80
4/76	42.30	28.30
1/78	42.90	26.70

Notes:

1. Nominal price per lb U_3O_8; 1950-1967 from USAEC purchases, ERDA, Statistical Summary of the Uranium Industry (1976); 1968-1978 from NUEXCO Spot Market Price reports.

2. Deflated by the GNP Implicit Price Index for Non-Residential Structures (1972 = 100).

12,700 STU_3O_8 in 1971, when the AEC ended its purchase program. As a result, uranium demand in the United States was kept relatively constant during the transition from military to civilian use.

The net result of these events was severe depression in uranium industries outside the U.S. and a static, but not especially disruptive environment in the U.S., as shown in Figure 4.1. This pattern did not have immediate consequence for commercial nuclear power development; however, it was to have profound consequences later.

Enrichment. The effects of fuel cycle developments on nuclear power came most immediately from changes in U.S. enrichment policy. The 1964 Atomic Energy Act changed the terms of enrichment availability for domestic and foreign customers. The new policy allowed toll enrichment of uranium procured abroad, though the AEC would also sell uranium from U.S. stocks if requested. Whereas previous procedure had been to provide whatever amounts of enriched uranium might be desired by bilateral partners, the new policy was to provide material under the long-term contracts discussed above. The purpose of these contracts, beginning in 1968, was to allow longer-term planning by the builders of an expected wave of new power plants and by the AEC in its enrichment operations.

The revision in U.S. enrichment contracting represented only a small change in the U.S. role in the international fuel supply system. However, it came at a time when the international commercial context was changing. Other industrialized countries were beginning to enter international reactor markets, and they very likely saw the U.S. monopoly of enrichment as putting them at a commercial disadvantage.* The

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*In an effort to deal with the potential spread of enrichment technology--and especially the centrifuge, which was regarded as more proliferation-sensitive than gaseous diffusion--the United States, in 1971, proposed a multilateral approach to new enrichment capacity. However, the terms of this proposal seem only to have reinforced suspicions abroad that U.S. security concerns were really a cover for commercial ambitions: not only was the proposed technology transfer apparently one-sided (with the prospect that the U.S. would learn more about European technology than vice versa) but the U.S. explicitly required protection of its commercial interests in supplying components for whatever plant might be built, and insisted on continued access to all markets for U.S.-supplied enrichment services.

"privatization" of nuclear fuels--part of an overall effort by the AEC and the Nixon Administrations to put all of nuclear power on a commercial footing--implied that fuel supply could become tied to private commercial ambitions in the U.S. as well as to governmental international security interests. The U.S. dominance of reactor orders abroad could only increase such concerns. While commercial motives may not have been dominant in U.S. decisions, attitudes abroad clearly reflected a growing concern about U.S. commercial dominance and revealed the difficulty of distinguishing between commercial and international security motivations in the new atmosphere of international competition.

One result of these concerns was increased interest in European enrichment projects. In 1968, FORATOM, the European nuclear industry organization, had begun plans for ventures which would provide increased autonomy. In 1970, Germany, the Netherlands and the U.K. established Urenco, an enrichment venture based on centrifuge technology. In 1972, the Eurodif enrichment consortium was chartered, using French diffusion technology. Also in 1970, European utilities and reactor companies began to contract with the USSR's Techsnabexport for considerable quantities of enrichment services to be delivered between 1974 and 1990. West Germany has been the largest purchaser, though others include Sweden, Spain, France, Belgium, Finland, Italy, Austria and the U.K. These contracts with the USSR serve to decrease dependence on the U.S. during the few years remaining before Urenco, Eurodif and other ventures reach full output.

4.3 The Period of Conflict and Instability

By the early 1970s, a number of processes were under way which ultimately would alter perceptions of nuclear fuel security, and affect the viability of the nuclear option itself. There were changes in U.S. policy regarding enrichment, including new efforts to transfer enrichment to the private sector and a change to long-term fixed commitment contracts. In 1974 the U.S. closed its books to further enrichment orders. At the same time, the uranium industry was on its way from a buyer's to a seller's market, in part because of a rise in demand, but also because of the demand induced by changes in U.S. enrichment contracting policy. Additional disruptions were induced by the formation of a uranium cartel, the unexpected loss of Australia as a prospective supplier, massive sales by Westinghouse of uranium for which it did not have contracts with primary producers, changes in Canada's rules for holding domestic reserve margins and a U.S. import embargo. These events and their interrelations are sketched in Figure 4.2.

Concurrently with these changes, competition for reactor orders was increasing with the entry of European vendors, and the focus of sales efforts was shifting to the developing countries (Figure 4.3). This competition, combined with the drive for nuclear autarky in Western Europe, served to accelerate technological change and increase the pace of commitments to plutonium fuels, breeder reactors, and indigenous enrichment and reprocessing plants. And, in the midst of all this came the Indian nuclear explosive test. The Indian explosion, coupled with plans for transfers of proliferation-sensitive technologies to other LDCs, raised fundamental questions about the effectiveness of the existing non-proliferation regime, and led to retroactive as well as prospective changes in the political conditions for fuel exports from the U.S. and Canada.

All these events occured in the space of about five years and were highly interdependent. The net result was a sharp decline in the perceived security of nuclear fuel supply. In the following sub-sections, we look at these events in more detail, focusing on developments in enrichment and uranium markets and in the national policies that determine the conditions of nuclear fuel trade.

Enrichment

Because of the dominant role of the U.S. in enrichment, its domestic policies regarding ownership, operation, and contract terms could not avoid affecting nuclear fuel supply and nuclear development. The policy changes of 1971 to 1975 had a particularly large impact, the most important events being the introduction of Long-Term Fixed Commitment Contracts and closing of the U.S. enrichment order books, and the associated changes in plans for stockpiles and tails assays.

At the end of 1972, the U.S. had entered into Requirements (REQ) contracts for 107,000 MWe of nuclear capacity, 25,335 MWe of which was

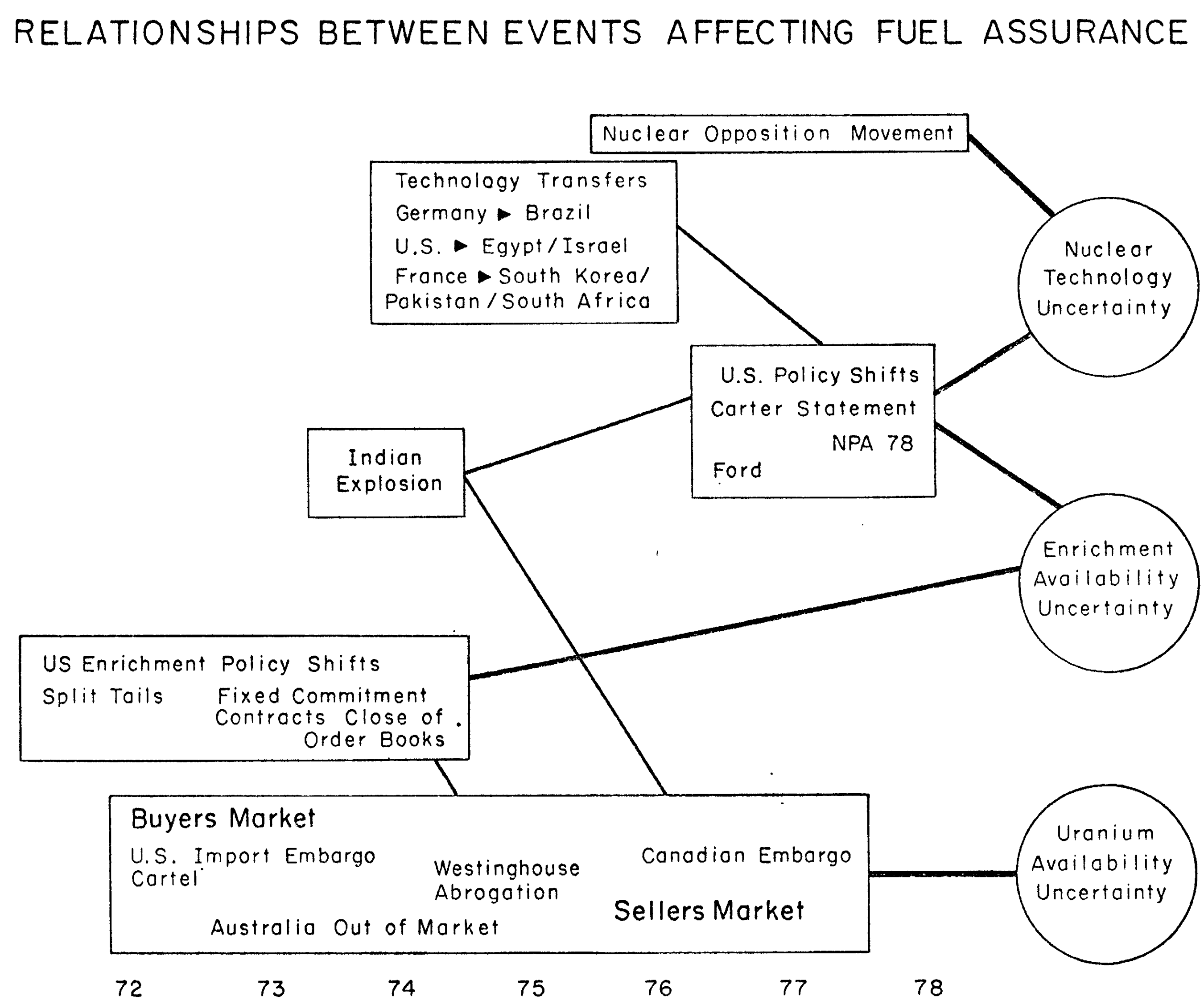

Figure 4.2 Events affecting nuclear fuel assurance and their interrelationships.

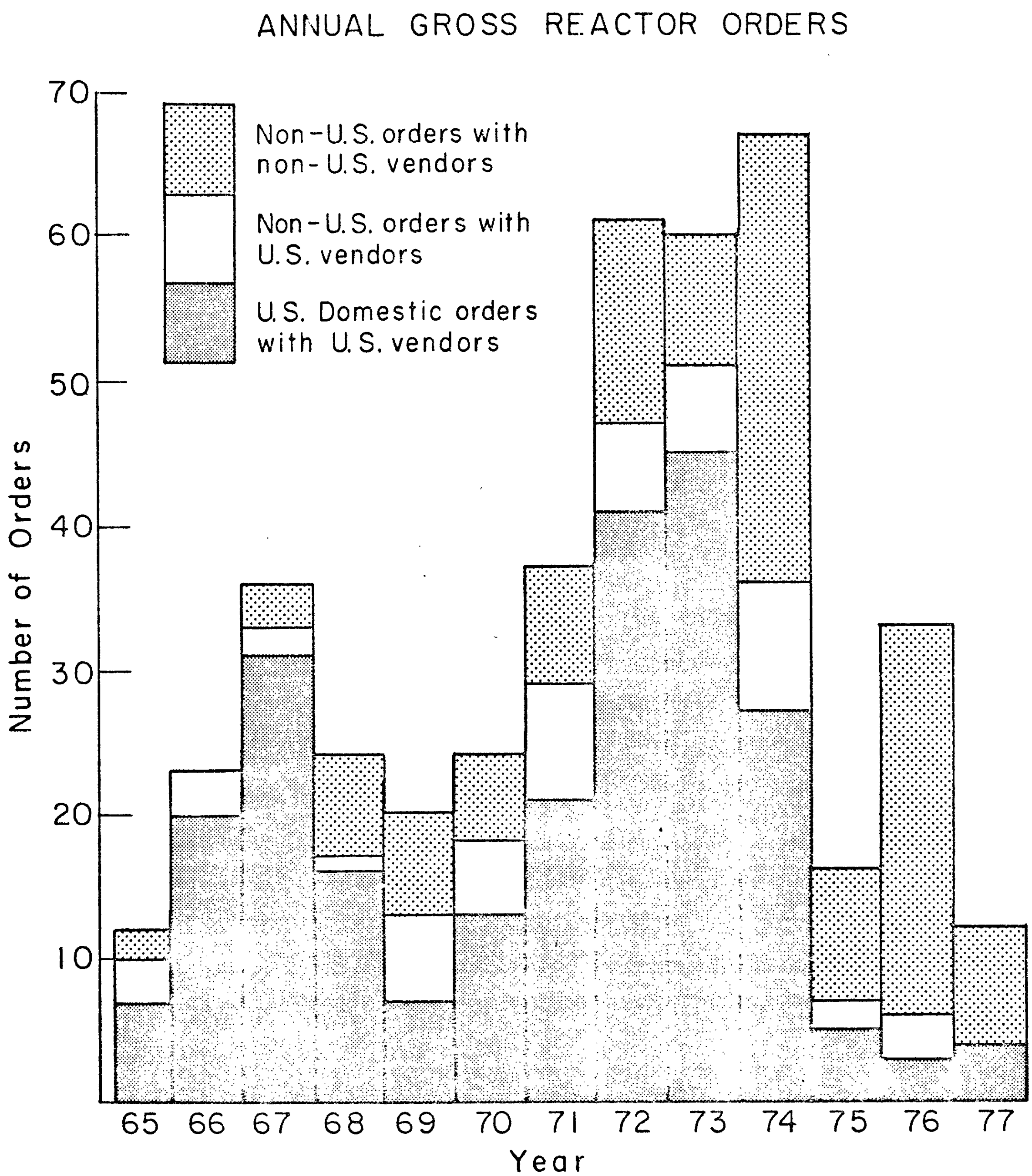

Figure 4.3 Gross reactor orders by year of order. Some reactors were subsequently cancelled; the largest cancellations were in the United States. Data from Kidder-Peabody Reports of October 6, 1978 and September 2, 1976 with supplemental data from Nuclear News lists of 1972-1978.

for foreign customers. In January 1973, the AEC announced its intention to offer only Long-Term Fixed-Commitment Contracts (LTFC), and in September 1973, the Commission began to accept LTFC orders. Unlike the flexible REQ contracts, the LTFC contracts required that firm commitments for enrichment of initial cores be made eight years in advance, and that reloads (usually ten years' worth) be committed soon thereafter. Moreover, the AEC announced that contracts would be issued only for reactors requiring enrichment of initial cores before July 1982. Heavy penalties would result from deferral or cancellation of LTFC contracts.

By July 1974, ERDA (which inherited the AEC enrichment functions) had executed LTFC contracts for 166,000 MWe of reactor capacity, 42,000 MWe of which were with foreign buyers. Unfilled requests totaled 91,000 MWe (75,000 MWe foreign). Additional firm contracts (above nominal enrichment capability, if plants were operated 0.3% tails assay) were written, but 44,000 MWe of reactor capacity (mostly of foreign customers) remained unsatisfied. Contracts were offered for this capacity, conditional on the U.S. proceeding with plutonium recycle, and 27 of these conditional contracts were written. To deal with the uncertainties imposed on these customers, President Nixon announced a month later that the U.S. would "in any event" fulfill the conditional contracts.*

The effects of the LTFC contracts and the closing of the U.S. order books were significant. Not only did the contracts seem to encourage commitments to large numbers of reactors worldwide (an effect consistent with the large number of reactor orders in 1973 and 1974 as shown in Figure 4.3) but the substantial long-term commitments put considerable pressure on an already tight uranium market (as discussed below). These effects, combined with a decline in growth of electricity demand, environmental opposition and other factors, led to intense pressure in 1975 for readjustment of the LTFC contract arrangements. ERDA responded in mid-1975, with a "once and for all" open season -- a period in which

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*Of the 27, 18 holders of conditional contracts later terminated, some because they had been assigned a LTFC contract by an earlier purchaser. In 1977, 7 of the remaining contract holders terminated and 2 (both in South Korea) converted to LTFC contracts.

delivery, and thus reactor schedules, could be slipped. However, first cores were not allowed to slip beyond 1985, and a fraction of the natural uranium feed had to be delivered on the original schedule.* As of mid-1976, foreign capacity covered by LTFC contracts stood at 78,834 MWe.

Even more important than the pressure on reactor procurement and fuel cycle activities was the effect on the perceptions of foreign consumers and suppliers. These events damaged the confidence of consumers in the reliability of the U.S. as a long-term supplier, and some foreign reactor suppliers initially saw the U.S. move as an effort to induce commitments for new reactors which would be purchased from U.S. vendors. The U.S. move could also have been seen as a pre-emptive effort to tie up enrichment demand before new ventures abroad were in a position to write contracts.

In fact, the changes in U.S. contracting policies are probably best understood as resulting from the effort to shift enrichment to the private sector, begun in the late 1960s, and the desire to make long-term enrichment planning more secure in anticipation of a wave of new reactor orders expected in the late 1970s and early 1980s. While the reasons for privatization were probably more domestic than international--the original intention had been to make nuclear power a private endeavor and there was pressure to cut the size of the AEC budget--there appears to have been suspicion abroad that the U.S. was beginning to convert its traditional "promotion in the name of international security" into a drive for commercial dominance in an increasingly competitive world market. Whatever the facts, these perceptions could only add to the growing uncertainty about future availability of enrichment supplies from the U.S. and accelerate commitments to supply from the USSR and from the new European enrichment ventures.

Uranium

Up to 1973, the worldwide uranium industry remained weak. There had been a surge of reactor orders by U.S. utilities in the early 1970s

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*For contracts originally beginning in FY 1976-78, 100% of feed would be required; for 78-80, 50%; and 81-83, 25%.

(Figure 4.3), but it does not seem to have had much effect on U.S. spot prices (see Table 1), and in any event the rest of the world was excluded from the U.S. market by the continuing embargo on imports of foreign uranium. Utilities and consumer governments generally believed that uranium would be available at low prices; there was little interest in long-term contracts, buyers preferring the spot market where prices were falling (in real terms) in mid-1973.

The U.S. government also provided an additional demoralizing shock: just as reactor orders were picking up in the early 1970s, the AEC proposed to dispose of 50,000 STU_3O_8 from the U.S. stockpile. To reduce the impact on the uranium market, the AEC devised a "split tails" contracting arrangement. Utilities would deliver uranium as if the enrichment plants were to operate at 0.20% tails assay.* However, the plants would actually operate at 0.25% tails assay with the resulting requirement for additional uranium to be met from the AEC stockpile. This scheme would avoid a sharp blow to the uranium market, though it did mean that U_3O_8 demand would be about 20% lower than otherwise; it also showed that changes in enrichment contracting could suddenly alter uranium market conditions.

With a depressed uranium market in most uranium-producing countries, the atmosphere was created for government intervention, protectionist measures, and cartel formation. In the Spring of 1971 a series of meetings began which were to culminate in the "Club" or cartel of producers, which was active from 1972 to 1974. The government of Canada was apparently responsible for the first initiative, through discussion with Australian officials about uranium marketing strategy. In May, 1971 Canadian Resources Minister Greene was quoted [7] as saying that it was in the interest of Canada and Australia to work together on pricing, and that it was likely that agreement would bring in the large private producers like Rio Tinto Zinc. In the Fall of 1971, following a June

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*In enrichment, the feed (at 0.711 percent U235) is split into a product stream of, say, 3 percent U235 and a waste or "tails" stream of anywhere between 0.2 and 0.3 percent U235. For a given output of LWR fuel, the higher the tails assay the more uranium feed is required.

visit by Canadian officials to the U.S. to argue for relief from the import embargo, the AEC restated the U.S. intention to continue the embargo until the late 1970s.

By early 1972, there were reports of a meeting in Paris of representatives from France, Canada, Australia and South Africa intended to "put some order into the international uranium market...to coordinate uranium production and marketing policies" [8]. A second meeting was held in Paris in March, and a third in Johannesburg in May. Cartel documents released later [9] showed the development of a plan to allocate market shares for two periods, 1972-77 and 1978-80, and to establish minimum prices and bidding priorities for sales. The domestic markets of France, South Africa, Australia, Canada and the United States were excluded. Minimum prices were set to rise from around $5.50 to near $8.00 in the period 1972 to 1978. The cartel appears to have had little effect: by the end of 1972 the spot price (as computed by Nuexco) was still below $6.00 per pound. By the end of 1973, it had risen only to $7. The cartel may thus plausibly be viewed more as a symptom of the depressed market conditions of an earlier era than as a successful effort to control market conditions and price in a period of rising demand for uranium. In this regard, it was thus very different from the OPEC oil cartel.

Conditions in the uranium market did ultimately tighten, and prices rose, far beyond the expectations of the cartel organizers. However, the causes of these changes must be sought elsewhere. The relevant events are suggested in Figure 4.2. U.S. enrichment policy had a strong effect, for the introduction of LTFC contracts produced a surge in U_3O_8 demand in late 1973 and early 1974. Changes in uranium supplier government policies had similar, but smaller, effects: in 1972 a newly elected Labor Government put a lid on Australian exports; Canada (in September 1974) adopted a domestic reserve policy which required that a fraction of reserves be set aside for domestic use; and France (in April 1974) withdrew from the supply of uranium due to its new commitment to a much expanded reactor program. Finally, there was the Westinghouse abrogation of uranium supply contracts which was announced in September 1975, but had been rumored since 1974.

Of these events, the largest effects appear to have come from the large commitments to new reactor capacity in connection with the Long-term Fixed Commitment Contracts, and (in the United States) from the Westinghouse abrogations. The effect of the new enrichment contracts was two-fold: utilities were forced to take a longer-term view of procurement, and the new demand represented a sizable increase over previous expectations. The first cores (initial fuel loads) under the new contracts would require procurement by foreign customers of an extra 35,000 STU_3O_8(at 0.20 % enrichment tails assay) before about 1980, compared to deliveries under Requirements Contracts of about 20,000 STU_3O_8. Annual requirements for reactor reloads were to be increased comparably after 1980. The increase in domestic U.S. delivery commitments was much smaller.

The net result of all this was a shift upward in demand, occurring at the time when Australia had indicated its unwillingness to enter the market, and Canadian and French supplies were being reduced. At the end of 1973, outstanding U.S. utility invitations for bids stood at 40,000 tons [10]. As shown in Table 4.1, spot prices began to rise in 1973, probably more slowly than they might under these circumstances since Westinghouse's short position was still secret, thus isolating suppliers from the growth in demand.

Prices continued to rise during 1974, doubling by the end of the year. During 1974, U.S. producers and agents sold 17,600 tons to domestic buyers and 5,200 tons to foreign purchasers, who were appearing in the United States for large quantities for the first time (the previous year saw foreign sales of only 500 tons). Moreover, in 1974 the AEC announced that the U.S. ban on foreign uranium would be lifted beginning in 1979, and by the end of the year U.S. utilities had contracted for 33,000 tons abroad. (Previous U.S. purchases abroad were reported by the AEC as being only 7,000 to 8,000 tons total.) The procurement activities of U.S. utilities abroad increased the pressure on suppliers available to foreign utilities.

In the resulting seller's market the first "market price" contracts were written (the Canadian Rio Algom contracts with Duke Power and TVA).

Other changes also began to appear. Increasingly, utilities moved to arrange procurement directly: by the end of 1974, 68% of total U.S. forward delivery commitments had been arranged directly by utilities. The remainder were arranged by reactor vendors or other agents. By the end of 1974, rumors about the Westinghouse situation began to surface. So also did suggestions by ERDA that it would have to raise the tails assay on which uranium delivery requirements were based (a result of a revised stockpile policy), thus increasing the amount of uranium U.S. and foreign utilities would have to deliver to the enrichment plants.

Uranium prices doubled again in 1975 in this volatile atmosphere. ERDA's open season on Long-term Fixed Commitment Contracts gave an opportunity to reduce demand pressure for deliveries in the late 1970s. But Westinghouse made its first disclosure of its short position in July and in September claimed "commercial impracticability"* and declined to deliver on contractual responsibilities. The result was another scramble for new contracts and a further bidding up of prices. The main effect appears to have been on the domestic U.S. market: U.S. purchasers contracted for 16,200 tons from domestic suppliers and 4,400 tons from foreign sources; in contrast U.S. producers sold only 900 tons to foreign buyers [13].

In 1976, there were further changes in the uranium market as consumers and producers responded to growing uncertainties with a wave of vertical integration. Instead of contracts for deliveries, producers began to propose joint ventures with long-term financing arranged by utilities. This process had actually started during 1975, but the major impact on procurements waited until 1976 when a record 92,900 tons were contracted between domestic U.S. producers and consumers. Of this quantity, some 47% was from primary sources in which purchasers had a direct involvement [14].

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*A claim initially based on the OPEC price increases and embargo but later changed to allegation of uranium cartel price manipulation. The Westinghouse contracts affected were virtually all with U.S. utilities; only Swedish utilities were affected abroad. See Joskow [11]. Also, an excellent analysis of U.S. enrichment policy in this period has been prepared by Charpie [12].

A similar picture was emerging outside the U.S However, the energy security interests of countries like West Germany and Japan, and the risks of making investments abroad, led to relatively high levels of government involvement, either directly or through financing, guarantees or other subsidies. Government backing for foreign uranium ventures also reduces the risk of supply interruption by host country governments, particularly where the latter is in joint venture with the foreign entity.

The development of these patterns of integration appears to have stabilized the uranium market, though perhaps at the expense of making it less responsive to future changes in supplier and consumer relationships. Prices have not risen and indeed have fallen in constant dollars since mid-1976. The new procurement level in the U.S. fell back to 12,000 tons in 1977 [15], a figure comparable to annual production levels.

The uranium and enrichment market stabilization which began in 1976 is not the end of the story on fuel assurance concerns, however: just as market problems were being resolved, a series of political events further disrupted nuclear fuel supply arrangements.

The Changing Policy Context

The new difficulties arose out of an increasing politicization of nuclear exports due to proliferation concerns. The precipitating events, indicated in Figure 4.2, were the Indian explosion in (1974), and trade deals involving the transfer of reprocessing and enrichment technology (in 1975 and 1976). The planned technology transfers were from France and Germany--as new suppliers--to Pakistan, South Africa, South Korea and Brazil. These events reflected a change in the international balance of commercial and political influence in nuclear matters. The entry of new suppliers reduced the leverage of traditional nonproliferation leaders, like the United States, and this happened at a time when technological change and international technology transfers were bringing into question the capabilities of the nonproliferation regime negotiated during the preceding decade. The consequences for fuel assurance were profound, since nuclear fuel supply was the primary form of direct leverage over the nuclear activities of other countries retained by traditional suppliers.

The Indian Explosion. India's first nuclear device was exploded on May 18, 1974. It had been fabricated using plutonium produced in the "Cirus" research reactor supplied by Canada under a "peaceful uses" agreement. The event was a startling reminder to supplier nations that bilateral agreements and other arrangements could not prohibit misuse of transferred technolgies and materials. It also revealed an important ambiguity in bilateral and multilateral agreements. Even prior to India's nuclear detonation, disagreement arose between Canada and India as to whether all nuclear explosions were precluded by the peaceful use provision. India maintained, and does to this day, that peaceful nuclear explosives were not precluded.

The Indian explosion had its most immediate effect on Canada, which considered the Indian explosion to be in violation of their bilateral agreements. Canada stopped all nuclear cooperation with India, terminating fuel supplies to the U.S.-exported Tarapur power reactor. Canadian authorities also initiated reconsideration of export policies, which had not been a major political problem in Canada until the Indian explosion. The Indian explosion thus propelled Canada to the forefront of the proliferation policy issue; the result was new conditions on access to nuclear fuel, and disruption of supply.

Technology Transfer and Reactor Sales. The efficacy of the existing nonproliferation regime was also called into question by the effects of competitive pressures for exports and the use of sales and technology transfers as instruments of national policy abroad. In 1974, the Nixon Administration offered nuclear reactors and fuel to Egypt and Israel. It was argued by the Administration that American nuclear technology should be used as a general tool of diplomacy, and if the U.S. did not make the sales, other, less responsible, suppliers would. However, there were complaints in the U.S. Congress and elsewhere that the pursuit of diplomatic objectives through nuclear sales might ultimately increase the chance of nuclear conflict in the Middle East. There were also questions about whether such visible sales to non-NPT signatories were in the best interests of U.S. policy. This use of nuclear sales for general diplomatic and commercial purposes may have weakened U.S. nonproliferation leadership in a key period of international change. The arguments used to justify the U.S. offer to Egypt and Israel were later echoed by other nuclear technology suppliers entering the export market.

The political context of international nuclear trade was further complicated by the multibillion-dollar sales by France and West Germany to Brazil, Iran, South Korea, Pakistan and South Africa. The nuclear export market was becoming extremely competitive, with not only power reactors but fuel cycle equipment becoming involved. The political leverage of any one exporter thus was reduced at the very time that sensitive nuclear technologies were spreading over the globe. While U.S. policy was to prohibit the export of reprocessing and enrichment plants, France and Germany were offering both to foreign customers, giving them a competitive advantage over American manufacturers.

In June 1975, Brazil and West Germany signed a contract calling for a large transfer of all stages of fuel cycle technology. The deal involved the possible construction of eight power reactors and certain privileges for Germany in exploiting Brazilian uranium resources, and included were an industrial-scale enrichment plant, a fuel fabrication facility, and a pilot-scale reprocessing plant. Though Brazil agreed to safeguards stricter than those of the IAEA, there was concern that these controls could not be sustained after transfer of the facilities. Brazil has not signed the NPT, and claimed that the safeguards agreement in no way prejudiced her access to "nuclear devices" in the future.

France also became involved in commercial activities involving proliferation-sensitive technology. In 1975, France entered negotiations for the sale of a reprocessing plant to South Korea, and in 1976 agreed to sell a reprocessing plant to Pakistan. In each case, the deal involved a safeguards package to be negotiated between France, the buyer and the IAEA, and promises not to use equipment or materials for the manufacture of explosive devices. However, even these arrangements raised great concern in the U.S. and other countries. South Korea suspended negotiations in early 1976; current indications are that the contract with Pakistan is now suspended.

There was sharp competition for reactor sales in other countries as well. Iran made major purchases from Germany in 1976 and France in 1977, all against U.S. competition. Germany did not promise reprocessing or enrichment technology to Iran, though it was reported that the two countries were discussing an option for a reprocessing plant [16]. Also in 1976, a French consortium signed its first contract with South Africa. In this case, General Electric had submitted the lowest bids and expected to get the sale. One possible reason for the choice of the French offer was the difficulty G.E. had in guaranteeing the supply of components and fuel, given the complexities of NRC procedure and the possibility of a confrontation over South African racial policies. There also were rumors [17] that the French won the contract due to promises to go easy on safeguards against military uses and that the deal had been coupled to conventional military weapons sales to South Africa [18]. These rumors were officially denied by the French Government.

Whatever the facts of the matter, it is clear that over the period of 1974 to 1976 fundamental changes had taken place in international trade in nuclear equipment. Strong competition was established, altering the balance of nuclear influence in the world. Moreover, the transfer of fuel processing technologies became an important element in the bargaining and differing national policies on technology transfer further modified the former pattern of commercial advantage.

Canadian Policy Changes. Canada, whose exports had been used by India to produce a nuclear explosive, responded first with a series of changes in export policies. In December 1974, Canada called for a renegotiation of existing agreements and the retroactive and prospective imposition of new nonproliferation conditions on all uranium contracts with other countries. While Canada was able to modify agreements with some countries (for example, Argentina), progress with Switzerland, Japan and the Euratom countries proved difficult. The renegotiation period ended in December 1975. After two subsequent six-month extensions had expired without agreement, Canada announced a uranium export embargo.*

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*Nuclear generation was not affected. According to Canadian officials, analyses were performed to verify that there would be no direct effect on energy supply (private communication).

At the same time, Canada further increased the stringency of her export criteria. Under the new regulations, new contracts, or contracts pursuant to existing agreements, would be approved only if the consumer country accepted the NPT or agreed to safeguards on its entire peaceful nuclear program, a provision commonly referred to as "full-scope" safeguards. Canada also required a prior approval condition on reprocessing and retransfers to third parties, a pledge not to develop "peaceful" nuclear explosives, and implementation of Euratom-IAEA agreements on the latter's safeguards role.

Euratom posed a special problem for the Canadian initiative. As discussed above, the formation of Euratom had involved major political accommodations within Europe, including agreement to free transfer of material within the Euratom community and the establishment of an internal safeguards system. The EC members thus contended that Canada had to deal with Euratom as a whole, despite the fact that most uranium contracts with Canada had not been initiated through Euratom. Canada's position was that material could not be transferred to France, which had not signed the NPT nor executed a trilateral safeguards agreement with Euratom and the IAEA (as had the other members of Euratom).

The Canadian embargo was relaxed by early 1978, with a temporary remission of disagreements aided by events outside Canada. Policies were changing in the U.S., as discussed below, and the International Fuel Cycle Evaluation (INFCE) was begun. INFCE provided an opportunity to deal with the Canada-Euratom dispute by postponing resolution of the renegotiation issue until the year following the completion of INFCE. During the interim period, Canada has suspended its original demands for veto power over reprocessing, enrichment and retransfer; now only "prior consultation" is required. The interim agreement, developed in December 1977, was made without prejudice as to the outcome of ultimate negotiations: to grant Canada a suspension of its veto would have implied Euratom recognition of the Canadian veto power. The interim agreement thus represents a suspension of the sensitive prior-approval issue (a position weaker than that in the U.S. legislation discussed below). In exchange, however, Canada did achieve the implementation of trilateral safeguards agreements with the non-weapons states in Euratom and the IAEA and with the IAEA and the U.K. France, the principal stumbling block in the Euratom negotiations, was to have negotiated a separate agreement with the IAEA but has not yet done so; in the interim, there is agreement that Canadian-supplied material will not be transferred within Euratom to France.

In addition, there was the negotiation (in December 1977) of an interim Canadian-U.S. agreement on "double-labeling" (i.e., the imposition of separate safeguards systems by two countries). Under the agreement, the U.S. is committed to consult with Canada concerning imposition of safeguards conditions prior to releasing Canadian-origin material (e.g., following enrichment in the U.S.). This arrangement provided the key to resolution of a disagreement between Canada and Japan. Japan renegotiated its agreement with Canada to reflect the new Canadian conditions in January 1978. The new agreement provides for Canadian approval of safeguards on reprocessing, enrichment, storage and retransfer.

Another factor which may have been important in Canadian accommodation was the economic significance of uranium exports to the nation and to the uranium industry; both remembered the hard economic times which had only recently given way to rising uranium sales at increasingly high prices. As early as March 1977, news reports indicated mounting pressure from the uranium industry for resolution of the safeguards deadlock. The embargo had tied up contracts worth more than $300 million. Late in 1977, the Canadian Trade Minister was quoted as saying that Canada was waking to the "commercial realities" of its safeguards policy [19]. Such a mixture of nonproliferation and commercial interests undoubtably will remain an important factor in the future evolution of Canadian policy.

U.S. Policy Changes. While the Indian explosion stimulated an early response in Canada--due to the direct involvement of Canadian equipment--the effect on U.S. policy was slower to develop. The U.S. first responded to the German and French technology transfers by attempting to intervene directly with the countries involved or indirectly through the London Suppliers' group (discussed below); basic shifts in nonproliferation policy came later. In part, this delay was due to the fact that nonproliferation policy was complicated by a growing pluralism and ambiguity in the policy formulation process.

The Energy Research and Development Reorganization Act of 1974 began to open up what had been a monolithic nuclear policy process within the AEC and the Joint Committee on Atomic Energy. Licensing of exports was assigned to an autonomous Nuclear Regulatory Commission (NRC) which began to play a day-to-day, independent role in interpreting nonproliferation conditions. Such a system would have been relatively stable in an era with little change in international nuclear problems and little need for change in U.S. policy. However, with rapidly changing international conditions, the NRC was put in the uncomfortable position of having, in its routine licensing decisions, to play an important foreign policy role. In March 1975, the NRC began a policy of closer scrutiny of potentially sensitive exports by the commissioners themselves; this change in procedures delayed licenses and was widely interpreted abroad (and still is) as an export ban. In West Germany, the Research and Technology Minister stated that the "export ban underlines the need to become as independent as possible from foreign energy sources" [20]. That even small changes in procedures could raise such concerns revealed a growing uncertainty about the reliability of U.S. supply, and increasing sensitivity to the security of nuclear fuel generally.

The NRC also had to respond to the effects of the Indian explosion, and a growing awareness of the difficulty of making reprocessing amenable to traditional safeguards measures. The issue was brought to the fore early in 1976 with consideration of an export license for fuel for India's Tarapur reactors. For the first time, nuclear opposition groups (the NRDC, the Sierra Club and the Union of Concerned Scientists) sought to intervene in opposition to the granting of a fuel export license, citing the lack of Indian acceptance of the NPT or adherence to full-scope safeguards. The announced purpose of the intervention was to force alteration of U.S. policy--an issue which went beyond the functions of the NRC. The license dispute was clearly focused on the reprocessing of plutonium, with consideration given to U.S. buy-back of spent fuel. When the license was finally issued at midyear, it was with a dissent by

Commissioner Gilinsky contending that safeguards on plutonium resulting from the irradiation of U.S.-supplied fuel could not be considered adequate.

While the NRC could only respond to growing proliferation concerns in its application of existing law to specific exports, 1976 also saw the beginnings of the legislative revolution which would ultimately culminate in the Nonproliferation Act of 1978. Activities in the 94th Congress appear to have been motivated by the sensitive technology exports undertaken by the FRG and France. Attention centered not only on conditions for U.S. exports but also on the exercise of U.S. leverage on the policies of other suppliers; it also focused on the roles to be played in the policy process by a host of governmental entities,* with increasing importance attached to the role of a Congress experiencing a resurgence of interest and power in foreign policy. However, action in Congress was itself inhibited by splits between committees: the Joint Committee had to yield its monopoly on domestic nuclear policy to the Government Operations Committee and the Foreign Relations Committee in the Senate and to the International Relations Committee in the House only when export issues were considered. The result--until the demise of the Joint Committee in 1977--was difficulty in passing new legislation.

Legislation considered by the 94th Congress in the Summer of 1976 included virtually all of the provisions of the NonProliferation Act of 1978, including prior approval on retransfers and reprocessing (of material irradiated in U.S. supplied reactors, or of U.S. supplied fuel), no "peaceful" explosives, timely warning criteria,** renegotiation of

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*Including the NRC, ERDA, the State Department, the Department of Commerce, the Arms Control and Disarmament Agency, the State Department, and the National Security Council.

**The issue here was whether ordinary IAEA safeguards could be politically relevant when dealing with plutonium fuels or sensitive facilities. It was argued that a primary role of safeguards is to provide a signal to the world that diversion or misuse is occurring in time for international response to be mobilized prior to consummation of nuclear weapons construction or an irreversible commitment to weapons. The timely warning condition was intended to ensure that this function of safeguards remained intact and put the burden of proof on those proposing new fuel cycle activities.

existing Agreements, and full-scope safeguards. The only significant piece of legislation passed by the 94th Congress was the Symington Amendment to the Foreign Aid bill. The amendment provided for a cutoff of U.S. aid to those countries importing or exporting enrichment or reprocessing equipment without guarantees of full-scope safeguards. This condition was made subject to Presidential exception, with Congressional override possible--again a model for the procedures of the Nonproliferation Act of 1978.

Foreign supplier exports were also the subject of a proposal, made prominent by Senator Abraham Ribicoff [21], to implement reactor market sharing as a way to avoid the competition which led to inclusion of sensitive technologies in reactor sales in an export market increasingly centered in developing countries. Ribicoff also proposed the internationalization of spent fuel storage and, to undercut arguments for reprocessing, the provision of low-enriched uranium fuel assurances. The Ribicoff proposal thus continued the trend toward increasing emphasis on technological choice as a determinant of proliferation risks; it identified commercial competition as part of the dynamics of proliferation; and it proposed low-enriched uranium fuel assurance, in a multilateral context, as a way to alleviate the pressure for commitments to plutonium. Anticipating future U.S. policy shifts, Ribicoff also suggested that the fuel assurances which were to be used as a carrot in the developing world could also be used in industrialized countries as a stick, to compel conformity of foreign suppliers to U.S. nonproliferation goals.

Since very little of the legislative and other activity of 1976 resulted in actual changes in U.S. policy, there was little direct cause for alarm abroad. However, lack of clarity in U.S. export procedures, growing pluralism and dissonance in the policy formulation process, and indications of incipient changes in the basic assumptions and modes of action underlying U.S. policy, tended to increase uncertainties, in major industrialized countries and developing countries alike, about the market and sovereign costs which would be associated with future supplies.

These issues came to a head in late 1976 and early 1977. The growing debate over the efficacy of U.S. nonproliferation policy found expression in the Presidential campaign and changes in the 95th Congress cleared the way for legislative action. In the later days of the campaign, the Ford Administration promulgated a new policy regarding reprocessing and recycle of plutonium in which that technological extension of the fuel cycle would be considered necessary only when economic or other benefits outweighted proliferation risks. While this was a relatively conservative statement compared to those emerging in Congressional debates or originating in the arms control community, it established an unusually strong linkage between domestic nuclear policies and foreign policy objectives.

It also marked a fundamental change in the basic assumption that there was no strong connection between technological change in nuclear power and the nature of the proliferation problem. While the U.S. had avoided direct transfers of enrichment and reprocessing technologies, the international nonproliferation regime it had helped to construct assumed that safeguards would be able to deal with technological change. The policies of France and Germany--which led to the deals with Brazil, South Korea, South Africa and Pakistan--were consistent with the old assumptions but not with those emerging (in part as a result of these transactions) in the U.S.

The Carter Administration carried the debate further in a major announcement of April 7, 1977. Domestic reprocessing and recycle of plutonium were deferred indefinitely and the commercialization phase (though not longer-term R&D) of the breeder reactor program was suspended. Alternative fuel cycles, which inhibited access to weapons material, were to be emphasized in U.S. programs; fuel assurance was to be improved by increasing U.S. enrichment capacity and making enrichment contracts available; the export embargo on enrichment and reprocessing technology would be continued; and the U.S. would explore ways to insure adequate energy supplies multilaterally while reducing the spread of capabilities for nuclear explosive development. The President also called for an international nuclear fuel cycle evaluation program.

The focus of these statements, including that on fuel assurance, was on the proliferation implications of reprocessing and plutonium utilization. While the announcement indicated that the U.S. would not attempt to force abandonment of reprocessing in countries already having reprocessing plants in operation (Japan, France, Great Britain and Germany were mentioned), the U.S. attitude toward the much larger number of countries with reprocessing plans (some predicated on waste management assumptions) was far less clear. In addition, there was a suggestion (in response to a press question) that supply of fuel by the U.S. could be used as an instrument of compulsion as well as assurance.* In subsequent actions, the U.S. initiated the renegotiation of Agreements for Cooperation to reflect the new conditions.

Abroad, responses to the new policy were vigorous and largely in opposition. There were several reasons for this. Until the Carter statement, U.S. proposals for more restrictive nonproliferation conditions--which had included virtually all of those finally endorsed, and some more extreme--had been raising suspicions and concerns outside the U.S. But they had not been carried to implementation and thus confrontation. Even the issues raised during the Presidential Campaign could be viewed casually, and with some skepticism, as campaign rhetoric. The final statement of a firm position thus catalyzed and focused reactions to trends which had been building for some time. In part because of a lack of precision in the announcement, the interpretation of the U.S. statement was frequently more extreme than was warranted; for example, the trade press and foreign nuclear officials often saw the U.S. as attempting to deny reprocessing and breeders everywhere.** Such a denial would threaten long-standing plans for enhancing long-term energy security in some of these countries.

The early response came primarily, and most vehemently, from those directing nuclear programs in foreign countries or formulating national

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*The statement is somewhat unclear: "If we felt that the provision of atomic fuel was being delivered to a nation that did not share with us our commitment to nonproliferation, we would not supply that fuel" [22].

**This impression may also have been enhanced by discussions-not-public between the U.S. and other countries prior to the April 7th speech.

energy policies (often the same individuals). The new U.S. policy questioned the basic assumptions (the energy efficiency and independence provided by plutonium, a putative need for reprocessing for waste management, and so forth) on which programs and policies were built, and this happened at a time at which domestic public opposition was beginning to be felt in those countries. Some nuclear supplier states were put in a difficult position by the new U.S. policy. Germany on the one hand, did not want to retreat on its contractual obligations to Brazil; on the other hand, proceeding in the face of U.S. opposition risked other foreign policy costs and a strengthening of domestic nuclear opposition.

Nuclear planners in some smaller countries also saw the shift as reshaping the future nuclear fuel market, forcing reliance on a few suppliers of enrichment and reprocessing services rather than allowing competition to emerge (e.g., there were reports of Swiss concern about depending on France for reprocessing [23]). More importantly, others, such as Spain and Yugoslavia, saw the demand for renegotiation of existing agreements as a new sign of unreliability on the part of a traditional supplier of fuel and technology, and as a further threat to the sovereignty of smaller less-developed countries already highly dependent on large industrialized states.

This issue was already one of concern to developing countries in the context of the NPT, and more generally in the debate over the relationships of rich and poor nations. By emphasizing the need to slow the spread of sensitive nuclear technologies beyond a few industrialized countries, the U.S. was adding another level of discrimination among countries--that is, all would not have equal freedom of technological choice in nuclear power development. Non-weapons countries had seen the NPT as offering free access to technology and fuel, with safeguards being the price to be paid. Now, the U.S. was proposing to limit technological access, but offering a countervailing benefit in the form of improved fuel assurance.

The indefinite deferral of domestic use of plutonium in the U.S. based on a lack of economic or other need, was expected to minimize the appearance of discrimination. The U.S. shift was thus interperable abroad as an effort to redefine the NPT bargain, an effort not obviously contrary to the interests of many developing countries but politically difficult to accept.

During this same period the new Congress was completing a committee reorganization which abolished the Joint Committee on Atomic Energy and established the exclusive oversight of international nuclear policy in the House International Relations and Senate Foreign Relations Committees. This step, and the emergence of an Administration position, led eventually to the passage of the Nonproliferation Act of March 1978 (NPA78). The terms of this Act, which are described in Chapter 3 above, are the result of a process of compromise between Congressional attitudes and those of the Departments and Agencies of the Executive branch. The major difficulty was to find a way to establish uniform conditions for nuclear exports, which would make approval predictable as soon as basic nonproliferation conditions were met, while preserving flexibility for the Executive in dealing with specific situations. To provide this, the Act specifies sequential and conditional procedures involving the various governmental actors (the NRC, the President, the Departments of State and Energy, the Arms Controls and Disarmament Agency, and Committees of Congress).

In regard to fuel supply, a basic question about the Act, raised by a number of countries, is whether it provides a clear and predictable export policy: many of the situations to which it applies will not satisfy the general conditions, and recourse to the exemption procedures will be required. This procedure introduces less predictable factors (e.g., Presidential override of the NRC sustained by Congress). It is thus difficult for some countries to regard the Act as providing much greater assurance of supply, especially those which have not signed the NPT or accepted full-scope safeguards. Ironically, some of these are countries in which assurance may be most important as a nonproliferation measure.

Indeed, by creating greater uncertainty--or lack of assurance--for countries which do not accept all of the basic nonproliferation conditions, the NPA78 is perhaps more easily seen abroad as a tool of the U.S. drive for more stringent nonproliferation conditions, than as streamlining and making export conditions more predictable. Perhaps attempting to compensate for lack of manifest improvements in assurance through export policies, the Act creates a separate institutional mechanism to deal with fuel assurance concerns, an International Nuclear Fuel Authority. The extent to which such a mechanism can deal with fuel assurance concerns--especially those of countries whose primary uncertainty is U.S. export policy--will be discussed in Chapter Six below.

Multilateral and Other Responses. Changes in the terms of nuclear trade, and thus the environment affecting nuclear fuel assurance, have not been limited to the U.S., Canada and Australia. The export policies of Germany and France, the predominant new suppliers of nuclear technology, have been altered since their entry into export markets in 1975 and 1976. In general, these policies are now more restrictive than at the outset, especially in regard to transfer of proliferation-sensitive technologies. This change was the result of internal policy changes stimulated by international discussions and pressures. In Germany, a traditional business and trade orientation in export policy has been tempered by greater sensitivity to domestic and international political factors. In France, the creation of a Council on Nuclear Foreign Policy in 1976 similarly integrated political factors into an export policy which had until then had been dominated by the Ministry of Trade and Industry.

An important forum for the discussion of export policy issues was the London Suppliers "Club", an initially secret group of representatives of nuclear exporting countries which began meeting in London in 1975. The initial members were the U.S., the USSR, the U.K., France, West Germany, Canada and Japan; other countries, including Belgium, Sweden, Italy, the Netherlands, East Germany, Czechoslovakia and Poland, were participating by early 1977. Participants have taken the position that the results of their discussions are not binding agreements but rather, to the extent that common positions emerge, a series of unilateral policy actions taken by individual governments. Such a position was made necessary by the legal restrictions of the Euratom Treaty (which requires that all nuclear agreements entered into by members be approved by the

Euratom Commission) and by a desire not to be regarded as a suppliers' cartel. The Group has not entirely escaped the latter interpretation, however, particularly in the developing world.

During the past three years, the Group has agreed to increasingly restrictive common export conditions on nuclear trade and has provided an opportunity to discuss nonproliferation issues. The group also produced a "trigger list" of materials and equipment whose transfer to non-nuclear weapons states should involve formal governmental assurances concerning non-explosives use, physical protection, IAEA safeguards (including safeguards on facilities constructed using transferred technology), and the security of an IAEA safeguards presence in the recipient country. Consultation with the Group is required for exceptions. Suppliers agree to exercise restraint in the transfer of sensitive facilities, technology and weapons-usable materials; multinational arrangements are to be preferred. Suppliers are also urged to make provision for subsequent "mutual agreements between the supplier and the recipient on arrangements for re-processing, storage, alteration, uses, transfer or retransfer of any weapons-usable material involved." The Guidelines also call for continued consulation between suppliers on the implementation of the Guidelines, on the existence of possible violations of agreements, and on responses to such violations.

According to press and other reports, the Suppliers' Group has also considered proposals by the USSR and the U.K. for more restrictive supply conditions, including a suggestion that items on the "trigger list" be provided only to countries accepting full-scope IAEA safeguards on all fuel cycle activities [24].* France (and perhaps other countries) has opposed such a condition on the grounds that it would be equivalent to signing the NPT. While French policy has shifted toward greater prudence in exports and willingness to discuss export issues, it appears (as in the 1976 communique of the Council on Nuclear Foreign Policy) to favor emphasis on bilateral rather than multilateral arrangements--a position

*The U.K. also proposed to the IAEA than non-NPT signatories also be given the opportunity to accept full-scope IAEA safeguards. The proposal was reportedly opposed by some non-NPT countries on the basis that it would lead suppliers to insist on stronger conditions than otherwise [25].

which puts a high value on independence and sovereignty for supplier and consumer alike. As discussed below, if not modified, this position may impose significant constraints on political accommodations which might otherwise result in improved fuel assurance.

4.4 Summary

The evolution of commercial nuclear power and nuclear fuel supply internationally has been characterized by interdependent changes in technological, political and commercial dimensions. What was once a world in which the U.S. was the dominant force in all three dimensions--the major source of technology and fuel supplies as well as political leadership in spreading atomic power and controlling it--is now a world in which these powers must be shared with other states whose balance of interests is not necessarily the same as that of the United States. Other industrialized countries have developed their own domestic nuclear industries--first reactors and now enrichment and other fuel cycle services--thus reducing U.S. involvement and influence abroad. New suppliers have also begun to compete with the United States in the remaining export markets, notably the developing countries; this competition has been made more intense by the need to find external markets for nuclear industries whose domestic markets are threatened by public opposition or other difficulties. In addition, the rising expectations and desires for autonomy of the developing world have altered their traditional relationships with industrialized countries.

These changes have been paralleled by a new awareness of the importance of secure energy supplies to national health and security, engendered, initially, by the oil embargo and price increases of 1973-74. The countries of Western Europe and Japan--whose established economics are critically dependent on energy which is largely imported--and the developing countries--whose hopefully rapid growth is dependent on increasing energy supplies--were also more strongly affected than the U.S. by multiple failures and growing pains of the nuclear fuel supply system over the past five years.

Thus, while insecurity of fossil fuels was intensifying interest in nuclear power, there were increasing concerns about the security of nuclear fuel supply. In part these were due to conventional market development problems but they also reflected the changing political and commercial relationships between the United States and its traditional nuclear customers. Both have been responsible for the drive for nuclear autonomy represented by acquisition of LWR fuel cycle facilities and development of plutonium breeders. This drive for autonomy, and the prospective use of plutonium, has intensified concerns, especially in the United States, about proliferation hazards. And these concerns have led to new U.S. efforts to strengthen the nonproliferation regime negotiated in the last decade.

In the past, the major source of U.S. leverage to accomplish this would have been its dominant role as a supplier of nuclear technology and fuel. However, in the present world, exercise of this leverage--which is declining--is difficult since it could intensify desires for autonomy and might be suspected of being part of a U.S. effort to remove what appears to foreign suppliers to be a commercial advantage in export markets. The exercise of U.S. power through fuel supply is therefore at least problematic and perhaps self-defeating.

While some progress has been made since 1976 in controlling transfers of sensitive nuclear technologies, there remains considerable tension between the U.S. and other supplier and consumer countries, countries which undoubtedly perceive a different balance of commercial interests, energy supply insecurities and nonproliferation concerns than does the United States. The crucial issues are nuclear technology choice -- where, when and how plutonium is used, -- and the efficacy of institutional arrangements for dealing with proliferation risks. Policy makers in the United States now see these as interrelated: present and prospective institutions do not deal adequately with the risks of plutonium due to a lack of timely warning of diversion and misuse. France, West Germany and other countries -- committed domestically to plutonium and in great need of exports of reactors and fuel cycle services (including reprocessing) and of access to the natural resources and markets in developing countries -- have taken a more traditional view which is ironically similar to that of the earlier U.S. Atoms for Peace program: promotion under safeguards. While this view is changing, these countries do not yet fully agree with the U.S. on the means and ends of nonproliferation policy.

On safeguards, the difference between the United States and some other suppliers is one of degree: the U.S. would insist on full-scope safeguards on all peaceful nuclear activities as a condition for any export while some other suppliers require only safeguards on specific transfers (but may include facilities copied from those transferred or using transferred know-how). On plutonium, the United States wishes to restrict the pace and spread of plutonium stocks* by retaining a veto over reprocessing of fuel of U.S. origin or which is burned in U.S. supplied reactors. Some other suppliers do not make the underlying distinction regarding plutonium and do not require prior approval -- indeed France and the United Kingdom have entered the toll reprocessing business, though conditions for the return of plutonium have not been set down.

The resolution of these differences -- or the failure to resolve them -- will be a major factor in the future evolution of the nuclear fuel supply system and will affect the reality and perceptions of nuclear fuel assurance. At present, many of these disputes are in suspension or under negotiation. The International Nuclear Fuel Cycle Evaluation has provided a breathing space for national re-evaluation of nuclear power issues and objectives in an international context. It has also allowed a temporary remission in particular disagreements, such as that between Canada and the Euratom countries. However, the most important fact about INFCE is that it will end, in late 1979 or early 1980. The reconstruction of a common political and commercial context for nuclear power development and thus nuclear fuel supply, must be well under way by this date if fuel assurance is not to suffer new setbacks.

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*A similar condition applies to further enrichment or transfer to third parties.

5. TRENDS IN THE NUCLEAR FUEL SUPPLY SYSTEM

As shown above, concern about fuel assurance is the result of problems arising in the complex, coupled markets for uranium, enrichment and other fuel cycle services. These markets, in turn, are embedded in a larger political, technological and commercial context which has been undergoing major changes. Thus, discussion of future trends in nuclear fuel supply must consider not only conditions in fuel industries and markets but also the evolution of this larger context. We have not yet seen the end of the conflicts of the last few years: those over nonproliferation conditions, and also those associated with a changing political and commercial balance in non-nuclear as well as nuclear dimensions.

Conditions in nuclear fuel markets have improved considerably in the past few years. Rates of nuclear capacity growth have been lower than expected earlier, thus reducing the pressure on fuel supply systems. Tight market conditions and the fuel assurance concerns of the past have stimulated investments in uranium mines and mills and in additional enrichment capacity. Conservative planning by utilities and governments--planning for the worst while experiencing something less severe--has resulted in a building of fuel stocks which provide a cushion against future problems. We are also beginning to see increasing diversity of nuclear fuel supply industries and the creation of markets with greater stability and flexibility in responding to changing conditions. With some help from the intrinsic resilience provided by long fuel cycle lead-times, it has been possible to avoid any interruption of nuclear electricity generation, despite extreme shifts in supply conditions.

Optimism about these improvements, however, must be tempered by the recognition that a number of problems remain. These include the potential for disruption of markets due to cartelization of uranium supply, supplier failures, or mismatch between changes in enrichment and uranium markets. But the most critical issue affecting nuclear fuel assurance is the political conflict over the terms of nuclear fuel trade. If these conflicts are not resolved, flows of nuclear fuel will be constrained by the different restrictions imposed by different suppliers. Moreover, the security of future supplies will be threatened by the possibility of changing political conditions.

The effect of differing supplier restrictions is that market flexibility may be subtantially reduced. In a free market every consumer can contract with every supplier. There results a large number of degrees of freedom, which insures flexibility in dealing with the ordinary problems of supply and demand (e.g., strikes, natural disasters, errors of judgment in production, and so forth) and promotes economic efficiency. But in a highly constrained market the number of possible supply arrangements between suppliers and consumers may be severely reduced, even to the point where it is impossible to deal with changing conditions. Moreover, continuing conflict over political issues destabilizes the market, increasing the likelihood that conditions of supply will change in time. Fuel assurance is intrinsically low in a highly constrained market characterized by continuing conflict over basic conditions of trade.

The most important source of conflict is the lack of agreement on nonproliferation conditions; this disagreement is expressed in differing supplier conditions on access to nuclear fuel. Thus, we turn first to a review of the nonproliferation issue as it affects fuel supply and then discuss trends in fuel assurance based on alternative assumptions about the resolution of current differences.

5.1 Nonproliferation Conditions and Access to Fuel Markets

As discussed in Chapter 4, the past few years have seen increased agreement among nuclear exporters about the need for a stronger nonproliferation regime. This change has led to extended application of IAEA safeguards and stronger bilateral restrictions on use and retransfer of fuel and facilities, and on future application of technological know-how. There also is general supplier agreement to exercise restraint on transfers of sensitive reprocessing or enrichment facilities.

However, suppliers still differ significantly on nonproliferation conditions and on the extent to which low-enriched uranium fuel should be used as an instrument of nonproliferation policy. The differences center on two issues:

- whether full-scope safeguards are a necessary condition for any bilateral transactions, and
- where, when and how plutonium will be used.

Except under special circumstances, the new U.S. legislation demands full-scope safeguards as a condition for fuel exports, and requires prior approval for reprocessing or retransfer of U.S.-origin fuel. The procedures for gaining exemption from the first condition (basically, continuing Presidential intervention) are sufficiently problematic that most consumers could not be expected to rely on them in the longer term. Canada and Australia have expressed intentions to impose similar conditions on uranium supply. The USSR generally requires acceptance of full-scope safeguards.

In contrast, Germany and France (and the French-led Eurodif consortium) do not require full-scope safeguards, and reprocessing conditions appear to be limited to approval of plutonium storage or retransfer arrangements. Present African suppliers of uranium are also generally less restrictive.

The difference in safeguards requirements is on significance only for those consumers who have not signed the Nonproliferation Treaty* since NPT signatories are to accept full-scope safeguards. The reprocessing approval condition applies to all recipients of U.S.-supplied fuel (with the exception of certain grandfathered reprocessing facilities and contracts) and poses the greater potential for continuing conflict since it affects long-term technology choice and energy planning.

Underlying these variations in export conditions are differing attitudes towards the nature of the proliferation problems associated with nuclear power, and toward strategies for dealing with them. In

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*This statement requires some qualification in the case of peaceful nuclear explosives which are allowed by the NPT, under international supervision, but are not condoned by U.S. policy. In addition, imposition of full-scopes conditions on bilateral trade could improve consumer compliance with safeguards obligations under the NPT.

Europe and Japan, proliferation has usually been seen as largely a political problem which could best be influenced, through nuclear trade, by a nondiscriminatory policy of export promotion under safeguards specific to the transfer in question. While there has been increasing caution about exports of reprocessing or enrichment technologies to countries characterized as "proliferation sensitive," technological choice has not been considered a central proliferation issue. Finally, in many countries the supply of nuclear fuel is not considered an appropriate vehicle for implementation of nonproliferation policies. In short, these attitudes are remarkably similar to those governing U.S. export policies in the twenty years following the announcement of the Atoms for Peace program.

In contrast, the policies of the United States, and her nonproliferation allies, now reflect a new emphasis on technological choice as an important determinant of proliferation risks; the primary emphasis is on plutonium and plutonium fuel cycles. There also is a strong move toward the requirement of full-scope safeguards, a position endorsed by the other early nuclear weapons states, the U.K. and the USSR but not yet (or at least not publicly) by France, West Germany and other new suppliers. Under the terms of the U.S. Non-Proliferation Act of 1978, nuclear exports have become the primary source of direct U.S. leverage over the nuclear policies of consumer states, and over the export policies of other suppliers. Since the U.S. no longer has monopoly power over nuclear technology, the principal source of U.S. export leverage (and that of Canada and Australia) is nuclear fuel supply.

This disagreement over nonproliferation conditions, and their coupling to fuel supply, is complicated by the commercial interests of some suppliers (who may feel that they have an advantage in reactor export sales if they don't insist on full-scope safeguards or other more stringent conditions); by foreign domestic commitments to reprocessing and plutonium fuel cycles as ways of dealing with nuclear wastes or assuring long-term energy security; and by differing views of the relationship between developed and developing countries. For example, public acceptance of nuclear power in West Germany has been predicated (legislatively) on reprocessing as a step in waste management; it would be difficult for Germany to maintain this view domestically while taking a contrary position in regard to nuclear exports. Finally, France, Germany and perhaps other suppliers, tend to emphasize the autonomy of recipient states and are reluctant to insist on full-scope safeguards, or conditions on technology transfers, which would represent larger intrusions on their sovereignty. In part this may reflect a desire to maintain access to markets or sources of raw materials in these countries, but it also may reflect the earlier experience of these suppliers as the technological dependents of the United States.

From a fuel assurance perspective, it is crucial that a way be found to deal with differences over proliferation conditions. The task will not be easy, for involved are the commercial ambitions of suppliers, the energy needs of countries at different stages of development, technological relationships between developed and developing countries, and evolving public opinion in industrialized supplier and consumer states. We can foresee two possible approaches as shown in Figure 5.1. The first is to decouple low-enriched uranium fuel supply from all of these other issues. This could be done by agreeing to a set of export conditions no more stringent than those now commonly agreed to by all major suppliers. The second is to seek a new accommodation, at least among supplier states, on the issues above, and to construct a common policy for the use of fuel exports as an instrument of control over consumer states. Success with either approach would free nuclear fuel supply from an important source of insecurity and assurance concerns, with trade in LEU then taking place in one large worldwide market.

Consider first the prospects for "decoupling." Under current U.S. policy, as legislated in the Nonproliferation Act of 1978, nuclear fuel supply plays two potentially contradictory roles: as a fuel assurance inducement to avoid plutonium and as a threat of fuel withholding if the larger policies of recipients do not conform to U.S. nonproliferation goals. In practice, the Administration has taken advantage of the exception provisions in the Act (and exercised its influence on Canada and Australia) to place a high priority on fuel assurance. However, a

ALTERNATIVE NUCLEAR FUEL MARKET DEVELOPMENTS

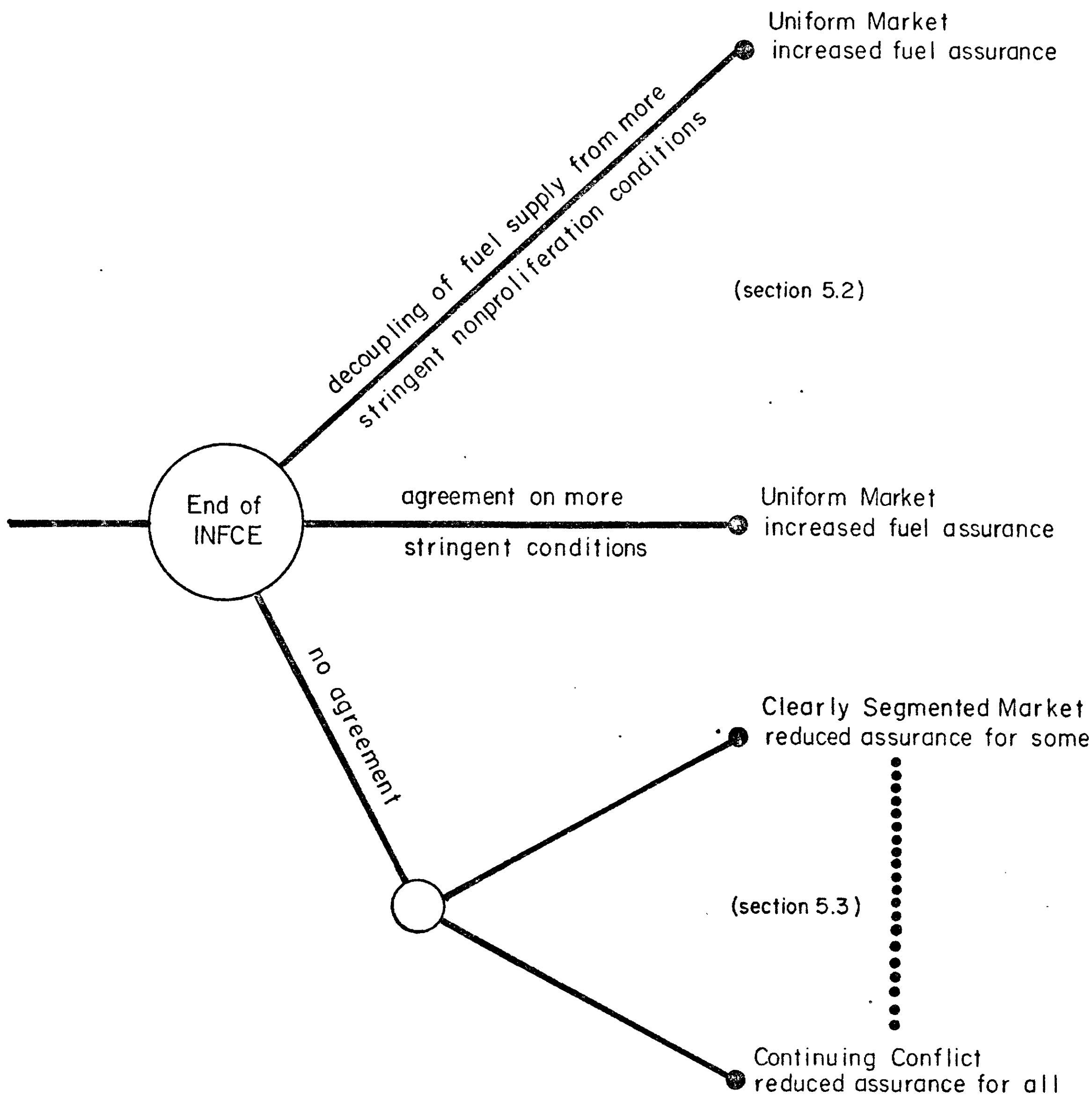

Figure 5.1 Possible developments in nuclear fuel markets, depending on the outcome of nonproliferation discussions.

formal separation of "fuel supply as assurance" from "fuel supply as a coercive tool of nonproliferation policy" would require modification of the legislative basis of U.S. policy--unless, of course, it is possible to obtain complete agreement to U.S. conditions. However, it does not now appear likely that the U.S. Congress, and other actors in the policy process, would be willing to accept the risks involved in releasing fuel supply from the constraints of new nonproliferation conditions. It also appears unlikely that all countries will be willing to accept all U.S. conditions.

The second approach, also shown in Figure 5.1, would require new agreements between major suppliers (and probably major consumers) on common nonproliferation conditions for trade in nuclear technology and fuel. While there is some possibility for agreement on full-scope safeguards,* the critical issue appears to be the terms under which plutonium is recovered and used internationally. In mid-1977, at the height of U.S. Administration and Congressional concern about this issue, the U.S. policy initiative appeared to be an effort to retard commitments to plutonium in Western Europe and Japan, as well as in the developing world. Subsequent clarifications have revealed a somewhat less restrictive U.S. position: the U.S. recognizes the energy needs of the major industrialized countries, as they bear on plutonium use; in return it is expected that these countries will give greater consideration to proliferation problems in domestic and, especially, export programs. Most of the countries to which this policy applies are actual or prospective exporters of technology or toll reprocessing services.

One basis for accommodation would be an agreement that plutonium will only be used in research and development on breeders (not for recycle in

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*As noted above, a number of countries involved in the Supplier's Group have called for such agreement. However, complete agreement among all suppliers may not be absolutely vital since a high percentage of possible transfers would be from suppliers requiring full-scopes, thus creating considerable pressure for their acceptance. What would be necessary, if it is not possible to reach general agreement on full-scopes, would be agreement that the U.S. and allied suppliers would not use fuel supply to compel other suppliers to insist on full-scope safeguards as a condition for their exports and that these other suppliers not undercut U.S. efforts to promote acceptance of such safeguards.

LWRs) and will otherwise be stored in a particular subset of countries, and not be used or stored (in separated form) in the remainder. Such an agreement would include conditions on nuclear trade--including flows of spent fuel and reprocessed plutonium--between the two regions. Such a regime would also prevent plutonium from playing a role in international commercial competition and reduce one source of proliferation risk. It could also provide a compromise between the commitment of the U.S., Canada and Australia to stronger proliferation barriers and the nuclear plans, programs, and export desires of Western Europe and Japan.

While the distinctions between countries involved in such a solution might be politically unpalatable to some developing countries, it can be argued that it would not injure their overall energy security and might well improve it. There is little chance that plutonium could contribute significantly to developing country energy needs until sometime after the year 2000 in any event.* Until then, these nations would have secure access to a growing world market in nuclear fuel. Furthermore, the security of LWR fuel supply might be increased by special pro-assurance policies pursued by the U.S., Canada and Australia, who will be the major suppliers of uranium and enrichment over the next few decades. These policies might include a simplification of access conditions on low-enriched uranium fuel (within the agreement suggested above), measures to reduce the likelihood of further political disruption of supply and institutional mechanisms (such as a fuel bank or options on stockpiles in various countries) to backstop residual uncertainties.

A regime in which a basic technological distinction was made between countries would also have to be reconciled with the NPT, whose only present categorical distinction is between nuclear-weapons and non-nuclear weapons states and which otherwise calls for nondiscriminatory access. As discussed above, there has been considerable dispute over the implications of Articles I and IV for nuclear trade. Suppliers stress the prohibition in Article I against

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*An important remaining issue would be the prospect for access by developing countries to new nuclear technologies and materials in the next century, and the timing and nature of the transition.

assisting recipient countries "in any way" to produce weapons; developing countries stress the NPT's statement of the "inalienable right of all parties...to develop research, production and use of nuclear energy for peaceful purposes without discrimination...." Depending on how it is achieved, agreement to restrictions on sensitive facilities and materials could help resolve this dispute, or it could further aggravate the problem, undermining the nonproliferation regime. The U.S. is currently seeking (in the INFCE activity) agreement through a consensus mechanism which would result in countries accepting differences, rather than discrimination. However, the success of this approach in producing an agreement which is congruent with specific U.S. policy goals is in some doubt. The alternative may be a supplier agreement -- one allowing major industrialized countries to pursue their technology plans but limiting the access of most developing countries to sensitive technologies and materials. This, in fact, appears to be the current situation, but its continuation does raise the question of the future success of nonproliferation institutions.

These two solutions, decoupling or agreement to common trade conditions, might have different effects on nonproliferation goals; detailed analysis of this aspect is beyond the scope of this analysis. But either solution would yield a uniform set of trade conditions, and the likely trends in fuel assurance in such a circumstance is the subject of Section 5.2.

However, if there is failure of agreement at the end of INFCE, then there emerges a range of possible developments as suggested by Figure 5.1. On the one hand there could be continuing conflict over conditions on trade and over associated nonproliferation policies. In such a circumstance, the effects on fuel assurance appear to be serious. On the other hand, there may be various ways that the market can accommodate a difference in conditions of access maintained by various suppliers. It soon will be physically possible for the nuclear fuel supply system to split into two segments: a larger segment governed by the more restrictive nonproliferation conditions of the U.S., Canada and Australia, and a smaller segment with potentially less restrictive conditions. The smaller segment would provide greater technological freedom for some developing countries and, perhaps, a reduction in constraints on national sovereignty. The cost would probably be a reduced level of LEU fuel assurance for customers in the smaller segment, and the need to accept alliance with the few supplier states willing to participate. Morever, nonproliferation conditions would remain as a potential factor in nuclear technology competition with a consequent continuation of international conflict. The latter result could reduce fuel assurance generally. The existence of this possibility is probably the most compelling argument for the need to reach common agreement.

In order to explore the range of possibilities, Section 5.3 analyzes the technical feasibility of a bifurcated fuel market, the process by which it might come about, and the likely effects on fuel assurance.

Naturally, any event tree, such as Figure 5.1, is a simplification of the range of possible outcomes; what appear as stark alternatives really are more like model events which help lay out the range of possible developments. At present, however, the world appears to be at a point of unstable equilibrium, with key decisions suspended while the International Nuclear Fuel Cycle Evaluation runs its course. As discussed in Chapter 6, the end of INFCE may be the critical juncture for deciding between the various futures we have sketched above.

5.2 Likely Developments under Uniform Nonproliferation Conditions

For most of its history, the market in low-enriched fuel, and fuel cycle materials and services, has operated on the basis of export conditions that were uniform over most of the world.* On the assumption that such a system will be re-established for the future, it is possible to discern some important trends in market function, and LWR fuel

*To the extent to which there were differences, they were not immediately relevant to nuclear fuel cycle activities until the mid-1970s. For example, the U.S. usually imposed retransfer conditions for most fuel exports; however, this only became important when countries began to contemplate reprocessing or other activities associated with the back end of the fuel cycle.

assurance. We look first at enrichment, and then turn to uranium and stockpiles of low-enriched fuel.

Enrichment

During the next several years, the availability of enrichment will increase worldwide, both in total capacity and diversity of sources. Increases to which commitments have already been made are shown in Figure 5.2, along with the most recent OECD estimates of demand.* Ventures planned but not committed could add to this capacity in the later years of the period shown. Likewise, the current excess capacity could lead to the delay of some of these investments by a few years, though all are likely to be built as demand growth justifies. Thus through the end of the 1980s at least, the issue in enrichment is not capacity but the conditions of contracting and, perhaps, the level of utilization of available capacity.

This picture can be elaborated by looking at subgroups of consumers of the enrichment services of the U.S., the USSR, Urenco and Eurodif. We divide consumer countries (other than the U.S.) into four groups: the equity partners in Urenco (the U.K., West Germany and the Netherlands), the equity partners in Eurodif (France, Belgium, Italy, Spain and Iran), Japan, and "Others." For each country, supply is considered to be its equity share in any venture in which it is a partner, plus contracts with other enrichment suppliers. Demand is based on the OECD/IAEA present trend forecast of actual reactor needs, supplemented, where necessary, byindependent estimates (described in the Appendix). Year-by-year comparisons, for each country group, of capacity available plus other contracts with projected demand is shown in Figures 5.3, 5.4, 5.5 and 5.6. With the exception of the Urenco group (largely West German

*The capacity of enrichment facilities is stated in Separative Work Units (SWU). About 111,000 SWU are required to enrich the fuel to operate a 1000 MWe LWR for one year at 70% capacity factor (assuming a 0.20% tails assay for enrichment plant operations). The Soviet capacity shown is not the total USSR enrichment capacity but only that capacity which has been contractually committed to exports outside the Soviet bloc. The quantities indicated are thus a lower bound on those potentially available.

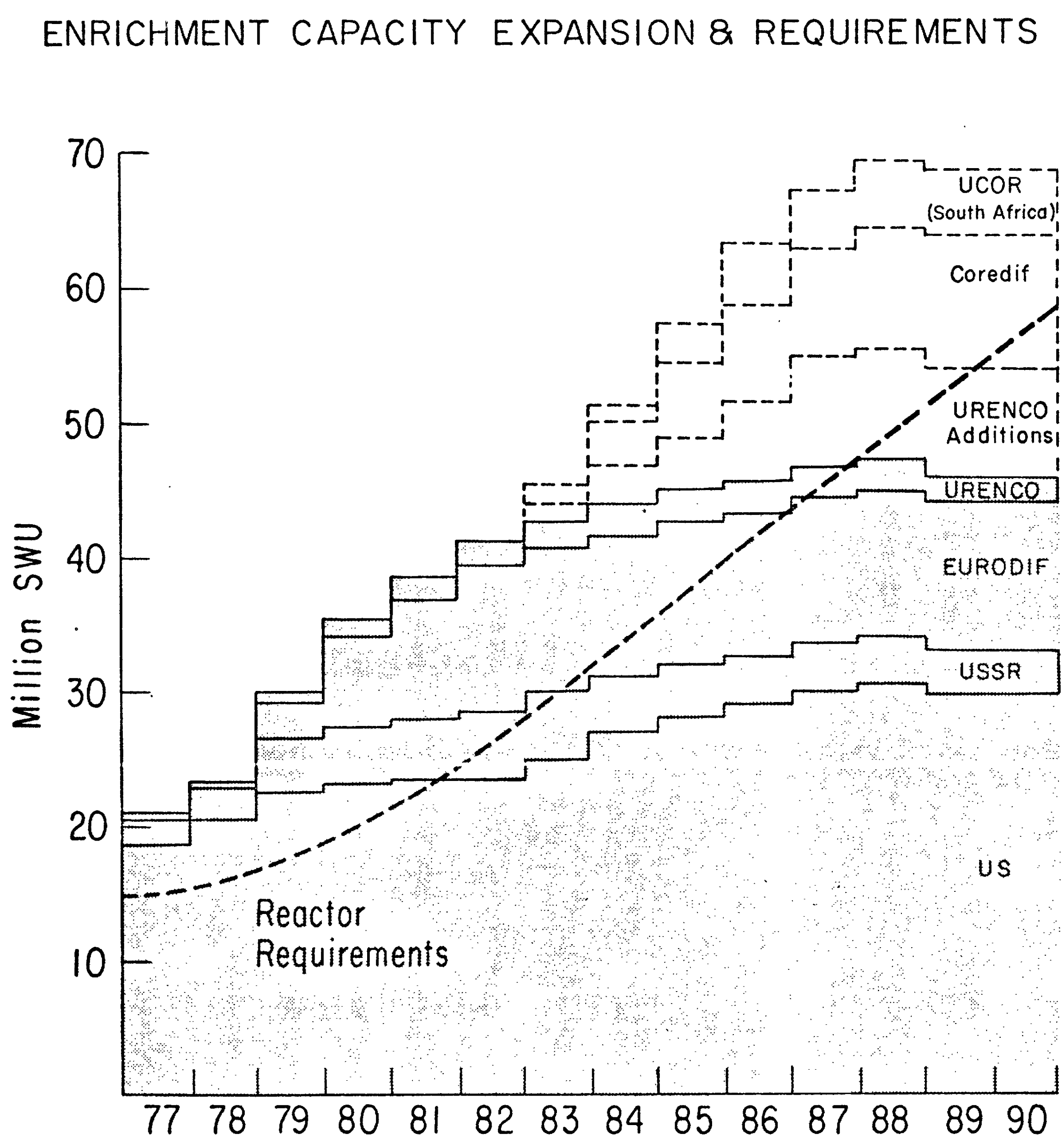

Figure 5.2 Enrichment capacity expansion as compared with projected reactor requirements. Reactor requirements are based on the December 1977 OECD/IAEA nuclear growth projections [1], assuming 70% reactor capacity factor and 0.20% enrichment tails assay. The solid lines indicate committed enrichment capacity and the dashed lines planned capacity. The capacity shown as available from the USSR is only that committed under current contracts; presumably it could be increased.

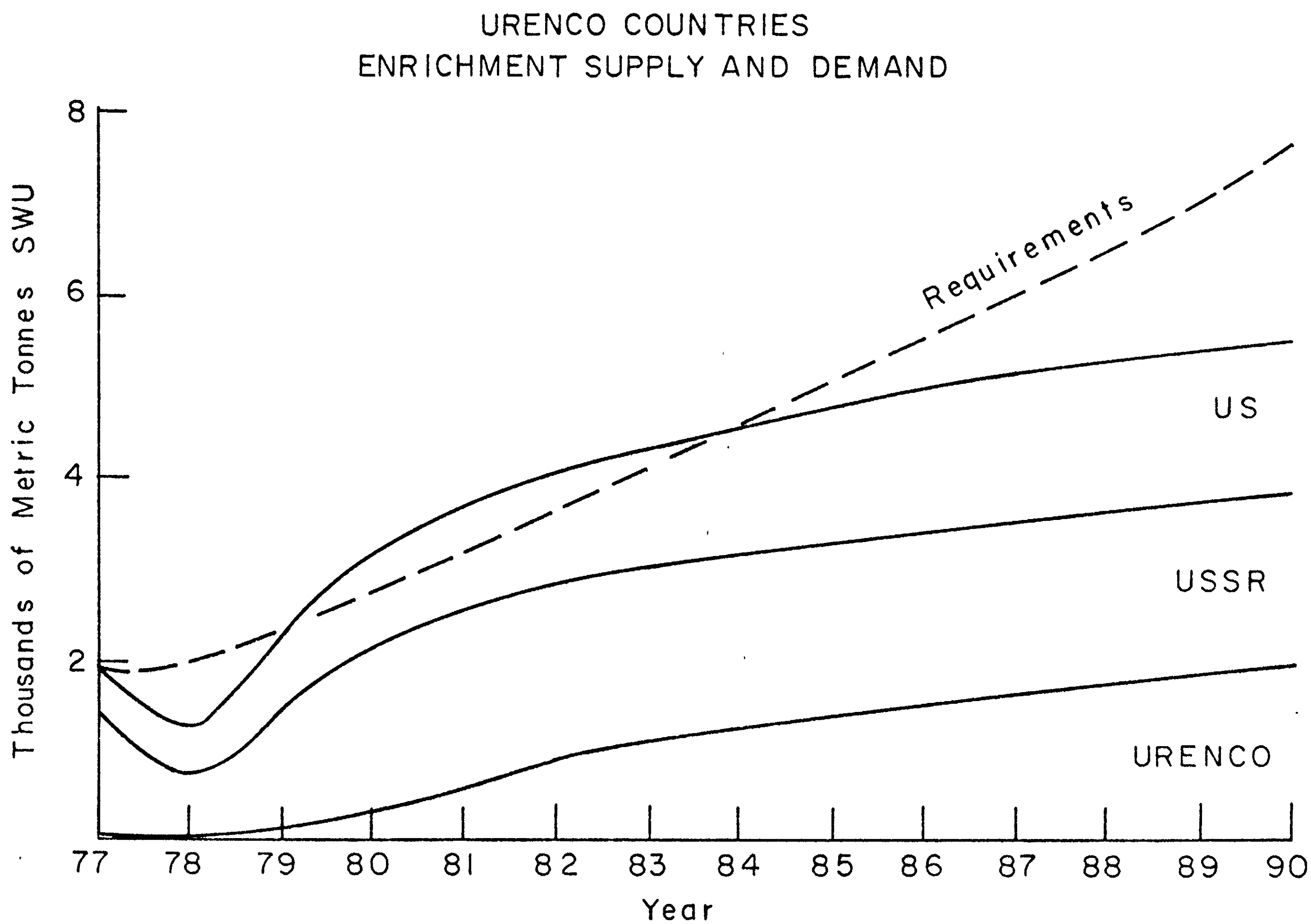

Figure 5.3 Enrichment supply and demand: Urenco utilities (West Germany, Netherlands, United Kingdom). Assumptions specified in Appendix A.

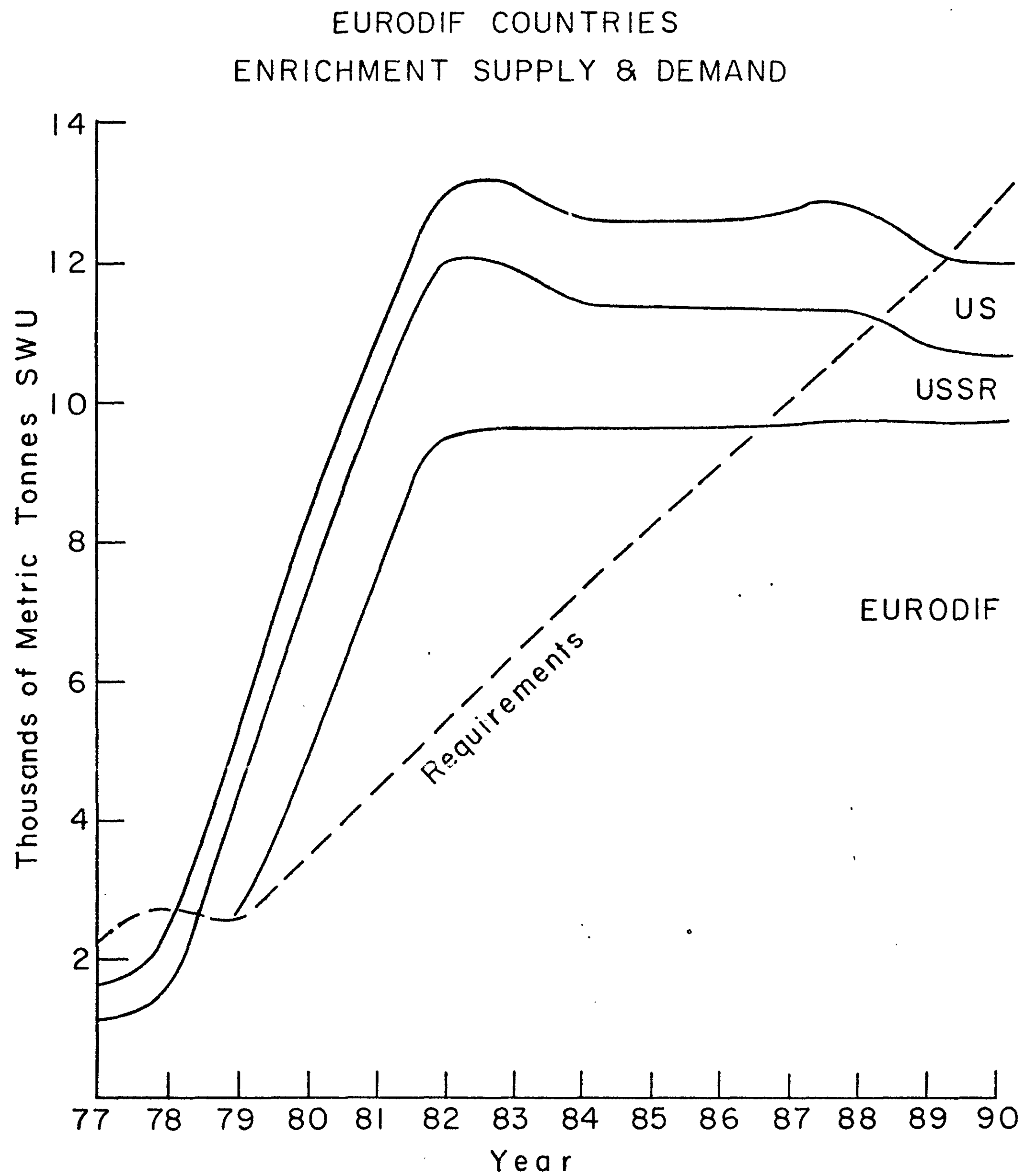

Figure 5.4 Enrichment supply and demand: Eurodif utilities (France, Belgium, Iran, Spain, Italy). Assumptions specified in Appendix A.

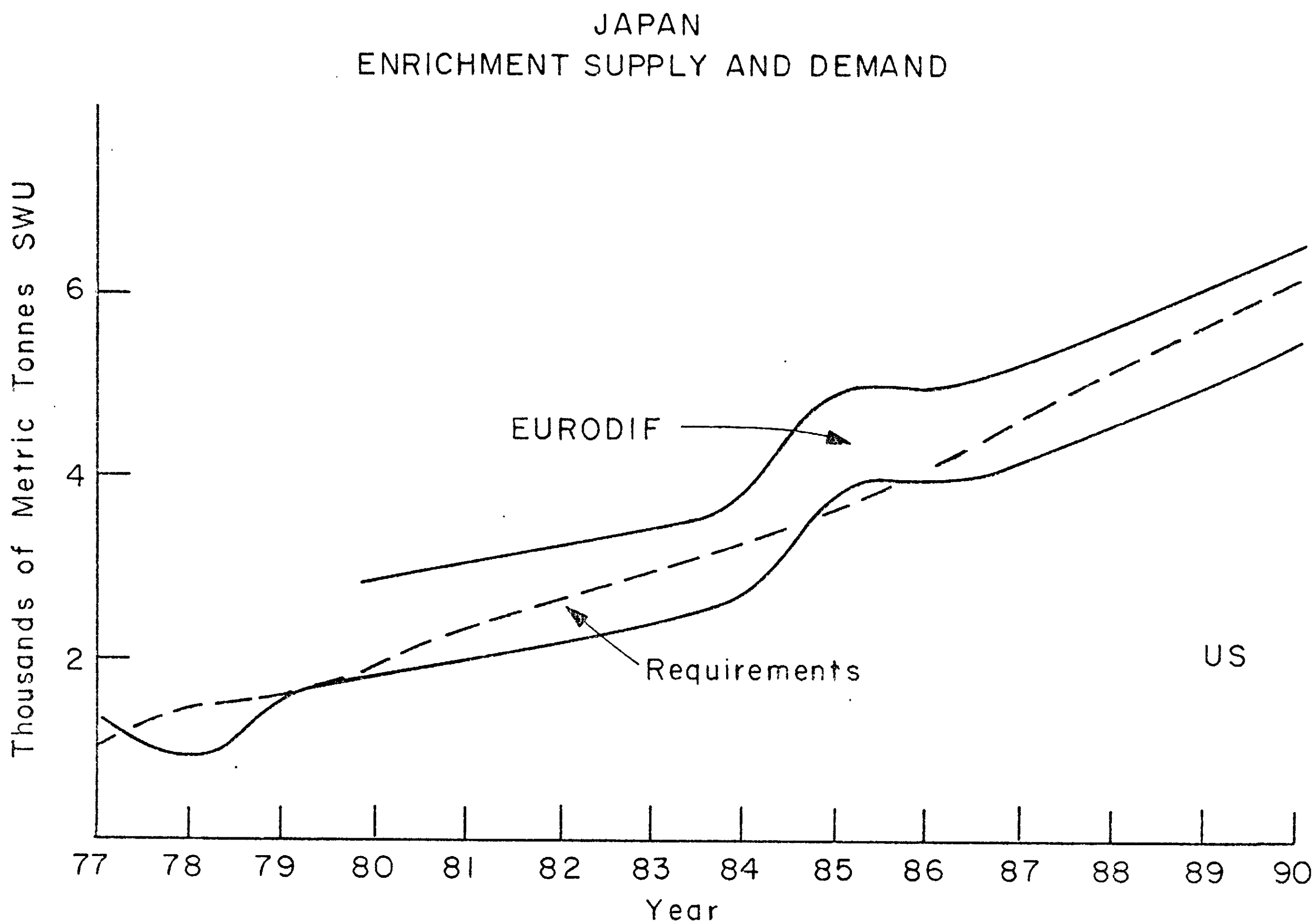

Figure 5.5 Enrichment supply and demand: Japan. Assumptions specified in Appendix A. Note that Japanese preproduction stockpile is not included in supply.

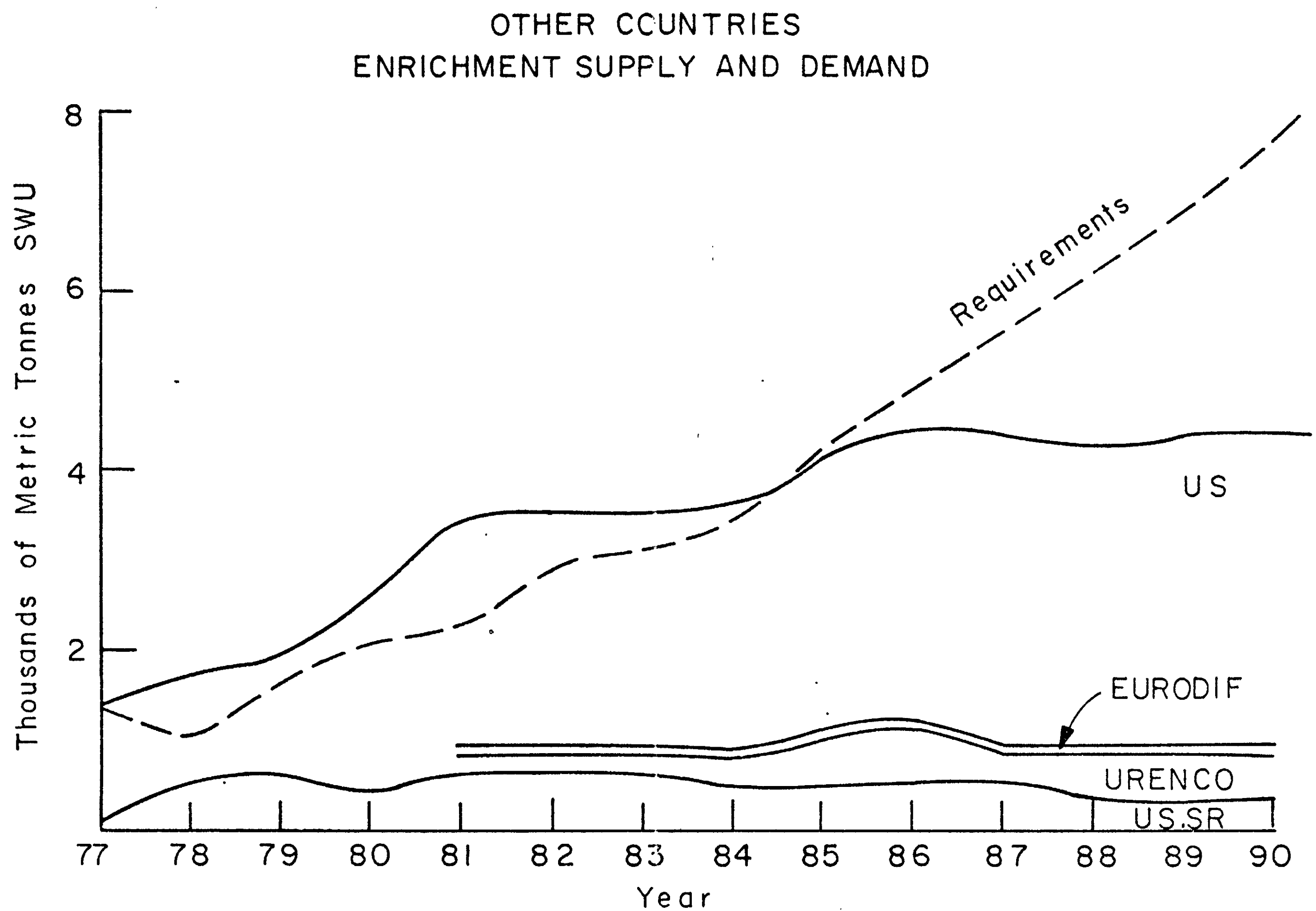

Figure 5.6 Enrichment supply and demand: Others. Assumptions specified in Appendix A.

utilities), enrichment supplies substantially exceec reactor requirements. The Urenco utilities apparent depend on their capability to expand centrifuge capacity in a timely manner.

In interpreting these comparisons, a number of qualifying factors must be kept in mind. The demand calculations are based on OECD/IAEA nuclear growth estimates, assuming 0.20% tails assay in all enrichment plants and 70% capacity factor for reactors. All of these assumptions tend to overstate requirements: some enrichment will be done at higher tails assay (at 0.25%, about 13% less enrichment is needed than at 0.20%); reactor capacity factors have been consistently below 70%; and the reactor growth projections are based on real data only out into the early 1980s. Beyond 1985, they are based on plans which, historically, have overstated actual growth.* Thus, the demand estimates shown are probably more like upper bounds on ultimate demand, especially after 1985.

However, the supply side projections are also uncertain. Actual enrichment capacity or production levels may be lower, or higher, than shown. For example, the U.S. has reduced power input to its plants, reducing SWU output, and has slipped plans for the CIP/CUP and centrifuge additions to capacity. Alterations in contracting policy--the switch to Adjustable Fixed Commitment Contracts (AFC)--will also affect the allocation of U.S.-supplied enrichment services, giving consumers the opportunity to drop or acquire new contracts and alter delivery schedules. All of these changes appear to be consistent with consumer desires and may thus be viewed as normal market adjustments to changing conditions.

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*For example, some recent U.S. projections for 1985 domestic capacity are below the OECD estimate of 115 Gwe and it is unlikely that Japan will deploy the OECD-estimated 27 GWe by 1985. The OECD projections also show a much more rapid growth after 1985, beyond the firm planning horizon of utilities. In part, this larger number of new reactors is due to deferral of plants planned for earlier years but not yet fully committed. Projections beyond about 1985 should be regarded with considerable caution.

Such adjustments also reflect a basic change in the character of the enrichment market. The entry of Eurodif at large scale and Urenco (whose centrifuge capacity can be expanded much more easily and quickly than that of a traditional diffusion plant) marks a great increase in diversity of supply. As indicated in Figure 5.4, Eurodif capacity exceeds considerably the requirements of its equity partners until at least the late 1980s. This excess raises the possibility of substantial shifts in the current worldwide allocation of enrichment contracts--a possibility whose political implications will be explored below. Properly exploited, excess enrichment capacity from several sources--which are notably politically independent--could provide opportunities for each nation to improve its fuel assurance by arranging supply (and perhaps building stocks) in ways which minimizes its market and political risks. Of course, previous contract, equity holdings, or regulatory conditions may reduce this flexibility, and countries or utilities may remain committed to enrichment services in excess of needs or desires. The removal of such barriers is thus an important class of governmental policy issues affecting fuel assurance.

Uranium

The international uranium market, which went through such extreme changes in the mid-1970s, now appears stronger and less susceptible to large fluctuations. Annual transaction volumes have decreased to levels more comfortably in line with annual production. Producers again have material or capacity available for spot market sales, and capacity for future delivery, and prices (in constant dollar terms) have declined over the past year. There are also reports of a trend away from the "market price" contracts of recent years.

These changes reflect a swing away from the extreme seller's market of recent years. While the market could repeat its historical pattern of extreme changes in market conditions, it is likely that the fluctuations will be smaller than in the past. The U.S. domestic market, at least, has developed mechanisms for dealing with such fluctuations, though it cannot yet be described as a mature commodity market. These mechanisms include mediation clauses for price disputes, and agents and brokers (like Neuxco) that can arrange loans or sales of material,* or act as leasing intermediaries. Internationally, such mechanisms are less developed, though there is some evidence that enrichment suppliers (like Eurodif) can play a mediating role.

In assessing trends in uranium supply and demand in the next decade or so, a large number of factors are relevant:

- Uncertainty about demand, which is dependent on nuclear power growth, on contract terms for enrichment (such as delivery schedules, and flexibility in altering tails assay) and on stockpile aspirations of utilities and governments.

- Problems associated with the supply of a depletable resource whose modes of occurrence are not well understood and whose exploitation is at varying stages of maturity in different countries.

- Factors influencing supply from known resources, such as environmental restraints, labor availability, regional political and economic conditions (e.g., extraction taxes), availability of financing, and so forth.

- Supplier and consumer governmental involvement in industry activities for reasons of domestic energy supply security, protection/promotion of domestic industries (uranium production in supplier countries, reactor industries in others), and nonproliferation.

- Coupling of uranium availability to the nature and pace of change in nuclear technology (e.g., introduction of plutonium recycle, laser enrichment, more efficient converter reactors or breeders, seawater extraction of uranium, etc.).

Many of these factors are interactive: for example, reduced expectations about demand may cause supplier governments to restrict domestic expansion of uranium industries and regulate exports. Given this complexity and the large uncertainties involved, it is not surprising that there is a wide variation in perceptions of future supply and demand conditions.

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*For example, excess material owned by a utility or fabricator may be loaned to a uranium producer to generate immediate cash flow for mine or mill expansion; the material, with interest, is then repaid out of future production.

Uranium Demand. The demand for uranium is largely a function of reactor capacity growth, but it also is affected by changes in nuclear technology, enrichment contract terms, reactor operating characteristics, and stockpile policies. Nuclear growth is itself only weakly dependent on uranium prices (which may account for 10% or less of delivered nuclear electricity costs), resulting in demand for uranium which is quite inelastic with respect to uranium price. Instead, decisions to build reactors are influenced more by the desires of electric utilities to maintain a mix of generation sources, public acceptance and regulatory conditions, and capital availability (especially in LDCs). Nuclear expansion also is affected by the problems associated with planning lead times which are long relative to those of alternative generation technologies.

Changes in nuclear technology could affect uranium demand in several ways. Improvements in uranium utilization in light-water reactors could reduce demand by 20% or more, compared to projections based on present technology and practices; much of this gain might be had before the end of the century. Similarly, advances in enrichment technology, such as laser isotope separation, would allow an increase of about 30 percent in the fuel manufactured from a given input of U_3O_8. Ultimately, new types of reactors--such as very efficient thermal converters or breeder reactors--could lead to dramatic reductions in uranium demand. (Indeed, the tight market for uranium and fears of energy insecurity in the mid-1970s accelerated interest in such reactors.) However, major changes in reactor technology cannot appreciably affect demand for uranium until some time late in this century or early in the next.

As discussed above, enrichment contracting requirements and governmental actions play a significant role in the near term. In the short history of this industry, we have already seen the important influence of changing tails assays, open and closed contracting opportunities, low flexibility in enrichment scheduling (and thus in uranium delivery requirements) when reactor plans slip, and government stockpile policies.

Recent changes in enrichment markets are also having a significant effect on expectations about future uranium demand. Until recently, government planners, here and abroad, analyzed uranium demand on the basis of enrichment contracts rather than actual reactor requirements, thus overstating uranium needs for power generation. These analyses also usually involved official expectations about rising tails assays, and thus higher uranium demand, than have proven necessary. In the past, uranium demand was largely determined by the rigid enrichment contracting policies of the United States, the only significant supplier. The entry of new enrichment suppliers and the consequent trend toward more flexible contracting arrangements restores some elasticity to what was a very inelastic demand--variations of ten to twenty percent in uranium demand may be possible, depending on consumer perceptions of relative security and prices of uranium and enrichment services. Utility and governmental consumers will thus play a larger role in determining short- as well as long-term demand and the uranium industry will likely see a change in the structure of its market.

The other factor in demand is stockpiling by utilities or governments. Uranium stockpiles (natural or enriched) have appeared for several reasons. They have arisen accidentally, as a result of mismatch between actual reactor needs and enrichment or uranium contracts. They also have been built intentionally, to cushion against market disruptions, supplier government intervention, and generally to reduce insecurity about energy supplies. A country may not need to make explicit decisions to build a stockpile: conservative planning to cover uncertainties about capacity growth, reactor operating efficiencies (capacity factors may range from less than 40 to more than 80%) or other factors in nuclear generation may result in procurement of larger amounts of uranium than will actually be used. For example, Japanese utilities have contracted historically for over 150,000 tons of U_3O_8, with more than 85% of this to be delivered before 1990; this contracted supply may exceed actual reactor needs during this period by as much as a factor of two, if reactor slippage continues.* Such over-contracting can also be

*Procurement was based on high projections of nuclear growth and on the assumption (based on U.S. announcements) that enrichment plants would operate at tails assays as high as 0.37% in the 1980s, instead of the 0.20% presently planned.

part of a more general and longer-term fuel assurance strategy: if the worst case conditions assumed for planning purposes do not materialize, the excess fuel can be stockpiled to provide a cushion against subsequent risks.

Stockpiles have also been created for reasons which have little to do with nuclear fuel supply issues. Examples include the German/American Offset Agreements, under which the FRG agreed to purchase enriched material (about 25 reactor reloads equivalent) to offset the cost of keeping American troops in Germany, and the Japanese preproduction purchase of 10 million SWU (equivalent to about 100 reloads) as enriched product. Similar sales have been discussed more recently as a way of dealing with balance of trade problems.

Observation of past contracting behavior suggests that as long as significant fuel supply uncertainties remain, demand-side planning will be biased in favor of uranium contracts exceeding actual reactor demand. This conservatism may weaken somewhat if stocks accumulate and the trend toward increased supply stability continues.

Uranium Supply. The supply of uranium is a function of the resource and reserve base, the conditions under which the supply industry operates, and the nature of the market system in which uranium is traded. The first of these factors is important only in the longer term, since reserves already proven appear adequate to fuel any reactors built over the next two decades. However, industrial development and market performance potentially are issues of pressing concern in the near term; they also affect the level of effort put into exploration and reserve definition and thus the level of production possible in the longer-term future. Uranium development problems are similar to those in other mineral industries: there is an increasing desire of regional or national governments to control or obtain compensation for the environmental and social impacts of extraction activities, and to realize the best return for the resources. These difficulties are amplified by the strategic role of nuclear fuel in energy supply and weapons proliferation and the regulatory scrutiny generally applied to things nuclear. Thus, government policy is an important factor shaping the supply picture.

Uranium industries in various producer countries are at very different stages of development; they operate in different geological environments and deal with different sets of political, institutional and environmental problems. In the United States, a large number of independent companies are involved in production from relatively small deposits in sandstone formations in which new inexpensive high-grade deposits are increasingly unlikely to be found. The impression is of a relatively mature industry moving--in the classic pattern of mineral industries--toward lower-grade or deeper and more costly deposits.* The major issues are rising labor and other costs, increasingly stringent environmental requirements, and state efforts to capture rents through extraction taxes. The relatively weak coupling between the U.S. and international uranium markets has restricted the importance of foreign policy issues, which tend to enter more at the enrichment stage.

In Canada, large high-grade deposits are to be mined by relatively few companies, one of the largest of which has significant government involvement. Despite a history of uranium exploration and exploitation, new discoveries of large, high-grade deposits continue to be made. The major influences on development include an increasing Provincial involvement (economically and environmentally), and--since most uranium is exported--the need to insure stable conditions (and revenues) for the domestic industry while pursuing nonproliferation objectives.

Australia is in a position similar to that of Canada, except that its industrial development is less advanced and there are greater internal political differences centering on nonproliferation, environmental effects and aboriginal-rights. Again, new discoveries of larger, moderate-grade deposits are occurring and may be expected for the future. The large potential for expansion of Australian and Canadian uranium output raises the question of price maintenance. We will return below to this issue and the possibility of a price-setting cartel in uranium.

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*This does not mean that new environments will not be found in the United States; indeed, success in sandstone formations has delayed incentives to look extensively elsewhere.

South Africa continues its export of uranium produced as a by-product of gold, and has plans to recover uranium from old gold slimes and even to produce gold as a by-product of uranium. Thus South Africa is in a position to expand output somewhat. The largest prospect for Southern Africa, however, is Namibia, where the Rossing mine is producing at about 3,500 tons/year. Major expansion (to perhaps double this output level) is feasible and other significant deposits appear to exist, although political change may threaten this output or alter the terms of its availability. Central African production--from Niger and increasingly from Gabon--is becoming more significant in the world supply picture.

Market Structure. Figure 5.7 shows two recent projections of uranium production capacity, one by the OECD/IAEA and one by McLeod and Steyn of NUS Corp. From the standpoint of diversification of supply, these data show an improving situation. The U.S., Canada and South Africa continue as major sources, and Australia appears ready to assume a significant market position. Moreover, the "other" category includes a growing number of countries who may be small but nonetheless offer the possibility for risk spreading by diversification of supply.

Also, as pointed out in Chapter 3, the degree of control of supply by large consumer countries does not appear high; private companies and others engaged in international buying and selling (as opposed to agencies developing resources dedicated to the homeland) still dominate uranium exploration, and mining and milling investment. If uniform nonproliferation standards can be achieved and nations have access to material from all potential sources, there appears to be little problem of access, and trends, to the extent they are discernable, are favorable.

On the question of price, and the influence of market structure on prices, the situation is much less clear. With U.S. as a net importer, Canada, Australia, South Africa and Niger will dominate net supply to international trade. As noted earlier, these four nations hold 84% of known reserves, and any of several subsets of the group (e.g., Canada and Australia) could, once again, attempt to establish an international cartel to control price. The longevity of such arrangements is always a

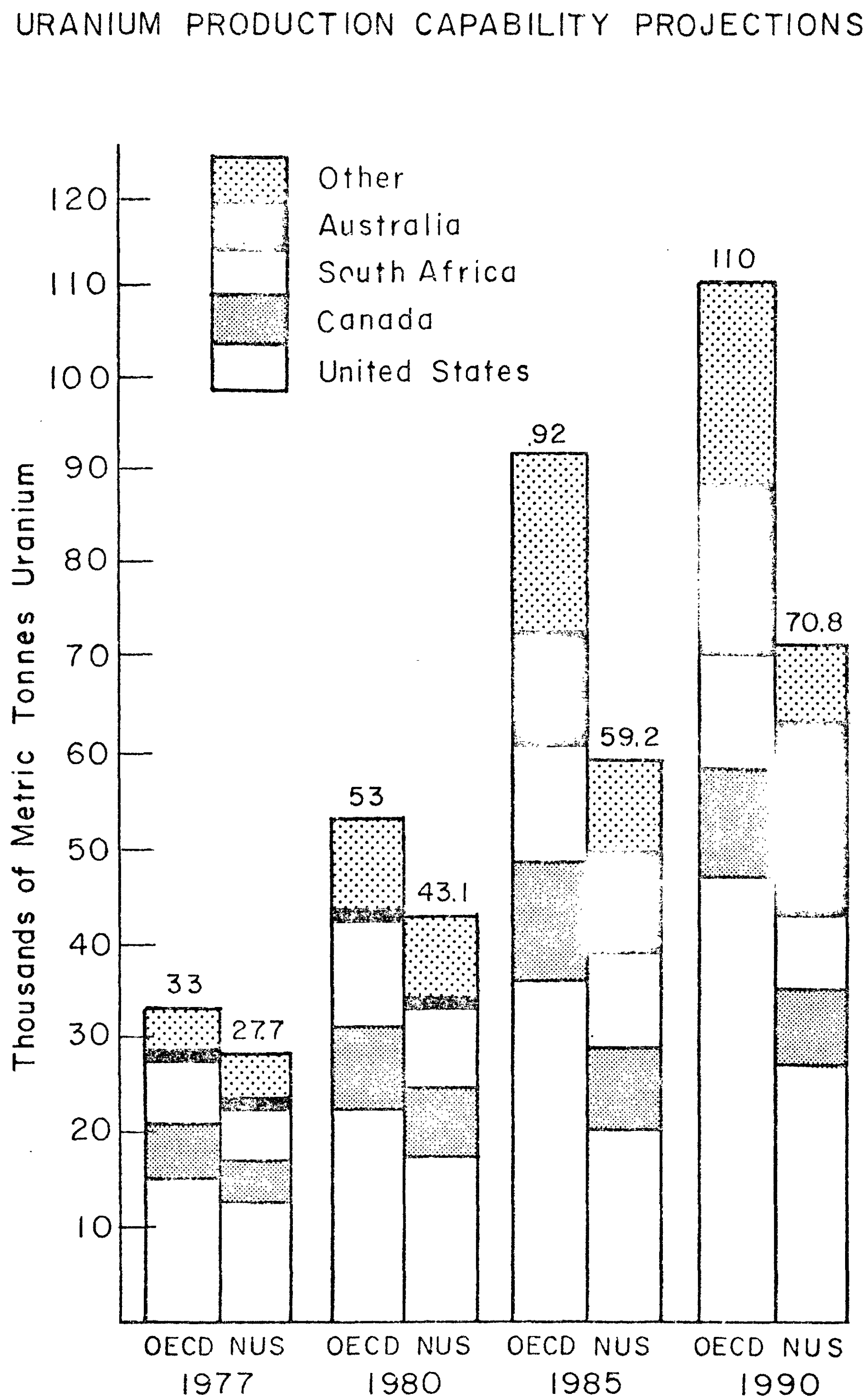

Figure 5.7 Uranium production capability projections. OECD projection from [1]; NUS projection from [3].

question,* but there seems little doubt that the machinery is in place to manage the price. Both Canada and Australia have government boards with control over export conditions, including price. Both countries also have similar political and economic interests. This congruence of interests makes it likely that these two countries could exercise considerable influence over prices even without formal price agreements or quota setting, at least in the short run.

Of course, such a cartel would very likely encounter the same problems that have plagued other arrangements of this kind. The nations maintaining the price must be able to control exports from their own suppliers. If domestic capacity (say, in Canada) expands beyond that which the market can take at the cartel-set price, then government authorities must find a way to allocate production among domestic producers. With several domestic operations, each with several international partners, this could prove a very difficult task. However, the existence of environmental and other impediments to new production could provide a control mechanism: since governmental action is usually essential to the removal of such constraints, a government can influence the pace of expansion simply by failing to take sufficient positive action, a much less sensitive procedure than would be involved in active restraint. The exercise of this power is complicated by the long lead times of mine and mill expansion. Unless accurate forecasts are available, errors in planning can lead to large future price fluctuations in such a controlled system. This issue of market concentration and government policy control over price and capacity is an important aspect of future uranium assurance conditions.

Supply-Demand Balance. As noted in Chapter 2 another question that arises in discussions of fuel assurance is the capability of the uranium industry to expand in the medium term. The resources may be there, and market conditions favorable, but there may be a question about the likelihood of availability of capital, labor, or other factors necessary for expansion.

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*For example, P.L. Eckbo [26] reviews the history of some thirty international commodity cartels, and for the successful ones, the usual life has not exceeded four to six years. Oil appears to be an exception, but whether uranium will fall in this category is not known.

Usually this issue is raised on the basis of analyses in which independent projections are made of demand and production capacity. Uranium demand projections usually involve review of reactor plans, and assumptions about enrichment plant operations. Capacity projections in the short-run involve review of current industry plans for mines and mills, and assumptions about the likelihood that these plans will be fulfilled. Longer-term projections (beyond a decade) are usually based on expectations about reserves and resources and the ability to exploit them. When such independent projections are made for any resource, there often is an apparent mismatch between capacity and demand, especially as projections are extended a decade or more into the future. The resulting "gaps" are often misinterpreted as portending important economic and security problems.

However, the independent projection of capacity and demand neglects the fact that these quantities are kept in balance over time by a dynamic process of equilibration in which producers and consumers adjust their plans, expectations and activities. The "gaps" between independent forecasts of capacity and demand thus simply indicate the magnitudes of the adjustments which must be made to the plans and assumptions on which the projections are based, rather than unavoidable catastrophes. The crucial issue is the process by which this adjustment takes place. For some commodities, traded in mature market systems and unencumbered by problems of depletion or politics, this process is fairly simple: price mechanisms lead to equilibration. Rising demand leads to increased prices which in turn provides incentives for increased production; residual risks associated with anticipating changes in supply and demand are allocated between suppliers and consumers and over time by contracts and other market instruments.

The process leading to equilibration in uranium markets are more complicated than those for some other commodities, in part due to heavy government involvement and the complexity of the total fuel supply system. However, the market forces which are responsible for equilibration should be able to deal with this complexity and uncertainty. The great increase over the past three years in exploration and investments in new mines and mills is testimony to this. Moreover, the complexity of the fuel cycle provides some room for adjustment. An example is the possibility of varying tails assay in enrichment--an option which has become available with the simultaneous maturation of the enrichment market: if there are indications of a tight supply situation in uranium, uranium prices will rise and enrichment tails assays will fall; conversely, a softening of the uranium market will allow higher tails assay. This mechanism can help deal with fluctuations over the period it takes for uranium output to readjust to changing conditions. Finally, the time to bring new uranium capacity on line is comparable to, if not less than, that needed to build reactors.

In Figure 5.8 we show uranium requirements computed for the OECD/IAEA nuclear growth estimates.* Also shown are the two projections of uranium production capacity from Figure 5.7. The uranium demand projections are for reactor needs only and do not include intentional stockpile building (though stockpiles may occur within the projections if reactor deployments lag behind the projections or if capacity factors do not rise to the 70% level assumed) or unintentional stocks due to enrichment contracts in excess of actual reactor needs. The demand projection is thus about that which would characterize an efficiently functioning system.

Both supply projections show an excess of uranium production capacity over reactor needs in the near term. In the longer term, the OECD forecast remains above total reactor needs while the NUS projection drops below projected demand in about 1985. The near term excess capacity probably reflects industry efforts to deal with the inefficiencies and uncertainties in the fuel cycle. These uncertainties and inefficiencies include enrichment contract requirements, which exceed reactor needs, and the intentional and unintentional stockpile building which is occurring. The excess capacity margin may also reflect the uncertainty in the uranium market caused by the changing political conditions discussed in Section 5.1.

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*Assumptions and details are specified in the Appendix. Needs for each reactor type are specified independently; capacity factors are set at 70%, which is above actual reactor performance. Where enrichment is required, the tails assay is set at 0.20 percent.

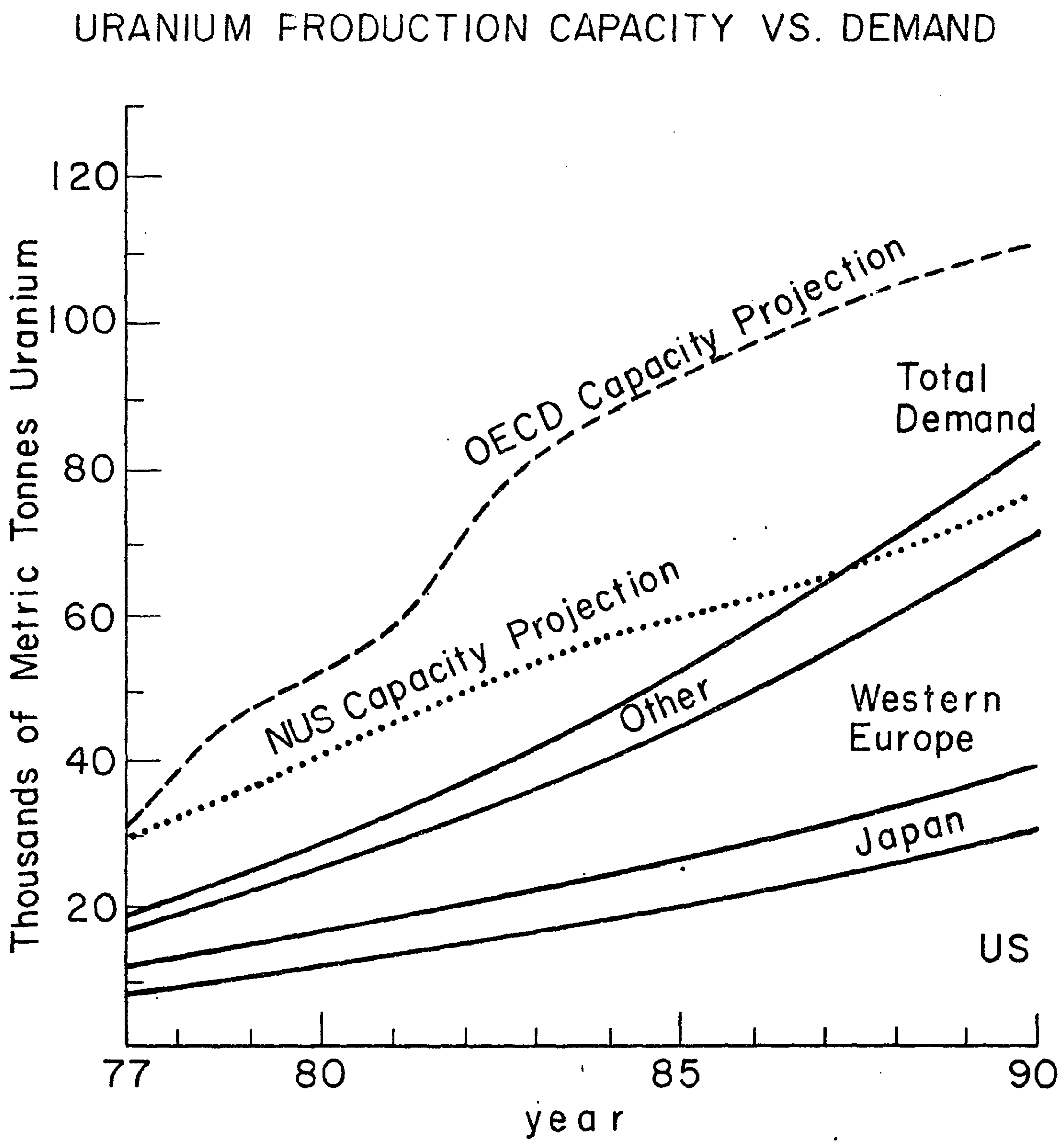

Figure 5.8 Comparison of potential uranium demand with uranium production capacity projections. Demand is based on the OECD/IAEA projection [1]. The two uranium production capacity projections are from references [1] and [3].

It is in the early 1980s that the OECD/IAEA and NUS estimates begin to diverge significantly. Both projections are based on industry expansion plans and normal development of reserves and resources. However, the OECD/IAEA projection is a "could do" estimate which assumes success in dealing with the problems of industry expansion. A number of difficulties of doing so are discussed but not explicitly reflected in the estimates. The NUS projection, on the other hand, assumes continuing difficulty in fulfilling plans; a delay of three months per year in all industry plans is assumed as well as a 3 percent loss from each year to the next due to declining grade. As the projections are extended in time this difference in assumptions makes for a striking difference in supply capacity projections.

As discussed above, however, the independent projection of supply and demand may produce misleading results when the question is whether supply will be adequate to meet demand. The reason is that producers will adjust plans to overcome foreseeable obstacles or take advantage of profitable opportunities. For example, if it is known that there may be delays in production plans (as assumed by NUS), at least some producers will anticipate better market opportunities by increasing their efforts to bring additional capacity on line and thus bring supply into congruence with demand. Conversely, producers will cut back on development and production rates, shift to lower grade ore, or take other measures to avoid creation of supply greatly in excess of demand since oversupply might drive prices down excessively. If the market allocation system works efficiently, both the NUS and OECD/IAEA projections are probably above what producers will strive for, until the mid-1980s at least. Thus failure of producers to reach output levels above actual demand should not be interpreted as a sign of ill health but rather as an essentially healthful sign of normal market clearing mechanisms.

The equilibrium dynamic might fail in several ways:

- Producers may fail to perceive potential markets (an historical example might be the conditions created by the Westinghouse short sales);
- There may be unforeseen common economic or environmental constraints on all producers;

- Production opportunities may be restricted by depletion rates worldwide that might turn out to be higher than now expected;
- A very large producer (say, Australia or South Africa) could suddenly cease exports due to a reversal of domestic uranium policy or other problems.

While such possibilities cannot be entirely eliminated, the existence of production capacity exceeding needs (and the potential for expansion) could compensate for a number of failures. Indeed most trends seem to be in a favorable direction on these counts, assuming for the present that the market operates under more uniform rules of trade. Nevertheless, these developments are not certain, and industry expansion could be retarded by short-term market uncertainty, perhaps magnified by the policy actions of key exporter governments. Therefore this set of issues is an important focus for further analysis.

Stockpiles of Low-Enriched Fuel

The data shown in Figures 5.2 and 5.7 indicate that it would be possible to build up large stockpiles of uranium, or low-enriched uranium, over the next decade. The enrichment capacity is at hand, and it appears that the uranium could be supplied without strong upward pressure on prices, at least for several years. Of course, potential is not realization, and the cost of building and holding these stocks is great even given that the enrichment capacity is available.

To see this aspect of the system we show a calculation of the possible stockbuilding given firmly planned enrichment capacity and possible uranium production capacity. The result is a stock of about 170 MMSWU in excess of actual consumption (by the OECD forecasts) by the late 1980s; proposed new ventures would add about 120 MMSWU by 1990. These stocks would correspond to about 1500 GWe-years of reactor reloads for firmly committed and an additional 1000 GWe-years from proposed capacity. They also represent three (firmly committed) to five (firmly committed plus planned) years forward supply for the 470 GWe estimated to be on line in 1990. Stocks could, in fact, be made even larger if the OECD forecasts of reactor growth prove high, as now seems likely.

As shown in Figure 5.9, the largest stocks would develop in the systems served by the U.S. and Eurodif plants. The smallest stocks develop in the Urenco utilities of Germany, Great Britain and Holland. While there appears to be adequate supply for the latter, there is not a very large margin. Of course, additional enrichment may be contracted for elsewhere. Urenco centrifuge capacity can be expanded well before 1990, and reactor demand in the Urenco partner countries very likely may slip. The relatively large stocks among U.S. utilities and at DOE are due largely to demand slippage and to continuation of a historically large unassigned stockpile; the large stock among Eurodif utilities is due to slippage in the reactor growth originally assumed when the Eurodif countries (especially Italy) made their commitments to the facility.

This is the quantity that could be built up should utilities and governments be willing to pay for them. Current evidence is that they are not: DOE is cutting back drastically on power inputs to its enrichment plants (estimates are for production of 12.5 million SWU in FY 1978, 14 million in 1979, and 10.5 million in FY 1980, whereas capacity is over 20 million SWU). So the stocks will surely be less than shown in Figure 5.6.

Nevertheless, even with substantial cutbacks in enrichment plant operation, the stocks held worldwide are quite large now and will grow over time (though not necessarily in proportion to total reactor throughput). This level of stocks, and forecast stock holding, bodes well for fuel assurance. The system as a whole is well situated to deal with short-term disruption, and over the next few years there will be susbtantial capability to increase output in the event of short-term supply/demand imbalance.

In short, the system is now demand limited and will be for the next five years or more. Thus "fuel assurance" is high relative to the last few years, provided all buyers have uniform access under the nonproliferation regime. Problems of uranium capacity may loom in the late 1980s, but that problem is deeply interdependent with current uncertainty about the future of reactor growth itself. That is, to the extent that there is a medium-term uranium capacity problem, it is more a symptom than a cause of problems in the nuclear industry, and an analysis of trends indicates that the uranium market can adjust to meet demand (perhaps at rising prices) given some reasonably stable expectations about what demand will be.

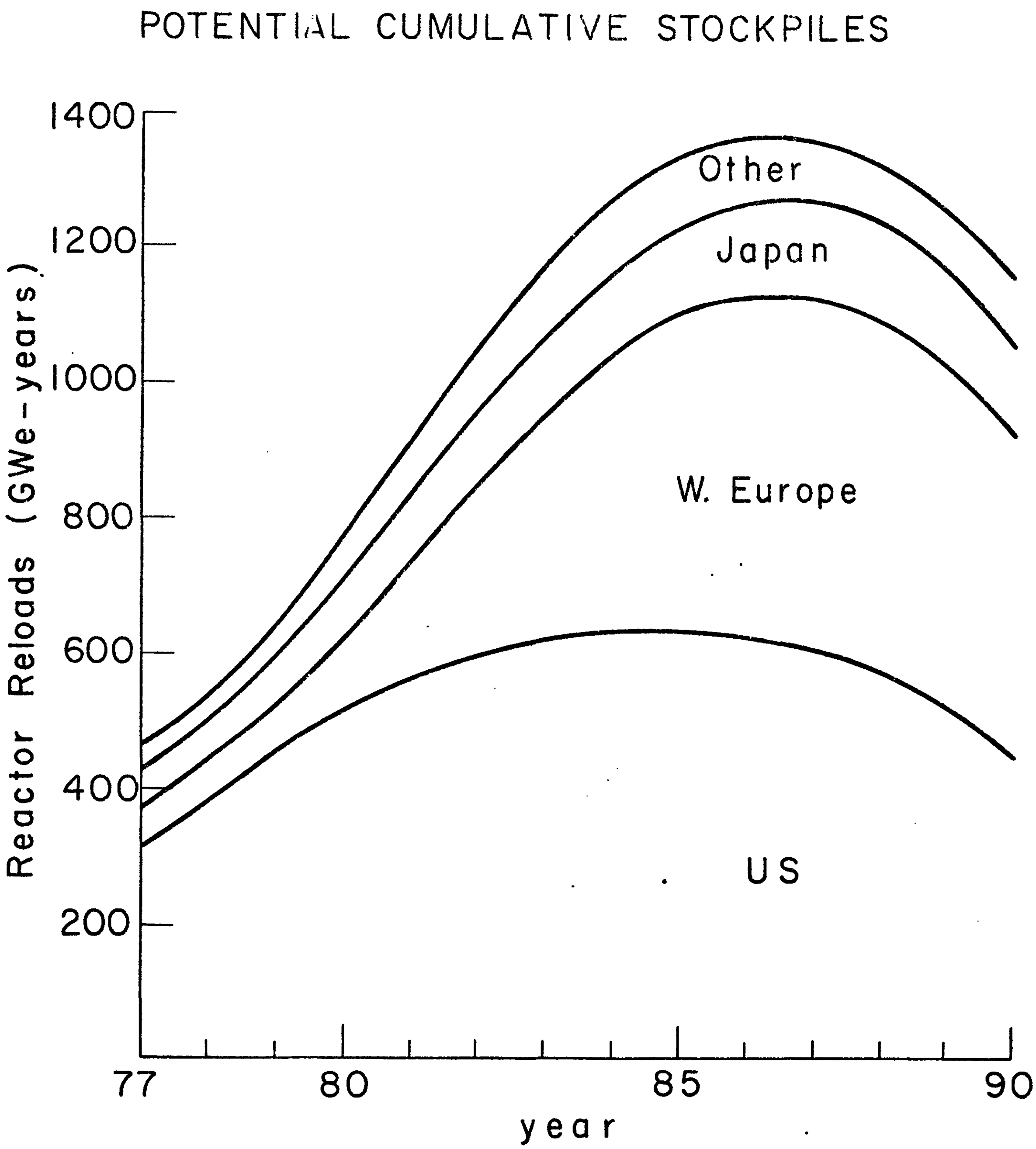

Figure 5.9 Potential cumulative stockpiles of low-enriched uranium fuel (expressed in terms of power generation capability). These projections assume that enrichment capacity or contracts in excess of actual needs are used to produce fuel for stockpiles. Only committed enrichment capacity is assumed; if planned capacity were built and used, stocks would continue to grow in the late 1980s. Adequate uranium would be available to build such stocks only if production comes close to the OECD projection in Figure 5.8.

5.3 The Possibility and Implications of a Segmented Market

Our optimistic outlook on nuclear fuel assurance in the preceding section was predicated on the assumption that agreement would be reached on uniform nonproliferation conditions and that all nations would thus be able to participate in a single worldwide nuclear fuel market. However, this is not the only possible outcome of the present debate. It is also possible that the U.S., Canada, Australia and the USSR will not be able to find an acceptable general compromise with Western Europe, Japan and other suppliers and consumers.

The failure to find compromise would lead to continuing conflict in international nuclear trade, a high likelihood of new political interference in nuclear fuel supply, and a consequent low level of fuel assurance. With continuing disagreement, there are many possible paths the world could follow and prediction is thus difficult. However, the major issues, and especially the interconnections between fuel assurance and nonproliferation, are illustrated by a specific example representing one of the more extreme responses to differing nonproliferation conditions. We refer to a gradual separation of the world nuclear fuel market into two segments, each characterized by a separate set of nonproliferation conditions. Three important questions bear on this possibility:

- Is such a segmented system physically possible, given the supply sources for uranium and enrichment and the demand levels of prospective consumer participants?
- How might the transition to a segmented fuel supply system occur, given the political, commercial and other interests of key participants?
- What would be the fuel assurance characteristics of each subsystem?

Let us consider each of these in turn.

Physical Possibility. At present, there is little evidence of bifurcation in nuclear fuel markets. While particular consumers may show preference for particular suppliers, such arrangements are rarely exclusive and do not appear to reflect differing nonproliferation conditions. For example, we have found no evidence substantiating common rumors that some consumers are paying higher prices for uranium which does not carry a reprocessing veto or other conditions. Indeed, though the evidence for this is weak, uranium from the African suppliers, which do not impose such conditions, appears if anything to be priced lower than that from Canada or the U.S.

Of course, up until recently, the development of a segmented market was physically and politically impossible. To obtain fuel for light-water reactors* which is free of the new nonproliferation-related conditions (reprocessing approval and full-scope safeguards) one must procure all uranium, enrichment and other fuel cycle services from countries or organizations which do not impose such additional conditions. Until recently this has been impossible. With the U.S. and the USSR controlling virtually all provision of enrichment services, and attaching strict conditions (the USSR full-scope safeguards and retransfer conditions, the U.S. gradually escalating to comparable and even stricter conditions), it was not possible to free this key fuel cycle step from such external control.

The first sign that it might be possible to avoid nonproliferation conditions more restrictive than IAEA safeguards on specific transfers came with the German-Brazilian deal in which enrichment services were to be provided by the new Urenco facility. The second sign was the arrangement for fuel supply which was made part of the sale by France of two reactors to Iran in 1976. However, subsequent efforts by political forces in the Netherlands (an equity partner in Urenco) to nullify the contract or increase nonproliferation conditions suggest that it will be very difficult for Urenco to undercut the U.S. and the USSR on nonproliferation conditions in the future.

Thus, for at least the next decade, the only way in which it is remotely possible to put together a fuel supply regime independent of the major traditional suppliers would be to use the Eurodif enrichment plant

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*Heavy water reactors utilizing natural uranium are presently available only from Canada, a country now imposing strict non-proliferation restrictions. In addition, use of such reactors necessitates obtaining a secure supply of heavy water under acceptable political conditions; while indigenous supply is technologically somewhat simpler to obtain than enrichment, it is still not easily within the reach of most developing countries.

and uranium from France, Niger, Gabon and South Africa (and perhaps other new suppliers). Whether this is politically feasible will be discussed below, but the physical possibility appears to be within reach, at least for a system that does not grow too large.

While virtually all of the prospective Eurodif output is under contract (to Japan and Switzerland) or assigned to equity partners (France, Belgium, Spain, Italy, and Iran), the shares held by all equity partners are in excess of realistic expectations about reactor requirements. For example, Italy is entitled to about 2.4 MMSWU per year but will require none of this until about 1986 (assuming it keeps its contracts with the USSR and the U.S.). The potential for over-capacity in Eurodif is enhanced by contracts held by the equity partners with the U.S. and the USSR, contracts which are priced lower than those with Eurodif. In Figure 5.10, we show the enrichment supply required by Eurodif equity shareholders from Eurodif (assuming that these countries keep current contracts with the U.S., and the USSR)--except for Iran--and the Eurodif capacity already committed to Japan and Switzerland. With the consent of Eurodif, the remainder would be available to supply other countries.

Which other countries might be interested in, and able to take advantage of, this opportunity to avoid the more restrictive conditions of the U.S. and the USSR? Many consumers of nuclear fuel already accept full-scope safeguards as a result of signing the NPT. Others like West Germany or Japan may desire to avoid prior approval conditions on reprocessing. However, they have requirements too large to fit through the excess capacity window in Eurodif and, in any case, could not avoid dependence on Canada or Australia for uranium. This leaves a number of countries with smaller nuclear programs such as Taiwan, India, Iran, South Korea, Brazil, Argentina, Egypt, or Pakistan.* Some of these are also countries of proliferation concern, and they may have the most to gain (or the least to lose) by seeking a nuclear fuel supply unencumbered by the conditions imposed by the U.S. and its nonproliferation allies.

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*South Africa and Israel might be added to this list; however, their requirements are comparable to the demand projected for Brazil or Iran but now unlikely to occur due to ecomonic problems in those countries..

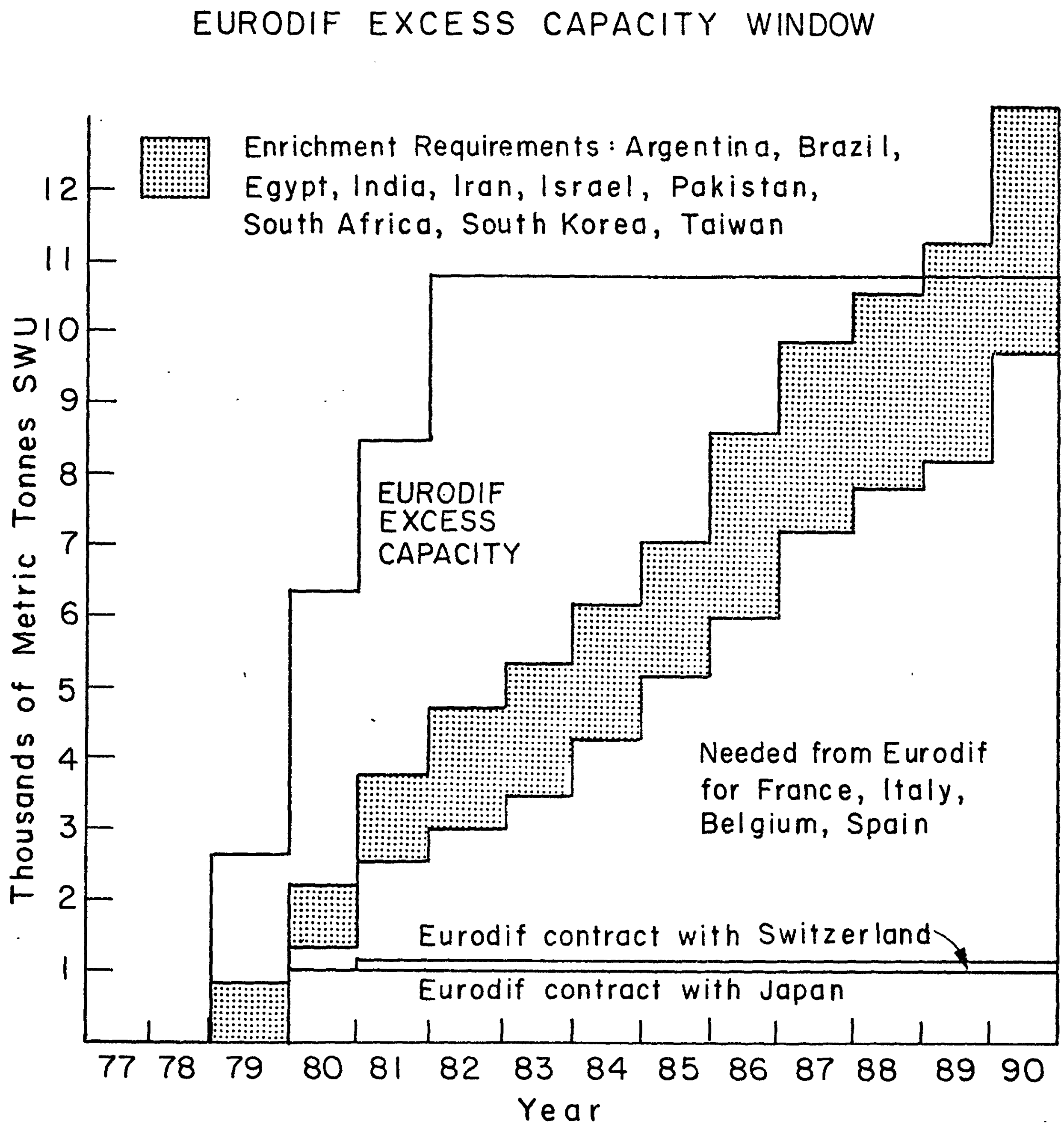

Figure 5.10 Comparison of excess Eurodif capacity with needs of representative group of countries with small nuclear programs (shaded area). Eurodif excess is computed by taking OECD projections of enrichment needs of France, Italy, Belgium and Spain, less any contracts now held by these countries with the U.S. and the USSR. Details of calculations are given in Appendix A.

In Figure 5.10, we have indicated how the enrichment needs of a number of these countries--which we call the Group 2 Countries--fit easily within the Eurodif excess capacity window. This is especially simple for the countries which have not signed the NPT since they also appear to have particularly small enrichment requirements.*

If Eurodif output increases on schedule, as we expect, it is evident from Figure 5.10 that there will be excess capacity available as early as the end of 1979. If contracts held by Eurodif partners with the U.S. and USSR were to be dropped or cancelled, the availability of excess capacity would be postponed until 1980. As long as the non-Eurodif enrichment contracts of France, Belgium, Italy and Spain remain in effect, present plans show a continued availability of enrichment--for the representative groups of countries shown in Figure 5.10--until about 1989 when the window begins to close somewhat. If U.S. and USSR contracts were terminated, the window would begin closing in about 1985. However, the nuclear growth projections on which these conclusions are based are uncertain after about 1984 and may overstate enrichment demand in subsequent years. Moreover, additional enrichment capacity could be brought on line by the late 1980s. Finally, some of the excess capacity available in the period 1980-85 could be stockpiled, or enrichment tails assay could be raised from the 0.20% assumed; either measure would displace any prospect of tight supply to some point beyond 1990.

To provide a supply of nuclear fuel free of more stringent nonproliferation conditions, significant quantities of uranium would have to be procured. Potential suppliers include France--whose domestic production plans satisfy the major fraction of domestic requirements--and several countries in Africa. Figure 5.10 shows projections of French production, the 44% share of Niger's output controlled by France, the production of Gabon and the projected output of South Africa (not including Namibia)--based on OECD/IAEA and other estimates.

Also shown are the requirements for the French nuclear program and for the countries used as examples above, including fuel for gas-graphite

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*In part this is because of a preference for natural uranium reactors not requiring enrichment.

and heavy-water reactors. Some of this potential uranium supply is already under contract; however, a significant fraction (which must be determined by further research) is already associated with Eurodif enrichment contracts which are likely to be in excess of actual needs and thus directly available for other consumers.*

As may be seen from Figure 5.11, uranium supply from French-controlled sources is adequate to the needs of the countries considered until the mid 1980s--it is only at this time that South African uranium would be needed. This is also the time at which some of the South African capacity comes out from under its current contracts. Of course, given the five to ten year lead time for new uranium production it might also be possible to increase output from existing or new sources by the late 1980s.

The net conclusion of this analysis is that it will be physically possible for the nuclear fuel supply system to separate into two components, given current supply and demand trends, and that there may even be some economic incentives to make market adjustments along the lines indicated.

Mode of Occurrence. The discussion of physical possibility above is quite hypothetical as regards the political and institutional processes which might be involved in the emergence of a segmented market. Having demonstrated the physical possibility, these are then the critical issues. The most important concerns are the willingness of particular Eurodif countries to participate in reassignment of enrichment allocations and the effects of the bifurcation on relationships between nations--especially those between the U.S. and Europe.

During the early 1980s the reallocation involved would be small compared to the Eurodif excess; it is comparable to the amount of

*It may also be possible to interchange uranium supply flows through Eurodif; for example, excess Canadian uranium now under contract to Italy could be used to satisfy the needs of a country in conformity with Canadian nonproliferation conditions and thus free up African supply which does not carry such conditions. Similarly, France could purchase new uranium supply from Canada or the U.S. and thus free up some domestic production for export.

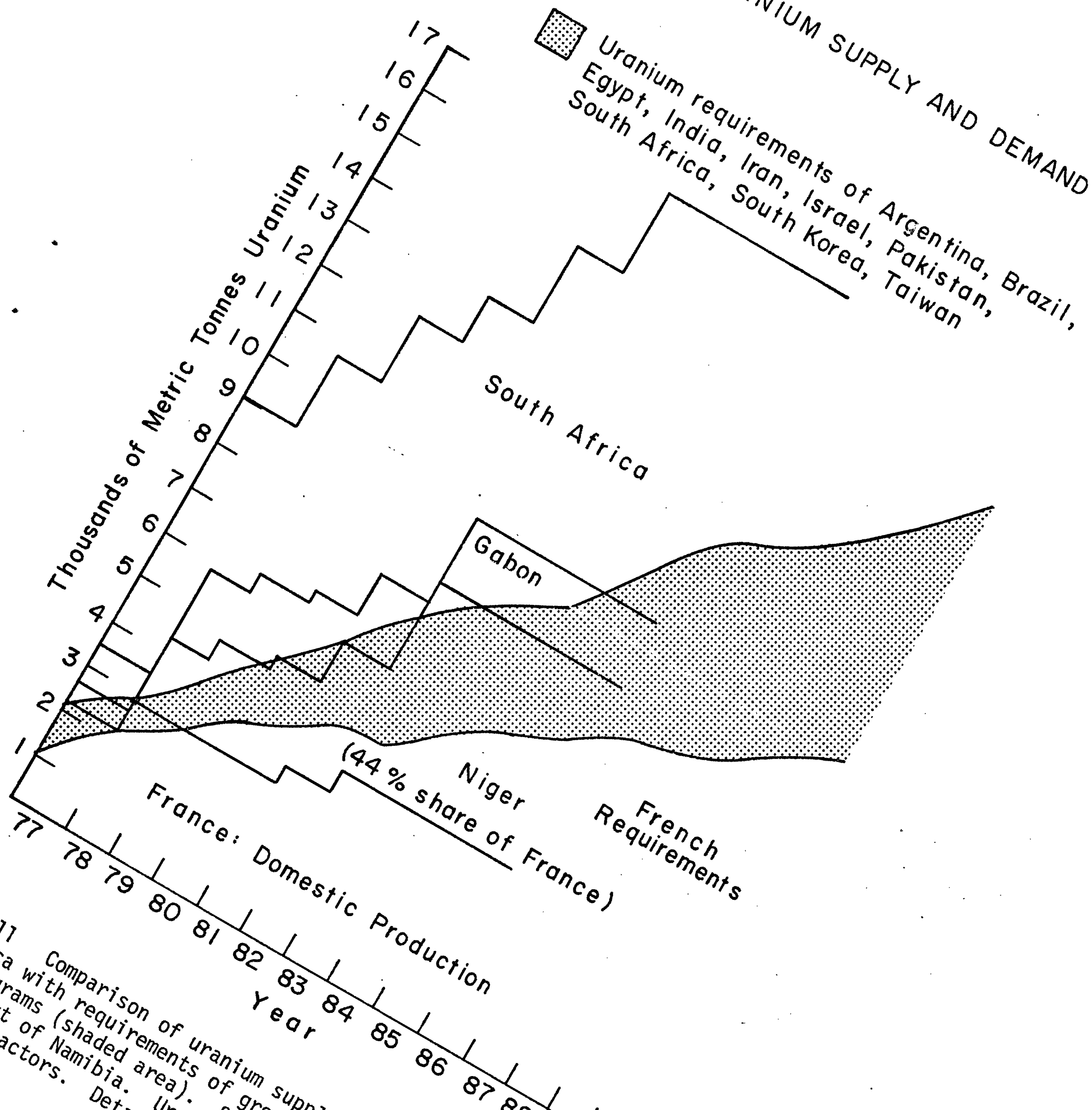

Figure 5.11 Comparison of uranium supply controlled by France and South Africa with requirements of groups of countries with small nuclear programs (shaded area). South African projection does not include output of Namibia. Uranium requirements include those for heavy-water reactors. Details in Appendix A.

capacity Eurodif is already trying to sell on Italy's behalf. Indeed there are economic pressures on most Eurodif partners to escape the financial obligations involved, and thus little reason to suspect a lack of flexibility.* A more subtle issue is whether there would be political opposition among the Eurodif partners to particular reallocations. Since a bifurcation of fuel markets is necessary only in the event of a failure to reach accommodation on nonproliferation conditions and since at least some of the countries in Eurodif are among those most opposed to the imposition of political and technological conditions, there is a good chance that the Eurodif partners would not actively oppose reallocation along the lines indicated. The attitude among these countries appears to be that the safeguards principle embodied in the NPT and IAEA procedures is adequate to deal with nuclear fuel trade; where they differ with U.S., Canadian and Australian policy is in the use of trade in low-enriched uranium fuel to impose additional constraints (such as the constraint on technological choice implied by an ability to exercise a reprocessing veto) on other nations which they regard as having little to do with fuel supply.

Since one of the purposes of the U.S.-imposed constraints is to retard the spread of plutonium fuels and plutonium breeders, and since the Eurodif countries are domestically committed to the use of plutonium, these countries would find it difficult to follow the U.S. lead and use nuclear fuel supply as a source of leverage to retard such commitments elsewhere (though they may seek other mechanisms). On the other difference between nonproliferation philosophies--mandatory application of full-scope safeguards as a condition for fuel supply--the issue is somewhat less clear. However, this is relevant only in the case of countries like Brazil, Argentina, India and Pakistan which have not signed the NPT.

It is not necessary that market segmentation involve explicit decisions or agreements or even conscious leadership by any particular

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*If France keeps her present contracts with the U.S. and USSR, the needs of the smaller nuclear programs shown in Figure 5.7 could be satisfied entirely from French-held excess Eurodif capacity, until at least the mid 1980s. Thus the issue of agreement to reallocation would not need to arise until later.

country, though France must be considered an evident candidate for this role. Instead, such a separation would probably occur gradually and perhaps imperceptibly, in a series of small decisions and changes in contracting. The Group 2 countries considered above now hold contracts for only 13 GWe with the U.S. and the reopening of U.S. contracting would allow even these contracts to be dropped with only small penalties, thus removing them from direct influence by the U.S. in nuclear matters. Some of the new reactor capacity already purchased by the Group 2 countries will be provided by European vendors* and it would be natural to seek fuel supply in Europe. As additional reactors are ordered, fuel supply contracts will be necessary and could be arranged through Eurodif as easily as elsewhere.

In fact, the ability to offer fuel supply free of the new nonproliferation constraints could give an advantage in export orders to France or to other supplier countries with access to the smaller part of the segmented market--an economic incentive which cannot be overlooked in assessing the likelihood of its occurrence. The eight developing countries used as examples above represent a market for about 10 GWe of new reactor orders before 1983, according to the projections used to compute the requirements shown in Figures 5.10 and 5.11. In addition, such a pattern of nuclear trade would help preserve an advantage in future advanced technology exports--for example, an eventual market for French breeder technology which might otherwise be limited by the necessity to obtain prior approval from the U.S., Canada or Australia--even though sensitive technologies or materials need not be involved in the near term.

The political costs of a gradual shift in market patterns depend largely on the importance attached to it by the U.S., the USSR, and other countries. The chance of a major confrontation over the bifurcation of the fuels market might inhibit its occurrence. However, it is difficult

*For example, Iran has purchased two reactors each from France and West Germany and Brazil has purchased two reactors from the FRG and has options on six more. Iran's reactors from France come with a ten-year fuel supply, the two from the FRG are presently covered by enrichment contracts with the U.S.

to see how such a confrontation could occur, unless sensitive technologies and materials were involved: it would be difficult to object to countries seeking assured supplies of low-enriched uranium fuel.

It is important to note that this situation is fundamentally different from that occasioned by sales of sensitive facilities in the mid-1970s, and in a way represents a major achievement of U.S. efforts. However, it is possible to foresee governments (or entities within governments, such as the U.S. Congress) interpreting a fuel market segmentation as an effort to evade nonproliferation obligations--an interpretation made more likely by the close coupling in U.S. policy between U.S. provision of fuel and the issues of technology choice and full-scope safeguards. Such an interpretation would reflect a fear that sensitive technologies and materials might eventually flow along the new fuel supply channel. The result could be continuing conflict between the U.S., Canada, Australia (and perhaps the USSR) on the one hand and the suppliers and recipients in the smaller system on the other. As discussed in the next subsection, market conditions and fuel assurance will depend on this level of conflict as well as on the sizes and other characteristics of the two supply systems.

The likelihood that any particular country would cast its lot with the less restrictive supply system depends on a host of external factors, including the extent to which its other relationships would be affected. For example, countries like South Korea that value the security guarantees provided by the U.S. (and trade concessions or other commercial, strategic or political benefits) would be reluctant to risk a confrontation. Other countries, like India or South Africa, might be less reluctant to do so. How U.S. policy might regard a bifurcation of the fuel supply regime is thus an important factor affecting its likelihood, in at least some cases. What is needed here is a case-by-case evaluation of the status of each country's nuclear program, the nature of relations with the United States and other suppliers and the general political stability of the country and surrounding region. Many of these countries maintain a web of important relationships with the United States, including nuclear cooperation, and may not want to risk upsetting economic or political security and nuclear links just to gain more freedom of choice in one area.

Effect on Fuel Assurance: The picture which emerges from this analysis is of a possible segmented market in which basic nonproliferation conditions are universal--i.e., traditional IAEA safeguards on particular transfers, probably extending to retransfers, and on further processing and applications of knowhow. However, particular segments of the market would carry additional conditions. Some countries will accept all U.S., Canadian or Australian conditions; others may reject these conditions and seek alternative suppliers (the Group 2 countries). Within these two groups would be a set of consumers participating in both systems, probably obtaining most of their fuel from the supply system with more stringent anti-proliferation conditions, but participating in the smaller system with less stringent conditions when advantageous. Among the countries participating in both systems would be those large consumers that are also exporters (e.g., West Germany and France) or those wishing to maintain a supply of material for use in research and development programs* which is free of conditions.

These overlapping supply regimes are shown schematically in Figure 5.12. Segment 1 would be characterized by a requirement for full-scope safeguards and a yet unclear level of control over reprocessing; segment 2 would be free of these conditions. The issue of how plutonium would flow between the two systems (e.g., only from system 2 into system 1) is a major issue yet to be resolved by the U.K. and France, the two prospective suppliers of reprocessing services.

The implications for fuel assurance of such a market segmentation may depend on how smooth the process is. First, we may consider the results if the market divides smoothly, without policy intervention by the U.S. and its nonproliferation allies. In this circumstance, the effect on

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*These materials might include a supply of plutonium for research and development on plutonium breeders, highly enriched (or enrichable) uranium for use in research reactors (the U.S. is urging a conversion to 20% enriched uranium instead of the 90% material now used) and uranium for experimentation on advanced enrichment technologies such as centrifuges or lasers.

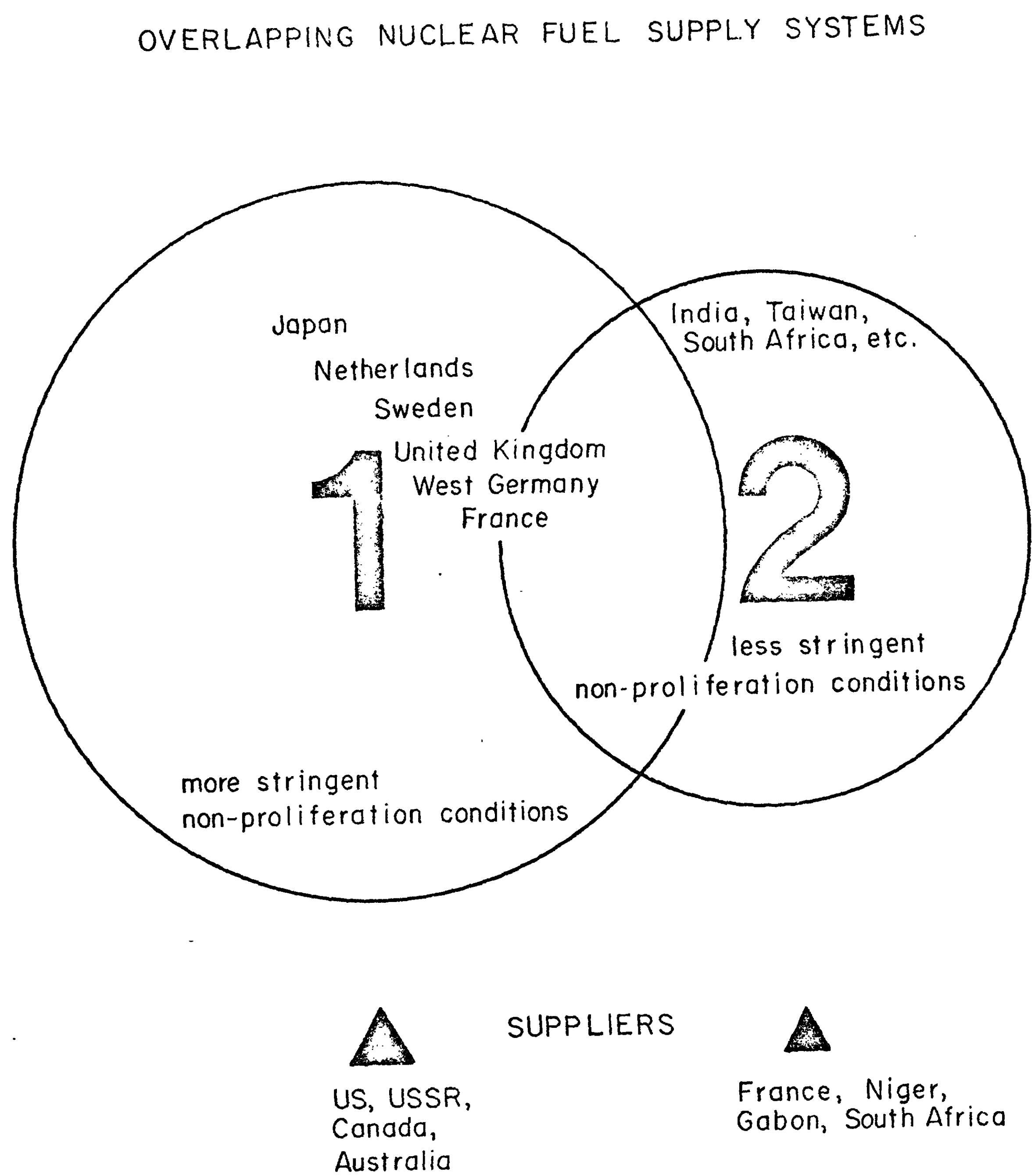

Figure 5.12 Split nuclear fuels market. Countries such as West Germany and France would participate in both market segments; nuclear technology export trade would generally flow from region 1 to region 2.

Group 1 consumer countries would be small. They would still have access to all sources of uranium and enrichment; the circumstance would not be perceptively different from that under uniform export controls. For the Group 2 countries, on the other hand, assurance could decline. The market to which they would have access would be smaller and more concentrated: they would thus lose the advantages of diversity of supply in enrichment and uranium. As shown above, the Group 2 system would become dependent on uranium sources in Africa, and this narrow market segment would be highly vulnerable to disruption of supply from any one of those countries. Therefore, the level of fuel insecurity could be significantly greater than under a uniform system. In effect, the dominance of the U.S. in the 1960s and early 1970s would be traded for a monopoly relationship to France in the 1980s.

Moreover, under this circumstance, incentives may be created that are unfavorable from a proliferation viewpoint. Group 2 nations would have reason to feel less assured of fuel supplies and would have greater incentives to seek supply systems free of dependence on uranium enrichment. These substitutes could include plutonium fuels for converter or breeder reactors--both of which France and other supplier countries may be able to provide. Indeed, there may be considerable pressure within France to create export markets for reprocessing services and breeder reactors if the recent history of the LWR industry is any guide. By participating in a segmented nuclear fuels market, developing countries may replicate the fuel assurance fears that have driven France and other major consumers toward early adoption of plutonium technologies. Thus, the segmented market would offer the worst of both worlds, both decreasing assurance and creating a circumstance where the lowered assurance is likely to have a effect on flows of weapons-sensitive materials and technology. Evidently, the policy of France could be crucial to the outcome.

These effects could occur even if the process of segmentation is smooth. Active opposition by the U.S. and other suppliers could aggravate these effects and reduce fuel assurance among large consumers, and especially those participating in supply to Group 2 countries. It is not known what kinds of measures may be taken in such an event, but one can imagine attempts to establish even more distant "third party" controls through fuel exports; the establishment of heavy penalties for altering enrichment contracts; and the creation of uncertainty about fuel supply to nations who are suppliers to the Group 2 countries. Likewise, the uranium and enrichment problem could become involved in a larger context of international political and commercial policy, for such developments would be viewed as having influence on reactor export opportunities and, more significantly, on general strategic interests.

6. POLICY ISSUES AND ACTIONS

In this study, we have reviewed the nature of fuel assurance problems, explored their origins and analyzed current trends. Assurance problems are distinguished by the time horizon involved. Short-term problems of supply interruption are much reduced by the long time-lags inherent in the nuclear fuel cycle and by the large fuel stocks now on hand.

Concerns about long-term fuel assurance center on adequacy of the uranium resource base. Knowledge of any mineral resources reflects not only the nature of the geologic endowment but also the history of its industrial development: rarely does the known forward supply extend much beyond the ten to twenty year planning horizon of the industry. This is also the case with uranium; the resources estimated by the OECD/IAEA would provide fuel for estimated nuclear growth only until some time soon after the turn of the century. However, increased concern about energy has resulted in a need to know more about longer-term uranium resources or to initiate the long lead-time process of technological change necessary to make more efficient use of the potentially scarce resource. While the best strategy to deal with this situation is clearly deserving of further attention, the issue of longer-term fuel availability impacts on medium-term assurance since the plutonium fuel cycles currently favored by some countries for the longer term also aggravate the proliferation concerns which are an important part of the medium-term assurance problem.

In the medium-term, fuel assurance involves the ability of a country to contract for future supplies of uranium or fuel cycle services under an acceptable set of political conditions, and with reasonable certainty that the contract will be fulfilled as written. To some extent, problems of insecurity in fuel provision are inherent in the industry itself: the fuel cycle is complex technically, with many stages; and key steps in the supply chain have been in the hands of very few suppliers. Since nuclear-electric power grew out of military programs, large-scale processing facilities, such as enrichment, have been limited to the U.S.

and the USSR, and the supply/demand conditions in enrichment have been subjected to severe buffeting due to the actions of government agencies.

The uranium market is still maturing--it went through a period of severe depression in the period between the decline of procurement for weapons programs and the buildup of civilian demand--and even today the industry (production, reserves, and exploratory activity) is concentrated in a few nations. Thus the uranium market has been vulnerable to external shocks; prices have been unstable and there yet exists much uncertainty about future demand/supply conditions and likely price trends. There is a possibility of cartelization of the uranium market, raising additional uncertainty about supplies and prices.

For nations committing large amounts of capital and pegging energy security to nuclear-electric facilities, there is reason to worry about fuel assurance simply on the grounds of the normal commercial and foreign-trade risks. Fortunately, there are encouraging trends in the commercial market, including a growing diversity of supply (and thus lowered vulnerability to events in any one exporting nation) and ever more mature and efficient mechanisms for contract and trade. And, as discussed below, there are additional measures that could be taken to help reduce even further the sources of insecurity in the medium term.

But the strong conclusion that comes from our investigations is that the risks associated purely with monopoly or oligopoly of supply, and associated commercial risks, are not at the heart of the fuel assurance problem today. The actions which feed the concern about fuel assurance are those which are being taken in the name of nonproliferation.

Here there is a disturbing paradox: the driving force behind the fuel assurance issue, from a supplier point of view, is not so much a concern for the general economic health of their customers but a desire to remove incentives to acquire proliferation-sensitive substitutes for LWR fuel. There is no question that this is a laudable goal. But in the wider constellation of policies intended to restrain the transfer of proliferation-sensitive materials and technologies, assured fuel supply is expected to play two roles: as an inducement to avoid sensitive facilities and materials and, in its withholding unless conditions are met, as a threat. In short, fuel supply is being used simultaneously as a carrot and as a stick. As a result, U.S. policy risks self-contradiction, exacerbating the perceptions of fuel insecurity that drive countries toward plutonium and autonomous fuel cycle facilities.

The apparent inconsistency of these two lines of policy would be less relevant if any one nation had a complete monopoly of nuclear technology, or if there were unanimity of export conditions among suppliers. But whatever the situation in the past, ongoing changes in the nuclear fuel supply system are rapidly exposing the vulnerability of the assumption that fuel supply can be used to induce policy changes and improve fuel assurance simultaneously. The entry of new suppliers and lack of agreement as to the degree to which nonproliferation objectives should be sought through restrictions on the supply of fresh fuel have created a situation which can only be resolved through new agreements and accommodation, or changes in basic policy assumptions.

Thus, with an eye on fuel assurance as a goal, there are two categories of issues and actions that will influence the future of the international fuel cycle. First, there are those rules and regulations, national and international, that govern trade in nuclear fuel. Their evolution is the most important determinant of the narrower issue of fuel assurance. Second, there are actions which may influence the performance of nuclear industries, and the international nuclear market, whatever the outcome of current contention over the nonproliferation constraints within which the market will operate. Let us look at each set in turn.

6.1 Institutional and Political Resolution

As argued earlier, the international nuclear fuel industry stands at a point of unstable equilibrium. For the duration of INFCE there is a set of arrangements, between the United States and European nations and between Canada and her trading partners, which allow trade in uranium and enrichment to continue even though long-term agreements remain to be renegotiated. At the end of INFCE, this balance will very likely be disturbed, and the world trading system will move toward one of several conditions. On the one hand, if the United States, Canada and Australia can come to an agreement with European suppliers, then there will be a consistent set of supplier nonproliferation conditions applied to all fuel customers worldwide. This might occur by deciding to decouple nonproliferation policy from more stringent export controls on LWR fuel, or by common agreement on the means by which fuel supply will be used as a policy instrument. A uniform market for fuel will evolve, with the issues of full-scope safeguards and vetos over retransfer somehow resolved.

Another possibility is that agreement on nonproliferation conditions will not be reached, and France and her partners will continue with a set of rules less restrictive than those insisted upon by the United States, Canada and Australia (and the USSR in the case of full-scope safeguards). In this case, the nuclear fuel market may split. Our calculations for the hypothetical case of a two-part market indicate that this is technically possible, though there may be engineering and contractual details that would make the process more painful than our simple analysis suggests. Were this split to come about, several consumer countries could be put in the position of choosing between further constraints on sovereignty (in the form of full-scope safeguards and restrictions on technology choice) and reductions in fuel assurance.

The ultimate effect of such a development on proliferation risk is beyond our scope here. However, one can foresee a possibility of continued conflict, with some suppliers again exploiting differences in political conditions for commercial advantage. To the extent that this biases the direction and pace of technological change to the point where it strains the political and technical capabilities of the nonproliferation regime, the effect could be contrary to the objectives of the current policies of the U.S. The other result of bifurcation would be a great reduction in the leverage that the U.S. (and to some extent, Australia, Canada and the USSR) have been able to exercise over smaller nuclear programs through control of the fuel cycle. This suggests that fuel cycle leverage is a far from secure basis for nuclear foreign policy and that traditional diplomatic, security and other non-nuclear tools will remain the chief source of international influence in nonproliferation matters.

The implications of market segmentation, or other changes that might come with a failure to achieve agreement, are many and complex. But in the effect on fuel assurance, which is our focus in this study, the likely result is clear. To the extent that segmentation takes place, the security of LWR fuel supply for nations in the smaller, less restricted market will be reduced, as compared to conditions under a uniform market. Thus, one of the most important determinants of fuel assurance of the next few years is the resolution of current disputes over nonproliferation conditions. A satisfactory accommodation of supplier interests and policies is of crucial importance to the health of future nuclear markets and the security of nuclear fuel supply.

Timing is important. A gradual move toward segmentation could start at any point, and without overt, or perhaps even conscious, leadership; in a technical sense, bifurcation could be accomplished over the next few years. In case political accommodation cannot be reached, it is important that the U.S. (and Canada and Australia) have a clear idea of the appropriate reaction should this change begin to take place.

Depending upon the response of the U.S., Canada and Australia, there are other states into which the market could move at the end of INFCE; the worst, as laid out in Figure 5.1, would be protracted debate, conflict and disruption. This would happen if uniformity of export conditions cannot be achieved, and the market begins to segment, and the U.S. (and perhaps others) attempt to stop this process. This might be done in a number of ways, and involve linkage to a host of non-nuclear diplomatic and commercial issues. But the most damaging to fuel assurance (and perhaps to other international relationships) would be to try to use further manipulation of the fuel cycle to prevent the change. The incentives to take preventive action are not inconsiderable: U.S. firms would be put at a commercial disadvantage in a number of countries with growing nuclear programs and bifurcation of nuclear markets would mark a significant erosion of the general worldwide influence of the U.S. (and for the USSR too, for that matter) and action to avoid such a loss would be only natural.

In the U.S., the ability to deal with this situation beyond the next year or two will be complicated by underlying assumptions in current nuclear policy, especially as it is formulated in the Non-Proliferation Act of 1978. As discussed in Chapters 3 and 5, the Act has at its core the assumption that U.S. provision of fuel and other nuclear assistance gives the U.S. an inescapable leverage over developments abroad. In effect, the Act extends the carrot of fuel security to developing countries and others, some of which may otherwise be sources of proliferation risk due to acquisition of sensitive technologies or materials. The stick of fuel supply is applied not only to these countries but to the major industrialized supplier states as well; for the latter, the ultimate U.S. goal appears to be the development of common export policies, including limitations on international flows of plutonium as well as technology. The prior approval condition of retransfers and reprocessing is one way to ensure consideration of U.S. nonproliferation concerns in the majority of sensitive international transactions as well as in domestic nuclear programs. However, as we have seen, this control is not universal and it will soon be possible for an important corner of the world fuel market to emerge from the shadow of a nonproliferation policy based on fuel cycle control.

The effects and dangers of this policy problem are not immediately evident, but may become so during the tenure of the 96th Congress. At present, the Administration is taking advantage of the exemption provisions in the Act (as in the case of the Tarapur fuel or the Tepco and Kansai reprocessing transfers), and the 18 to 24 month implementation period for full-scope safeguards, to soften the impact of the Act while drawing recipient countries closer to the U.S. position. Indeed the existence of the more restrictive legislation may temporarily enhance the Administration's negotiating position. However, while the Act may thus contribute to U.S. nonproliferation goals in the near term, it does little to improve long-term fuel assurance and may, in fact, represent a net reduction. Dependence on the exemption procedures cannot provide the predictability which is the basis for low-enriched uranium fuel assurance in the longer term.

An even more serious assurance problem may result in the future if the fuel supply assumptions in the Act are used as the basis for further legislative or other policy action. If fuel market segmentation begins to occur, the underlying fuel control assumption may lead to direct attempts to prevent countries from slipping outside U.S. control. The complexity of the nuclear fuel cycle, and the pervasive involvement of the U.S., might offer considerable short-term opportunities to use disruptive measures as a way to induce conformity to U.S. wishes. Indeed, the export procedures--requiring a separate determination for each specific export license or retransfer and involving a host of institutional players (NRC, DOE, State, ACDA, Commerce, the Office of the President and the Congress)--guarantees such opportunities unless there is capitulation to U.S. conditions. Such procedures are problematic even without a movement toward bifurcation. The danger is that some participants in the U.S. policy process (the NRC or the Congress, for example) will make increasingly severe use of the failing leverage of fuel supply; the result would be an even greater reduction in fuel assurance generally, perhaps accompanied (according to the logic of current nonproliferation policy) by a stimulation of commitments to sensitive nuclear technologies and materials.

While such discussions are necessarily hypothetical, and the full set of implications beyond the scope of our analysis, it is clear that fuel assurance is deeply intertwined with a set of larger nuclear policy issues: not only are the conditions of access to fuel supply dependent on resolution of larger political differences betwen nations, but fuel is being used as a source of leverage in the resolution of these differences. From the standpoint of fuel assurance, a key issue for the next two years is the manner in which the U.S. policy expressed in the Non-Proliferation Act of 1978 will be adjusted to a world in which the basic assumption underlying the Act--the continued existence of U.S. fuel cycle control--is gradually losing its validity.

6.2 Factors Influencing the Development of Fuel Markets

While it is our general conclusion that there is considerable reason for optimism about the functioning of the supply system, given resolution of current political conflict over the terms of trade, there are factors which will influence the performance of fuel markets and thus affect fuel assurance. These include policies regarding enrichment capacity and utilization, stockpiles (including fuel banks), the evolution (including potential cartelization) of uranium markets, better information about long-term uranium resources, and strategies for the timely development of uranium resources and alternative sources of fuel.

Present firm plans for expansion of enrichment capacity indicate a global capability which exceeds global needs until at least 1990. However, the utilization of this capacity and principles of allocation are still important issues. In the past, a high degree of concentration in the U.S. resulted, in the past, in an excessive dependence for supply security on the policies of the U.S., policies which underwent a number of disruptive changes. With the start-up of Urenco and Eurodif, the past monopoly will yield to oligopoly. Since Urenco appears to be in a difficult position as regards expansion, but Eurodif is already committed to capacity in excess of needs, it is likely that enrichment supply for much of the world will be dominated by the U.S., the USSR, and France. We believe that further diversification of supply would result in greater assurance of supply and that such diversification is far more important, from this perspective, than further expansion of U.S. capacity. Of course, the need for fuel assurance internationally must be weighed against domestic commercial interests, the competitiveness of the nuclear industry and balance of trade considerations. Moreover, to meet nonproliferation goals, additional capacity would necessarily be located in politically stable countries or, perhaps, undertaken multilaterally.

A second major area of policy concern is that of fuel stockpiles. Stockpiles of natural and low-enriched fuel affect both uranium market development and fuel assurance. Historically, stockpiles have accumulated because of government purchase programs, preproduction and other aspects of enrichment plant operations, and delays in reactor start-up. Stockpiling thus accounted for a significant fraction of uranium demand. Once created, however, such stocks can change the future environment in which the uranium industry operates, in constructive or destructive ways depending on how the stocks are managed. For example, great fluidity in stocks could reduce incentives for producers to maintain inventories for spot market sales. Recent changes in enrichment plant operations (the end of the split tails policy) and budgetary pressures appear to have stabilized the magnitude of U.S.-held stocks, though there is still some question as to how these stocks will be utilized.

Stockpiles also affect fuel assurance. The existence of stocks, especially if widely held, can increase the shock-absorbing capacity of the nuclear fuel supply system, making it possible to deal with short-term interruptions or delivery problems. At present, utilities with established nuclear programs worldwide appear to hold one, two or more years forward supply. In addition, the governments of major consumer countries (like the FRG, France, the U.S. and the U.K.) hold stocks which might be used at least domestically. A more subtle assurance issue is whether countries with small but expanding nuclear programs have adequate access to such buffering stocks. In principle, the stocks held by major nuclear countries could be made available to countries with insecure but smaller requirements on a loan, sale or lease basis. However, the fundamental issue from the perspective of the latter is likely to be the terms of access. This will be an especially difficult problem for those small consumer countries that believe their primary fuel assurance problems are the market access conditions imposed by the major suppliers.

Fuel banks have been proposed as a solution to the short-term assurance problems of small consumers lacking the buffering stocks held by major consumers. A relatively small bank (equivalent, say, to 10 GWe-years of reloads) might help alleviate potential assurance fears in these countries; it might also function as a symbol of concern on the part of the suppliers. As discussed above, however, the critical issue is what conditions are placed on access. For example, a contribution by the U.S. to such a bank would have no more fuel assurance value, if it carried with it a full set of U.S. nonproliferation conditions, than would derive from the market or from friendly relations with the U.S. or another supplier. However, it might relieve residual fears about the imposition of other conditions (e.g., on human rights or other activities of the recipient). The value of a small fuel bank is thus at least in part conditional on resolution of the larger conflict over terms of trade discussed in Section 6.1. Without such resolution it seems unlikely that the Congress and the Administration could relinquish control over a bank contribution.

It should be noted, however, that a bank might provide an institutional mechanism for avoiding some of the problems of a possible bifurcation in nuclear fuel markets, by partially decoupling fuel supply from technology trade. For example, if France and the U.S. fail to agree on the reprocessing issue, a bank could contain contributions from both countries with differing conditions on potential recipients. Such a system would fulfill the carrot aspect of U.S. policy regarding fuel assurance, but recognize the limitation of U.S. fuel leverage.* Presumably, the assurance benefit would reduce the urgency of commitments to reprocessing or enrichment and thus make some contribution to U.S. goals. By putting fuel supply in a multilateral context, such a bank would help isolate fuel supply from the more contentious issues dividing suppliers and from the commercial imperatives of reactor sales.

There has also been a proposal for an International Nuclear Fuel Authority (a major component of NPA78). Such a system would replace a significant fraction of the present market, with its overlay of bilateral and multilateral conditions, with a global authority allocating fuel under uniform conditions. The establishment of an INFA appears to require the achievement of the international agreement and political accommodation discussed in Section 6.1, as well as success in developing a major new international institution able to respond to and balance the needs of many nations. We believe that this is probably impossible; moreover, if it were possible to achieve the first condition, there would be little interest in or need for such an institution. Indeed, many countries (Japan, West Germany, etc.) have a stronger international trade

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*Such a system would work best if it is possible to reach supplier agreement on a common requirement for full-scope safeguards; without such agreement, recipients would divide into two classes depending on whether they had accepted the full-scopes condition since any single transaction with a supplier demanding adherence to such safeguards would imply acceptance of that condition generally.

orientation than the U.S. and would be confident of their ability to satisfy their needs in international markets, especially if the larger political uncertainties can be removed. The INFA proposal would undoubtedly raise fears of costly economic inefficiencies and a potential for politicization of allocation. It is also not evident that such a system would provide a superior environment for the uranium industry or satisfy the diverse interests of key supplier countries.

The third area of concern is the evolution of uranium markets. As indicated in Chapter 5, general conditions in the uranium market have improved, shifting back somewhat from the extreme seller's market conditions of the mid 1970s toward better equilibrium between supply and demand. However, there are impending changes. The renegotiation of enrichment contracts by the U.S. over the next year will free a portion of the market which had been the captive of stringent enrichment plant delivery conditions. This comes at a time when Australia is re-entering the market and large new uranium discoveries are being made. The result may be a softening of the uranium market. While this may be advantageous in the near term to consumers seeking supply assurance, there may again be a reduction in industry incentives leading to concerns about longer-term supply conditions.

Changes in the character of the uranium market may also increase the likelihood of government intervention in that market. In Canada and Australia, there are already mechanisms in place for managing export quantities and prices; at least from the outside, it is often difficult to separate economic and nonproliferation objectives in the use of these mechanisms. In addtion, as discussed in Chapter 5, these governments could use existing environmental and other barriers to control the pace of internal industry development. Instituted in a seller's market era, such governmental control may be perceived as even more important in an era of potentially weakening prices. The consequence may be sufficient commonality of interest, and sufficient policy tools, to result in informal or formal cartelization of a major part of the international uranium market. The major dangers in cartelization would be the possibility that capacity creation could fall out of step with demand growth and that the supplier countries could use their supply leverage to extract new market or sovereign costs. The policies, and policy-formulation processes, in Canada and Australia--and the way the market adjusts to them--are thus of great significance to the future security of uranium supply. Fuel assurance would benefit from continuing attention to these concerns by the countries involved, and by the U.S.

Beyond the cartelization issue and the possibility of changes in market conditions, there is an ultimate concern about continued reliance on particular suppliers whose output may not remain steady over time due to disruptive events, some of which may have little to do with nuclear issues. For example, disputes in Southern Africa--within South Africa or over the independence of Namibia--could lead to disruption of supply, though such a disruption would probably be temporary. The stability of Australian supply may depend on the resolution of nonproliferation issues, and on the success of the nonproliferation regime in inhibiting nuclear weapons acquisitions and use. New proliferation events could result in political changes, in Australia or other supplier countries, making continued supply highly uncertain. Efforts to establish or maintain stable export policies in key supplier countries and to resolve nonproliferation problems are thus important to fuel assurance in the current highly concentrated uranium market.

Finally, there are measures which might be taken to improve medium- and long-term assurance. These include better assessments of worldwide uranium resources and a program of investments in better data commensurate with the societal value (which exceeds the commercial value) of such information. Also needed is better information on world trade patterns in uranium and nuclear fuel so that vulnerabilities and impending problems may be identified in time to take (or avoid) action. In addition, limited measures might be taken to improve market mechanisms. These could include removal of barriers, or the creation of incentives, for the entry of new uranium suppliers. What is needed is not great institutional overlay, since trade appears reasonably healthy at this point, but rather efforts to avoid future problems that may stand in the way of the evolution of better trade relationships, within the framework of the nonproliferation agreements which dominate the assurance issue.

APPENDIX

SUPPLY AND DEMAND PROJECTIONS

The supply and demand analyses used in this report are based on projections and technical parameter assumptions documented here. Reactor capacity growth projections are derived from the OCED-NEA/IAEA "present trend" estimates of December 1977,* supplemented, where necessary, by independent estimates for non-OECD countries. These projections are shown in Table A-1 (note that the capacities are end-of-calendar-year totals). The capacity growth projections were apportioned among five reactor types (LWR [no recycle], HWR, HTR, GCR and AGR). The NEA/IAEA growth projections of late 1977 appear now to be upper bounds on prospective growth through 1985, and perhaps beyond. They are thus likely to be conservative in their implications for nuclear fuel cycle requirements. The nuclear growth projections were converted to enrichment and uranium requirements using the conversion factors and lead times shown in Tables A-2 and A-3. Fuel requirements were taken from the NEA/IAEA, modified to reflect tails assay in renrichment of 0.20%.

Supply estimates are based on public and propietary data on actual contracts from several sources. In the aggregated form shown in the text, we believe the estimates to be correct to within ± 10% as of the end of 1978. Where enrichment contracts are stated in reactor capacity covered, rather than SWU (as is the case for U.S. contracts), we have converted to SWU assuming 70% capacity factor and 0.20% tails assay. Since capacity factors stated in contracts are often higher, our conversion may understate slightly the supply of enrichment available from the U.S. The conversion to AFC contracts, which will continue over the next year, will undoubtedly alter the details of U.S. supply arrangements with foreign utilities.

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*Uranium Resources, Production and Demand, OECD Nuclear Energy Agency and the International Atomic Energy Agency, December 1977; see also Nuclear Fuel Cycle Requirements, OECD Nuclear Energy Agency, February 1978.

TABLE A-1

NUCLEAR CAPACITY GROWTH

COUNTRY	YEAR 1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	2000
Austria	—	.7	.7	.7	.7	.7	.7	.7	.7	1	2	2	2	2	
Australia	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Belgium	1.7	1.7	1.7	1.7	2.6	2.6	3.5	3.5	3.5	5	5	7	8	8	
Canada	3.3	4	5	6	6	7	8	9	10	12	14	16	18	20	
Denmark	—	—	—	—	—	—	—	—	—	—	—	1	1	2	
Finland	0.4	1.5	1.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.7	2.7	3.5	3.5	
France	4.7	6.5	12	15	19	23	27	31	34	38	42	46	50	53	
Germany	6	9	10.3	12	14	16	18	22	25	29	34	38	43	47	
Greece	—	—	—	—	—	—	—	—	—	—	—	—	1	1	
Ireland	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Italy	0.6	1.4	1.4	1.4	1.4	1.4	1.4	2.4	5.4	7	12	15	20	25	
Japan	8	12	13	15	17	19	22	24	27	31	35	39	44	50	
Luxembourg	—	—	—	—	—	—	—	—	—	—	1	1	1	1	
Netherlands	.5	.5	.5	.5	.5	.5	.5	.5	.5	1	2	2	2	3	
New Zealand	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Norway	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Portugal	—	—	—	—	—	—	—	—	—	.9	.9	.9	1.8	1.8	
Spain	1.1	2.1	4.1	8	8	11	13	14	15	16	17	18	19	20	
Sweden	3.2	4.7	5.6	6.5	6.5	7.4	7.4	7.4	7.4	7	7	7	7	8	
Switzerland	1.0	1.0	1.0	1.9	1.9	1.9	1.9	2.8	2.8	3	3	3	3	3	
Turkey	—	—	—	—	—	—	—	—	—	—	—	1	1	1	
U.K.	6.6	6.6	10.3	10.3	10.3	10.3	10.3	10.3	10.3	11.6	12.8	14.1	15.3	15.3	
U.S.	48	50	55	60	68	77	88	101	115	130	146	162	178	194	
OECD TOTAL	85	102	122	141	158	180	204	231	259	295	336	376	419	459	850
WORLD TOTAL	87	105	126	146	165	189	216	246	278	318	364	409	458	504	1000
Iran	—	—	—	—	—	—	—	1.2	1.2	2.4	2.4	2.4	2.4	2.4	
Brazil	—	.6	.6	.6	.6	.6	.6	1.87	1.87	3.12	3.12	4.3	5.5	6.7	
Egypt	—	—	—	—	—	—	—	—	.62	.62	.62	.62	.62	.62	
Korea	—	—	.564	.564	.564	1.19	1.8	2.75	3.7	5.5	5.5	5.5	5.5	5.5	
Taiwan	—	.6	1.2	1.2	2.2	3.11	3.11	4.02	4.93	4.93	4.93	4.93	4.93	4.93	
Pakistan	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	
Argentina	0.319	0.319	0.319	0.319	0.919	0.919	0.919	0.919	0.919	0.919	0.919	0.919	0.919	0.919	
India	—	0.6	0.8	1.02	1.24	1.24	1.5	1.7	2.4	3.1	3.8	4.5	5.2	6.0	
SUBTOTAL	.44	2.2	3.6	3.8	5.7	7.2	8.1	12.6	15.7	20.7	21.4	23.3	25.2	2 72	

Table A-2

REACTOR FUEL REQUIREMENTS

Reactor Type	LWR (no recycle)	HWR	HTR	GG	AGR
Initial Core					
Natural Uranium (MTU/GWe)	363	145	236	918	458
Separative Work (MTSWU/GWe)	243	--	310	--	252
Reloads*					
Natural Uranium (MTU/GWe)	138	119	57	214	131
Separative Work (MTSWU/GWe)	111	--	75	--	89

*Assumes 70% capacity factor, 0.20% tails assay where enrichment is required.

Table A-3

FUEL CYCLE LEAD TIMES

All but HWR	First Core	Reloads
Enrichment	2 years	Same calendar year
Natural Uranium	3 years	1 year
HWR		
Natural Uranium	2 years	1 year

Table A-4

ANNUAL GROSS REACTOR ORDERS

YEAR	United States Domestic Orders		United States Orders Overseas		Orders of Foreign Manufacturers	
	Number	MWe	Number	MWe	Number	MWe
1965	7	4,511	3	1,150	2	690
1966	20	16,423	3	1,065	0	0
1967	31	26,411	2	1,112	3	1,395
1968	16	15,120	1	822	7	4,535
1969	7	7,301	6	3,575	7	4,840
1970	13	13,683	5	4,356	6	4,308
1971	21	20,861	8	7,408	8	7,140
1972	41	45,201	6	5,308	14	8,890
1973	45	51,727	6	5,078	9	8,550
1974	27	31,888	9	8,828	31	27,951
1975	5	5,332	2	1,960	9	10,528
1976	3	3,720	3	2,581	27	27,364
1977	4	5,040	0	0	8	N.A.

Table A-5

PROJECTION OF URANIUM PRODUCTION CAPABILITY[a]

(Thousands of STU_3O_8)

	1977		1980		1985		1990	
	OECD	NUS	OECD	NUS	OECD	NUS	OECD	NUS
U.S.	19.1	16.0	29.4	23.0	46.8	27.0	61.1	35.0
Canada	7.9	7.2	10.3	9.4	16.3	12.0	14.7	11.0
Australia	0.5	0.7	0.7	1.2	15.3	13.0	26.0	24.0
South Africa	8.7	6.5	15.2	10.4	16.3	13.0	15.6	11.0
Other	6.6	5.7	13.3	11.5	25.0	12.0	25.7	11.0
TOTAL	42.9	36.1	68.9	55.5	119.7	77.0	143.1	92.0

a. The OECD projection is from Reference [1]; the NUS projection is from Reference [3].

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