DEPARTMENT OF NATIONAL DEFENCE

CANADA

OPERATIONAL RESEARCH AND ANALYSIS ESTABLISHMENT
DIRECTORATE OF STRATEGIC ANALYSIS

ORAE MEMORANDUM NO. M54

THE IMPACT OF ENERGY ON STRATEGY

NUCLEAR ENERGY

by

Maj. Andrew Nellestyn

OTTAWA, CANADA SEPTEMBER, 1974

ABSTRACT

The use of the oil weapon as a political instrument during the Yom Kippur War of October last demonstrated the vulnerability of the industrialized nations to Middle East oil import dependency. Nuclear energy alone possesses the technology and industrial base to lessen this dependency during the next twenty-five years. Presently the atom accounts for only one per cent of annual global energy consumption. It is unlikely that its contribution will be very substantial before 1985. By the year 2000, however, nuclear energy could provide about twenty-five per cent of the global energy requirements. In order to achieve the 2000 A.D. target, governments and the private sector must today establish policies and implement programmes to avoid the uranium ore, uranium enrichment capacity and manpower shortfalls predicted to occur in the first half of the eighties. These shortfalls if not surmounted could severely impede the orderly and timely expansion of the nuclear industry. In addition, governments at both the national and international level must improve safeguard arrangements and exact more stringent adherence to improved safeguards. It is encouraging to note that the major sources of nuclear fuel, i.e. uranium ore, are located in countries with stable, predictable, and pro-Western governments. Fast breeder reactors and fusion in particular are not expected to contribute significantly before 2000 A.D. Thermal spectrum reactors will provide the bulk of nuclear capacity.

RESUME

L'utilisation du pétrole comme instrument politique pendant la guerre du Yom Kippur, en octobre dernier, a démontré la vulnérabilité et la dépendance des pays industriels vis-à-vis l'importation du pétrole du Moyen-Orient. Seule l'énergie nucléaire possède les bases technologiques et industrielles qui permettront de diminuer cette dépendance au cours des vingt-cinq prochaines années. Actuellement, l'atome ne fournit que 1 pour-cent de l'énergie totale consommée annuellement. Il est peu probable que ce pourcentage puisse être accru considérablement avant 1985. Toutefois, il est possible qu'en l'an 2000 l'énergie nucléaire puisse fournir environ 25 pour-cent des besoins énergétiques de l'humanité. Si les gouvernements et le secteur privé désirent atteindre cet objectif, il leur faut établir dès aujourd'hui des politiques et mettre en oeuvre des programmes aux fins d'éviter la pénurie de minerai d'uranium, de capacité d'enrichissement de l'uranium et de main-d'oeuvre prévue pour la première moitié des années 1980. Si l'on ne parvient pas à enrayer cette disette, le développement régulier et normal de l'industrie nucléaire pourrait s'en ressentir énormément. De plus, les gouvernements, tant au niveau national qu'international, doivent améliorer les mécanismes de sauvegarde et exiger qu'ils soient plus strictement mis en application. Il est encourageant de noter que les principales réserves de combustible nucléaire, c'est-à-dire de minerai d'uranium, sont situées dans des pays dont le gouvernement est stable, leurs politiques prévisibles et qui sont favorables aux pays du bloc de l'Ouest. On prévoit que les réacteurs surrégénérateurs et de fusion en particulier ne pourront fournir une contribution importante avant l'an 2000. La majeure partie de l'énergie nucléaire sera donc fournie par les réacteurs à spectre thermique.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOTE: Tables 12 and 13 pertain to OECD countries.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of H.B. Merlin, Assistant Adviser Uranium, Energy Sector, Department of Energy, Mines and Resources, Ottawa, Canada, without whose information, advice, and patience, this report would not have appeared in print.

THE IMPACT OF ENERGY ON STRATEGY

NUCLEAR ENERGY

INTRODUCTION

1. The Yom Kippur War of October last confronted the industrialized nations with a new element in Middle East Politics, the oil weapon. The restriction of oil supply by selective embargo and the four-fold increase in crude oil prices demonstrated the vulnerability, politically and economically, of the industrialized nations, the majority of which depend extensively on Middle East oil imports. The effect on security of supplies and balance of payments focused attention on alternative sources of energy. One such alternative is nuclear energy.

2. The potential of the atom in providing energy to sustain economic growth has been appreciated for some quarter of a century. Unfortunately power derived from nuclear reactors has not met the expectations of its early proponents and today contributes only one per cent of annual global energy consumption. The expansion of the nuclear industry has been impeded by technical difficulties, labour problems, concern over safety and siting, regulatory processes and the capital-intensiveness of nuclear stations. All of these factors have led to construction schedule slippages, power derating, reactor order cancellation and a hesitancy to commit electric utility expansion to nuclear power. Yet of the alternative energy sources nuclear power alone possesses the technology and industrial base to lessen oil dependency during the next twenty-five years. Nuclear energy could account for twenty-five per cent of the world's energy requirements by the year 2000. Fast breeder reactors and fusion in particular are not expected to contribute significantly before 2000 A.D. Thermal spectrum reactors will bear the brunt of the load.

3. There are, however, a number of problems which could impede the orderly and timely expansion of the nuclear industry. Paramount amongst these are shortfalls of uranium ore and enrichment capacity which are predicted to occur during the first half of the eighties. Governments and the private sector must act jointly now to establish sound policies and implement dynamic programmes if these difficulties are to be surmounted.

4. The Yom Kippur War has focused world eyes on the potential importance of nuclear energy. Security of supply and price have moved governments to announce accelerated expansion of the nuclear industry and have also resulted in the doubling of uranium concentrate prices. These are encouraging signs for the development of nuclear energy.

5. This memorandum will attempt to portray the role of nuclear energy to 1985 and to detail the supply and demand patterns of uranium ore, enrichment capacity, and other fuel cycle activities. Industrial capacity and safeguards and the Non-Proliferation Treaty will also be examined.

ROLE OF NUCLEAR ENERGY

6. Electricity is projected to play an increasing role as a form of energy. This is attributable to the ease with which it can be transmitted over long distances, its cleanliness as fuel at the point of consumption, the tendency to electrification in the home and in industry and its flexibility of use. Forecasts depict electricity as accounting for 25 to 50 per cent of the total energy requirements in industrialized countries by the year 2000.

7. The estimated average annual rate of growth in primary electric energy [1] to 2000 A.D. ranges from 10 to 12 per cent. "This is almost double the rate of growth for electric energy as a whole and reflects the increasing proportion provided by nuclear power...Nuclear energy is expected to grow at an average rate of 32 per cent per annum during the first part of this period with a leveling off to 13 per cent per annum during the later years" (Ref 8). In terms of consumption, electricity is advancing at 10 per cent per annum (doubling time of 7 years) while energy is increasing at 4.5 per cent per year. Nuclear energy is evidently going to reckon very largely in the total energy picture particularly with respect to electric power.

8. Nuclear reactors provide base load electricity. Peak load electricity (or load following) cannot be met by nuclear reactors as economics and reactor physics dictate that availability and capacity factors be high and relatively constant.

9. In contrast to conventional steam raising plants which burn fossil fuels (coal and oil), nuclear energy does not emit pollutants such as sulphur dioxide, smog (oxides of nitrogen) and fly ash. In fact, coal burning plants release more radioactivity up the stack than do reactors in either gaseous or liquid form. And while first generation water cooled power reactors discharge more waste heat, it is likely that improvements in thermal efficiency and design and the introduction of high temperature gas cooled reactors will reverse this situation. Nuclear reactors therefore, are less damaging to the environment than are fossil fueled (coal and oil) fired stations. Waste management is addressed in the body of the memorandum.

---

(1) Primary electric energy is a conversion efficiency qualified term which is a measure of the heat value of the fuel burned to produce the output power. Thus a growth in output power will mean an even larger growth in primary electric energy. For example, approximately 3000 MW(th) (megawatts thermal) of primary electric energy, i.e. fuel, are required to produce a net electric output of 1000 MW(e) (megawatts electric).

WORLD NUCLEAR POWER GROWTH

10. Nuclear energy presently accounts for only 1 per cent of the annual global energy production. It is not expected to make a significant contribution by 1985 but will provide about 25 per cent of global energy production by 2000 A.D. Fast breeder reactors and fusion in particular will not figure prominently until after the turn of the century. Thermal spectrum fission reactors will thus provide the bulk of nuclear capacity.

11. World nuclear power growth is distributed between five reactor types: LWRs (light water reactors), HTRs (high temperature reactors), HWRs (heavy water reactors, e.g. CANDU), FBRs (fast breeder reactors), and SGHWRs (steam generating heavy water reactors). For the present decade this distribution of reactor types is relatively clear. Most of the installed and projected plants will be LWRs in which the uranium concentration has been enriched to 2 to 5 per cent. From 1980 onwards, it is not so clear what the distribution will be. Assumptions for this period can be based to some extent on present trends. Thus LWRs will continue to dominate the market. Advanced reactors such as the HTRs, FBRs and also natural uranium HWRs will take an increasing share of the reactor market. The proportion of the market devoted to SGHWRs is not yet determined but this will be increasingly important now that the British-Canadian SGHWR joint-venture has been adopted as the British reactor strategy.

12. To forecast the exact generating capacity provided by nuclear power is difficult. Forecasting in this area is exceedingly risky as national governments continually revise their reactor strategy. However, 600,000 MW(e)[2] by 1985 and some 2,700,000 MW(e) by 2000 are commonly accepted figures.

---

(2) MW(e) - megawatts electric

13. The recent oil crisis characterized by restriction of supplies and increased prices, has moved governments to accelerate the introduction of nuclear reactors into their national power grids. France, for example, recently announced a massive expansion. The adoption of nuclear power, spurred by a desire for secure energy supplies, a fair price and the decreasing life index of non-renewable fossil fuels, will cause both oil producing and consuming nations to look more to nuclear power.

14. Tables I and II (pp. 63-64) detail world nuclear power growth by global regional bases and by individual countries. Capacity factors for Tables I and II are 75% and 70% respectively. No exact figures are available for the Soviet Union or China. It is thought that both these countries, particularly China, are unlikely to match the pace of the non-communist world in switching to nuclear power. The extent of nuclear generated electric capacity in the LDCs (less developed countries) is too speculative to offer any quantitative assessment although nuclear reactors of about 600 to 800 MW(e) can be introduced on a limited basis. The recent quantum jump in oil prices has enlarged the scope for nuclear power in the LDCs as units of 100 to 400 MW(e) are now economical and can be absorbed in the LDCs' grids. Reactors in the industrialized countries will be of 800-1500 MW(e) unit size.

15. These projections are subject to a multitude of restraints each of which can radically alter the role nuclear power will play. They are:

a. oil prices;

b. public acceptance;

c. industrial capacity;

d. technical problems;

e. safety and siting criteria;

f. financing;

g. environmental considerations;

h. material and manpower availability;

i. uranium ore supply and production capacity;

j. enrichment capacity; and

k. alternative energy sources.

ESTIMATED WORLD RESOURCES OF URANIUM

16. The world growth of nuclear power depends materially on the availability of uranium. If present trends in uranium exploration and mining continue, the projections listed in Tables I and II could be severely curtailed by a decrease in the number of orders and/or derating of reactor power.

17. Estimated world resources of uranium are classified according to the price per pound of yellowcake (U_3O_8). Yellowcake is the form in which uranium leaves the mill-head to be further processed into natural or enriched uranium fuel as used in reactor fuel rods.

a. Reasonably Assured Resources (RAR). RAR refers to uranium which occurs in known ore deposits of such grade, quantity, and configuration that it can, within the given price range, be profitably recovered with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits, and on knowledge of ore-body habit. Reasonably assured resources in the price category below $10/lb[3] are equivalent to Reserves in the mining sense.

b. Estimated Additional Resources (EAR). EAR refers to uranium surmised to occur in unexplored extensions of known deposits in known uranium districts, and which is expected to be discoverable and economically exploitable in the given price range. The tonnage and grade of estimated additional resources are based primarily on knowledge of the characteristics of deposits within the same district.

c. The reliability is higher for the price range below $10 per pound and lower for the high cost deposits.

18. Natural uranium contains three isotopes. Characterized by weight per cent these are: U238, 99.3%; U235, 0.71%, and U234, 0.0005%. U235 is the only naturally occurring fissionable (fissions upon absorption of a neutron) material. U238 is a fertile material which, when bombarded by a neutron, yields the fissionable Pu239 (Plutonium 239) isotope used as fuel in fast breeder reactors. U234 can be fissionable and converted into U235; it is of little importance as a source of fissionable fuel. At 2000 A.D. world energy consumption rates of 1Q/annum

---

(3) The symbol $ is employed to represent US dollars at March 1973 values. All resources are expressed in metric tons of uranium metal (tonnes U) and are also given in short tons of U_3O_8 (1 short ton U_3O_8=0.7693 tonnes U). The recent increase in oil prices has caused an upward movement in uranium ore prices. The present price per pound of U_3O_8 is about $12. The $10/lb U_3O_8 can, with qualifications, be read as < $15-20/lb U_3O_8. The $10 and $10-15/lb U_3O_8 classification will be used throughout this memorandum.

($1Q=10^{18}$BTUs[4]), fissile fuels, i.e. U235, could provide 200 years of energy. If fast breeders are realized commercially this energy reserve could be extended to 2000 years.

19. Uranium constitutes about 3 p.p.m. (parts per million) of the earth's surface. It is widely distributed throughout the world, and is slightly less abundant than copper, lead, zinc and nickel. Most of the known large deposits have a uranium content of about 0.1 per cent, and it occurs in chemical combinations amounting to more than 100 known minerals. The most common mineral is uraninite (pitchblende), usually UO_2 with a certain UO_3 content. Other minerals include autunite, carnotite and tobernite. The ore occurs in sedimentary strata and most igneous rocks. Uranium also occurs in the waters of the oceans. However, because of economic and technological factors it is not considered recoverable, is therefore difficult to estimate and hence never included in world resources. Uranium is also believed to exist in the ocean floor. Fig. 1 (p 49) demonstrates the importance of uranium as a source of energy relative to other energy sources.

20. Reasonably assured world resources under \$10/lb U_3O_8 now amount to 866,000 tonnes U (1,126,000 short tons U_3O_8). This represents an increase of about 33 per cent over the past three years. Tables III and IV (pp. 65-66) list the estimated world resources of uranium by country. The USSR and China are excluded from this survey. While these two countries are self-sufficient in relation to their nuclear programmes, it is unlikely that they will be substantial or even minor exporters of uranium concentrate or any other form of nuclear fuel.

---

(4) BTU (British Thermal Unit') the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

21. The major portion of the world's resources of uranium are located in countries with stable, predictable, and pro-Western governments. In the category of RAR[5] uranium the USA has about 26%, Canada, 20%, South Africa, 17%, Sweden, 17%, Australia, 7% and others 13%. Under EAR[6] uranium the USA's share is estimated as 50%, Canada's as 26%, Australia's as 7%, and others, including South Africa and Sweden's as 17% (see Fig. 2 p. 50). Uranium ore supplies to fuel the industrialized nations' reactors should therefore be politically secure.

22. Uranium resources could be substantially increased if low grade ore-bodies, bodies with heavy overburden, and an increased rate of exploration were to be actively pursued.

ESTIMATED WORLD RESOURCES OF THORIUM

23. Thorium 232 (Th 232) is a fertile isotope which upon absorption of a neutron is transmuted to Uranium 233 a fissile isotope. The natural abundance of thorium in the earth's crust is about three times higher than that of uranium. It is not necessarily found in association with uranium. The chief source of thorium is monazite (primarily monazitic beach sand deposits). It is also closely associated mineralogically with both conglomeratic and pegmatitic uranium ores such as those found in Canada. Th 232 is therefore an important fuel for nuclear reactors and has been incorporated into the design of near-breeders[7] and thermal breeder reactors.

---

(5) Reasonably Assured Resources

(6) Estimated Additional Resources

(7) Near-breeder reactors unlike breeder reactors do not produce as much or more fuel than they consume. HTRs and HWRs (CANDU) are potential near-breeders.

24. Despite recent orders for HTRs no significant thorium requirements are expected in the 70's and no large thorium market exists at present. Thorium may begin to play a substantial role in the generation of power in HTRs and HWRs towards the end of the century.

25. For the reasons outlined in paras 23 and 24 above, the information available on thorium resources is scarce and far less reliable than that of uranium deposits dealt with in this memorandum.

26. Reasonably Assured Resources (RAR) are similarly defined as RAR uranium and are quoted at a price range up to US $10 per pound of thorium dioxide (ThO_2). Estimated Additional Resources (EAR) again are similarly defined but are not price categorized. Table V (p. 67) lists presently known world thorium resources. Again the USSR and China are omitted. The effect of increases in the price of oil have not been accounted for.

27. Thorium resources as uranium resources are politically secure. Self-sufficiency in energy is a realizable goal for India if she were to pursue a CANDU thorium cycle strategy along with a CANDU uranium cycle strategy.

WORLD URANIUM REQUIREMENTS[8]

28. Nuclear fuel requirements will depend upon the types of reactors installed, technological changes, the price of uranium relative to the cost of enriching and fuel cycle strategy. These variations may, however, be minor in attempting to forecast total requirements. "Notwithstanding the uncertainties with regard to

---

(8) tons U_3O_8=short tons U_3O_8.

future availability of natural and enriched uranium supplies, it is clear from the work of the Study Group (OECD/IAEA: Uranium Resources, Production and Demand) that the most significant variations in demand arise not from one or another strategy involving mainly enriched reactors, but from variations in the growth of nuclear power as a whole". (Ref 2).

29. Table VI (p. 68) lists world uranium requirements to the year 2000. Cases A and X present the lowest American and foreign forecasts based on the assumption that the current trend toward increased slippage in reactor construction will continue unabated and that long-term demand for electricity will be relatively low. USA case C and foreign case Z are the highest presented and are based on assumptions of legislative changes in the regulatory process, a marked improvement in construction time, relatively high future demand for electricity, and the predominance of nuclear fuel over fossil fuel for new electricity generating plants. Cases B and Y postulate continued improvement in the regulatory processes, fewer construction delays than at present and continuation of current trends in electricity demand. Case D assumes that actions are taken to achieve long-term energy conservation, continued improvements are made in regulatory processes, fewer construction delays are incurred, and the long-term demand for electricity is relatively low (Ref 4).

30. Uranium demand is influenced by a number of factors. The supply-demand situation can be gravely distorted by any one or a combination of these. The next few paragraphs will address themselves to these phenomena. Most of the data have been taken from Ref 1.

31. World nuclear power growth will be met primarily by LWRs which use enriched fuel (2 to 5%). The demand on natural uranium is subject to the degree of enrichment of the fuel, the number of LWRs and the tails content in the enrichment plants.

a. In the enrichment process, natural uranium is used as feed to produce the enriched product. A significant fraction (28% to 42%) of the U-235 contained in the natural uranium feed is discarded as waste from the enrichment process. The fraction depends upon the percentage of contained U-235 below which it is not economic to continue circulating the depleted uranium through the stages of the enrichment plant. The cut-off percentage or waste is referred to as the enrichment plant tails. Fig. 3 shows the relative requirements for natural uranium feed as the enrichment plant tails vary from 0.18% U-235 to 0.32%. Using 0.25% as the norm, decreasing tails to 0.2% reduces requirements by about 7 to 8% while increasing the tails to 0.30% increases requirements by 9 to 10%. Conversely the demand on the enrichment plant itself decreases with increasing U-235 tails from the plant. Contracts for enrichment services with the U.S.A.E.C. are now made on a "split-tails" basis, i.e. the plants are operated at 0.3% tails but customers supply uranium feed and pay for enrichment services on the basis of operation at 0.2% tails. The extra uranium required from operating at the higher tails is supplied by the U.S.A.E.C. from its stockpile. In effect then, the U.S.A.E.C. is selling its stockpile at a price linked to the cost of enrichment services. No distinction is made between foreign and domestic utilities. The latter may exert some pressure on the U.S.A.E.C. to discontinue the split-tails approach if they experience difficulty in securing uranium supplies.

b. The lower part of Fig. 3 shows how the optimum enrichment plant tails vary with uranium feed and enrichment services costs. If the ratio of enrichment services costs to uranium feed costs increases, the optimum enrichment plant tails will increase, while if the ratio decreases the optimum tails will decrease. Either uranium shortages or insufficient enrichment plant capacity could result in the enrichment plants being operated with non-optimum tails.

32. The spent fuel from most types of reactors contains plutonium which could be recycled in both light water and heavy water reactors. In light water reactors annual uranium requirements with plutonium recycle could be reduced by about 20% while in heavy water reactors the reduction could be 30% or more. Because of residual radioactivity and toxicity remote fabrication techniques for mass production of plutonium-bearing fuel will be required before plutonium is recycled on a large scale. While most uranium demand forecasts assume plutonium recycling to start in 1978, the earliest likely date for large scale plutonium recycling would be 1982. In the United States environmental statements and hearings must be held prior to the issue of rules and regulations by the U.S.A.E.C. on all aspects of the plutonium fuel cycle. The minimum lead time to bring a plutonium fuel fabrication plant into operation is estimated to be 5½ years after the issue of the final environmental statements. Only one fuel fabricator, Westinghouse Electric, in the U.S.A. has announced plans for a plutonium fabrication plant. The plant itself will cost twice as much as a uranium fuel fabrication plant with the same physical size. The output however, will only be a quarter of that of the uranium fuel fabrication plant.

33. The spent fuel from enriched uranium reactors has a U-235 concentration greater than that occurring in nature. Most forecasts of uranium demand assume this uranium is recovered from the spent fuel and recycled today. In fact, except for possibly a few experimental bundles, no uranium recovered from reactors using

enriched fuel has been recycled. Since recycling reduces requirements for these reactors by 25 to 35%, the actual date when uranium is recycled and the rate of recycling will have important influences on the short-term demand for uranium. Fuel reprocessing plants will have to be built to recover the uranium and special techniques and operational procedures will be required when the recycled uranium is used as feed for the enrichment plants. Scheduled operation, and in some cases construction of the planned facilities, will depend upon the timing with regard to plutonium recycling. As with plutonium recycling 1982 could be the earliest likely date for large scale uranium recycling. The effect of uranium and plutonium recycle is shown in Fig. 4.

34. Recognizing the above uncertainties in the forecasting of uranium demand, Fig. 5 shows the estimate of the most likely band of world uranium demand to the late 1980's. As illustrated plutonium and uranium recycle is assumed to be instituted in 10% of the reactors by 1982 rising rapidly to complete plutonium and uranium recycle by 1987. The upper demand level assumes operation of enrichment plant at 0.3% tails to 1980 reducing to 0.25% thereafter while the lower level assumes operation of the plants at 0.2% tails. The projection assumes an acceleration of the U.S. nuclear program to achieve 200,000 MW(e) of nuclear capacity by 1981, two years earlier than the 1972 U.S.A.E.C. forecast.(9) Acceleration of demand in other countries has not been factored into the projection and in this respect it may be considered conservative.

35. The projection shows annual demand increasing from some 25,000 tons of U_3O_8 to 75,000 to 85,000 by 1980, to 135,000

(9) WASH - 1139 (74): Nuclear Power Growth: 1974-2000, reports maximum U.S. nuclear capacity (Case C) as 112,000 MW(e) and 275,000 MW(e) for the end of 1980 and 1985 respectively. As acceleration of demands in other countries have not been factored into the projection, the data for world uranium demand may not be substantially affected. To date, France has announced an additional 13,000 MW(e) expansion by starting construction of 40 to 50 nuclear stations of 1000 MW(e) by 1980. This includes the 13 just mentioned. Other countries are liable to follow suit.

to 150,000 by 1985. Although this is in general agreement with other forecasts for those specific years the interim demand is somewhat higher.[10]

36. <u>In summary, factors which will influence uranium demand include</u>:

a. type and rate of installation of nuclear units and the capacity factor at which they operate;

b. date and rate of introduction of plutonium recycling; and for reactors using enriched fuel;

c. date and rate of introduction of uranium recycling;

d. percent of U235 in the tails discharged from the enrichment plant.

37. By the mid-eighties the Western world could require 135,000 to 150,000 tons of U_3O_8 per year. The equivalent petroleum requirements if uranium were not available would be 12 to 14 billion barrels per year or about 60 to 70% of today's world production.

---

(10) OECD Report: Uranium Resources Production and Demand 1973, forecasts that the annual demand for uranium is expected to stabilize in the region of 80,000 tons U_3O_8 by 1980 and almost double this figure by 1985. This is in general agreement with WASH-1139 (74): Nuclear Power Growth: 1974-2000.

WORLD URANIUM PRODUCTION CAPACITY

38. While uranium resources have increased by 33% over the last three years, the annual production of U_3O_8 has remained fairly stable. World production reached a maximum in 1959 at about 43,000 tons U_3O_8. Production declined steadily during the next eight years to below 19,000 tons U_3O_8 in 1967 and increased again to 25,000 tons U_3O_8 by 1972. Annual production capacity is planned to reach about 40,000 tons U_3O_8 by 1975 and could attain about 65,000 tons U_3O_8 by 1978. Tables VII and VIII and Figs. 6 and 7 indicated the historical and future production patterns.

39. The uranium industry has undergone a "boom-and-bust" cycle. Delay in reactor construction, the release of French and South African stockpiles at less than cost on the international market, government taxation and foreign ownership policy in the mining sector and the lack of forward commitments for nuclear fuel by utilities ordering nuclear reactors have all contributed to what is today a depressed fuel cycle industry. The staggering increases in oil prices and the resulting world wide plans to accelerate nuclear reactor projects might inject life into the industry. But this will not happen if governments do not coordinate policy with the industry and if the industry does not take steps now to remedy what might become a uranium supply-demand crisis in the early eighties.

40. There is ample reason for the industry to be in a buoyant mood. World uranium prices have soared to $12/lb U_3O_8 from last year's price of approximately $4-6/lb U_3O_8. In addition, commitments to nuclear power appear to be increasing rapidly. Demand is indeed exploding. By 1980 production must be three times the 1972 level of 25,000 tons U_3O_8 and at least six times this level by 1985.

41. No shortages of uranium supply are expected in the seventies but even this has to be qualified (see paras 43 and 44). However, the rapid growth in demand in the coming decade cannot be satisfied by existing uranium exploration and production levels. The mining industry must maintain a forward reserve of eight years production to assure uranium supply at the projected rate. A lead time of eight years is required between discovery and actual production. This concept of an eight year forward reserve can be conveniently illustrated by displacing the demand curve so that it lies eight years earlier as is indicated by the curve "Case A shifted eight years" on Fig. 8. Fig. 9 outlines several desirable discovery rates for low cost RAR to maintain an eight-year forward reserve. The intersection of the curve referred to in Fig. 8 shows that in 1979 the presently known reserves would just correspond to this eight-year reserve. A substantial proportion of world reserves could not be produced in this time frame. Thus from what is presently a position of over-supply (see paras 43 and 44) the eight-year reserve position worldwide is likely to be inadequate to provide needed production levels. Hence substantial investment must be forthcoming in new exploration and production if uranium demand in the 1980's is to be fulfilled. Currently the exploration level throughout the world is not increasing sufficiently to attain this objective (Fig. 10).

42. From the viewpoint of the utility planning to base an appreciable part of its electrical generating capacity on nuclear power, it would be advisable to make certain that a reliable source of the raw material of reactor fuel has been secured and that a large portion of the ore necessary for the 30-year life (now commonly predicted in estimating the cost of power produced) of a reactor has been arranged for. This is a concept somewhat new to the electric utility industry. However, such initiative and planning must be exercised if the fuel cycle industry is to receive adequate encouragement to embark on massive expansion programmes.

43. It was previously stated that a uranium shortage would not be likely before the turn of this decade. The Canadian uranium mining sector is experiencing a great number of enquiries from foreign sources for uranium supplies. The demand on the Canadian market is such that a shortfall might occur there in the later part of the seventies. Were Canada to release its stockpile and production, it could sell all of it now. This has been brought about by the withdrawal from the market by France, Australia and South Africa, all of whom are major world uranium producers. France is restricting its market activities due to the recently announced plans to accelerate and expand its nuclear programme and because its African suppliers (such as Gabon, Niger, and Zaire) are witholding their production until a uranium ore price commensurate with the value of other commodities (oil, etc.) is established. South Africa has restrained export so that it can supply the enrichment plant to be built there. Australia has not realized its market potential due to the foreign participation debate, desire to sell uranium in the enriched form, and low world concentrate prices.

44. Thus add-on-value by further downstream processing (enrichment), more favourable concentrate prices, increased domestic demand and the extent and form of foreign participation in the national mining sector are all contributing to a rapidly approaching world uranium shortage which, at the same time, is putting pressure on the Canadian industry. Governments will therefore have to formulate policies about the release of stockpiles (currently about 100,000 tons U_3O_8 worldwide), upgrading of prime materials, and surplus to domestic requirements formulas.

45. A production shortfall will result in a reduction of reactor orders and/or reactor power derating. Failure to achieve plutonium and uranium recycle will worsen the situation.

SEPARATIVE WORK (ENRICHMENT) REQUIREMENTS

46. While existing and firmly committed power plant capacity is tied to assured supplies of enriched uranium fuel, present enrichment capacity plus stockpiles will be unable to meet demand beyond the early 1980's (Table IX and Fig. 11).

47. Enrichment requirements are now being met largely by three plants in the USA which have a combined capacity of 17,200 tonnes of separative work units (MTSWU, Metric Tons of Separative Work Units) per year. These plants have been operating well below capacity for the past few years. Some enrichment services are also being supplied by the USSR[11] and small plants exist in the UK, France and China as well. All these plants employ the gaseous diffusion process to enrich uranium.

48. To satisfy world demand, additional enrichment capacity must be available by 1982 and certainly no later than 1984. By the year 2000 A.D., 135,000 MTSWU will be required. This is equivalent to 15 new plants of 9000 MTSWU per year coming on line at the rate of one plant every 15 months.[12]

---

(11) It is improbable that the USSR separative work capacity and any expansion thereof will be sufficient to permit her to export enriched uranium beyond her present contractual arrangements with western countries (the amount of which is small in any event). Domestic requirements will prohibit this. China's capacity is too small for it to mount an export drive and at the same time increase its stockpile and production for internal military and civilian programmes.

(12) There is no requirement to increase separative work capacity for military weapon production. In fact, except perhaps for China, the nuclear weapon nations appear to have sufficient weapon grade material stockpiled to cater to their defence programmes and ambitions.

49. The USA is planning to increase the capacity of its three plants to 27,000 MTSWU per year by cascade improvement and uprating programmes (CIP and CUP). In Europe, Eurodif (an association of nations headed by France) is planning the construction of a diffusion plant and URENCO/CENTEC (troika whose members are UK, Holland, and West Germany) are planning centrifuge facilities.

50. Three separation processes exist at present; gaseous diffusion, gas centrifugation and nozzle separation. Of these only the gaseous diffusion technique has been in commercial operation. The other two are still in the pilot plant stage. Isotopic separation by lasers is also a possibility but a very remote one.

51. Gaseous diffusion is highly power intensive (2500 MW(e) are required for the minimum economic capacity of 9000 MTSWU). The nozzle separation process is even more power intensive. The least power intensive is the gas centrifuge which requires about a tenth of the operating power of a gaseous diffusion plant. The gas centrifuge method requires 30 MW(e) for a minimum economic separative capacity of 1100 MTSWU or about 300 MW(e) for 9000 MTSWUs. The lead time from inception to production is about 8-9 years for each of these plants. Construction of new capacity should be starting now.

52. Australia, Canada, Japan and South Africa are countries which as yet do not have separative work capacities but are studying whether a sufficient market and a favourable political climate exist to introduce enrichment into their economies. South Africa recently announced that it would build a nozzle separation pilot plant there with West German technological and economic assistance. As to the process to be adopted by Australia, Canada and countries planning to expand separative work capacity, this is still uncertain. Until the URENCO/CENTEC 300 MTSWU pilot plant at Almelo in the Netherlands (due to go on stream in 1976) proves technologically and economically

feasible, gaseous diffusion will be the preferred process. It is still not clear what the novel technique announced by South Africa some five years ago is. Its nozzle separation process joint-venture with West Germany might suggest the novel technique is in fact nozzle separation. This is only speculation.

53. The choice for future processes will thus be based on the technical and economic feasibility of the gas centrifuge and the nozzle separation process. The power requirements for both the gaseous diffusion and nozzle separation techniques, will not be attractive in countries where low-cost and pollution-free electricity is not available.

54. Split-tails accounting, the tails concentration, and the effect of plutonium and uranium recycle can drastically alter both the separative work requirements and the amount of uranium feedstock for separation plants (see paras 31 to 34, Tables IX and XIV, and Figs. 4, 5 and 11).

55. As in the case for uranium production, government and industry coordination is essential and must be implemented today if the projected nuclear power growth is to be realized in a timely and orderly fashion.

AVAILABILITY OF INDUSTRIAL CAPACITY (OECD COUNTRIES) [13]

56. In the past, one of the main causes for delays in nuclear power station construction schedules was late delivery of equipment. In some cases, these late deliveries concerned major pieces like reactor pressure vessels, steam generators and turbine-generators. These large units of forged steel are indeed most critical as regards possible delays, and utilities and manufacturers who are

---

(13) source: OECD/NEA Report SEN/NELT 74(1), Paris, 11 Feb., 1974.

aware of this problem try to avoid difficulties by very early ordering of such equipment. Because the corresponding manufacturing plants represent a very heavy capital investment, a certain centralisation is needed in this type of production, thus increasing the requirements for early planning on a large scale. It is known, for example, that the heaviest forging pieces of the order of 400 tonnes are at present mainly fabricated in Japan, while their machining is carried out in the countries where the stations are constructed.

57. Table X has been compiled from the NELT Study Group's enquiry on construction capacities in the three sectors, pressure vessels, steam generators and turbo-generators.

58. The enquiry on overall nuclear power station construction capacities resulted in the information presented in Table XI.

59. The figures in Table XI show that countries endeavour to increase the domestic share of nuclear power station construction to the greatest possible extent. However, this trend is in some contradiction with economic factors. Nuclear power station construction lends itself better than many other fields to international co-operation on the industrial level. The economic aim would be to concentrate construction of major components on an international scale in order to increase the number of heavy units constructed per plant, thus rationalizing construction. Some efforts in this direction can be detected in European industry. At present only the US market seems large enough to justify national nuclear power plant construction firms.

60. As to future plans for capacity increases and possible bottlenecks, some countries have expressed their concern in the following ways:

61. In Canada the major constraint is likely to be the shortage of trained and skilled manpower for engineering, high technology manufacture and operation.

62. In France it is considered that industrial capacity will extend in parallel with the nuclear programme. Special efforts are necessary to increase production capacities for steam generators. It is also felt necessary to form supplementary teams of operators for commissioning of nuclear stations in accordance with the growing construction programme.

63. In Italy emphasis is laid on good future coordination and integration of nuclear industrial efforts on a European scale. It is recognized that this is the best solution to cope with the complex problems of nuclear plant construction from the conceptional design to plant start-up, also taking into account increases of unit size, the magnitude of investment required in component manufacturing facilities and the degree of qualification required by technical staff and labour.

64. The Japanese government has taken measures to increase nuclear capabilities and is also promoting research and development for fuel cycle plants. It is expected that private industry will develop sufficient domestic capacity for the Japanese nuclear programme.

65. In Spain it is planned to reach a production capacity of two NSS(14) units (1.2 GW(e)(15) each) in 1975 and of four units in 1980. Bottlenecks may appear in the turbine-generator production.

66. In Sweden it is felt that preparations for a possible accelerated programme would have to start immediately if they

---

(14) NSSS - nuclear steam supply system; NSS - nuclear steam supply.

(15) GW(e) - gigawatts electric (1000 MW(e))

were to become effective in time. This would include training of workers and construction personnel and increasing the manufacturing capacity of certain critical sectors such as valves. Decisions regarding the nuclear fuel cycle would also have to be taken in time.

67. Swiss industry has sufficient capacity for most reactor components needed for its own nuclear programme. Nuclear core components however are not fabricated in Switzerland.

68. In the U.K. the availability of industrial capacity depends on the reactor programme to be chosen. If more gas-cooled reactors or steam generating heavy water reactors (SGHWRs) are built, British industry will be capable of supplying all the components needed for both the NSSS and the conventional side of the stations. If however, LWR stations are to be ordered, the pressure vessel and steam raising plant would be imported into the UK for early stations. Subsequently, British industry would probably be in a position to provide all components. These remarks also apply to the accelerated programme. The development of any international bottlenecks would depend upon whether the programmes of other countries were accelerated on the same time scale. Nationally, the accelerated programme might initially create a bottleneck in the area of pressure vessels and steam generators, if LWRs were chosen for the UK. Britain recently chose the SGHWR as a short-term strategy. The reactor strategy for the long term is still to be decided.

69. In the United States a major problem in the case of a possible acceleration of the nuclear power programme seems to be the shortage of qualified manpower. This concerns not only nuclear engineers but craft construction labour as well. A solution to this problem seems to lie in increased labour productivity.

70. In conclusion, it appears that countries do not foresee major problems for the execution of their basic nuclear programme as far as industrial capability is concerned. It is felt on the contrary that some free capacity for nuclear power station construction is still available. Industry is furthermore confident in its ability to increase capacities according to the planned growth of demand. However, the situation becomes different if a large effort for acceleration of the nuclear programme should become necessary. The corresponding new requirements for capital investments in the reactor and fuel cycle industry can be deducted from the overall investment figures given in paras 72 and 73. It is furthermore very significant that several countries point to a possible shortage of qualified manpower as an important potential bottleneck. Finally, it is essential for a good co-ordination and integration of the industrial efforts on an international scale to take place in order to utilize existing capacities and experience to maximum extent.

FUTURE CAPITAL INVESTMENT IN NUCLEAR POWER (OECD COUNTRIES)

71. Future capital investment in nuclear power stations and in the corresponding fuel cycle plants is calculated at a specific capital cost for a nuclear station on a turn-key basis of $300 per kWe (1972 US $), and a fuel cycle plant investment of $30/kWe. Interest during construction is estimated to be 30% ($100) of the total investment. Under these assumptions the total specific investment amounts to $430/kWe. In order to calculate annual investment figures, a construction time of 6 years is assumed and as an approximation the total capital is taken to be invested 3 years before the coming into service of the station. Tables XII and XIII contain the so derived annual and cumulative investment figures on a regional basis.

72. These figures, \$303 x 10^9 (437 x 10^9) between now and 1985, and \$667 x 10^9 (10^{12}) between 1985 and 1995, for the total investment in the countries considered in the basic (accelerated) programmes, seem very high in absolute terms. According to the Study Group's enquiry, in some countries (Sweden, Switzerland, U.K., Portugal and Germany) special difficulties in financing their basic programme in the future on the same basis as in the past, are not foreseen. However, some sort of governmental intervention is thought to be beneficial, if competing requirements on the national or international capital markets increased rapidly (Canada, Italy and the Netherlands). In some countries (Canada, U.K. and U.S.) it is proposed that future investment costs should be borne to a greater extent by current electricity prices.

73. In Fig. 12 the capital investment figures have been set in relation to the gross fixed capital formation (GFCF) in the respective countries. While in 1975 and 1980 average nuclear investment corresponds to about 3% of GFCF, a rise to 5% for 1985 and almost 6% for 1990 is observed for the basic programme. With the accelerated programme these figures are still higher, reaching average values of about 7 to 8% in the 1980s. It can also be observed that the figures vary widely from country to country. It is therefore worth considering whether such a significant share of the gross fixed capital formation, as represented by the accelerated programme, can be devoted to investment in nuclear power without causing special problems.

NUCLEAR POWER IN DEVELOPING COUNTRIES

74. Nuclear power will not contribute significantly to the energy base in the developing countries before 1985. The absorptive capacity of these countries is limited by the level of industrial and other economic activity, existence and size of power grids, financing and professional and skilled manpower availability. The IAEA Report: Market Survey For Nuclear Power

In Developing Countries, Sept., 1973, deals comprehensively with this subject. This report was recently updated to reflect the effect of increased oil prices (Lane, J.A., The Impact of Oil Price Increases on the Market for Nuclear Power in Developing Countries, Bulletin, IAEA, 16(1/2), 1974).

75. There is a great potential for reactor manufacturers offering 100-600 MW(e) stations in this market. Canada's CANDU system is ideally suited as it is fueled with natural uranium therefore requiring no enrichment facilities, economics do not necessitate the recovery of unburned uranium so no reprocessing plant is needed and it is available in the desired unit capacities.

76. Any vendor entering the market in the developing countries must appreciate that their governments do not wish to enter into any arrangements which lessen their political autonomy. Dependency on foreign enrichment and reprocessing facilities (developing countries cannot finance these facilities) could be regarded as decreasing political freedom of action. A natural uranium fueled reactor is therefore more acceptable politically.

NUCLEAR ENERGY AND MANPOWER(16)

77. The successful achievement of the world's nuclear energy objectives depends on the availability of manpower to manage, direct and sustain the scientific, technological, and industrial thrust which up to now has produced spectacular results. The field of nuclear energy covers a wide range of science and technology and managerial skills. Rapid expansion of power generation will stimulate growth in all branches of the nuclear field. This will result in a severe strain on manpower resources. Manpower problems are not uncommon in other industries but the wide range of disciplines involved and the demands of safety and reliability emphasize the need for focusing attention on the impact of nuclear energy on manpower resources.

(16) Source: Varughese, J.M., Nuclear Energy and Manpower, Canadian Nuclear Association, 1974.

78. The experience of several major industries shows that critical shortages of managers, senior supervisory personnel, engineers and technicians are likely to occur. Traditional ways of obtaining and managing personnel will have to give way to intensive in-house training and development. A typical training programme for nuclear generating station operators shows the breadth of training, emphasis on safety and reliability, and the long lead time required to develop control room operators. Long-term planning taking into account several factors is essential in order to ensure that the nuclear industry is not short of experienced persons at all levels in future years.

79. The growing concern in the world's industrialized nations about an adequate supply of manpower for planned and necessary expansion will result in fierce competition in the manpower market. Manpower shortage is a serious yet little appreciated problem which will face not only the nuclear industry but all industries, particularly those in the energy sector.

RADIOACTIVE WASTE GENERATION AND MANAGEMENT

80. The prime objective of waste management is to minimize the exposure of the public at large to radiation. Exposure must be kept well within the limits set by the ICRP (International Commission on Radiological Protection) and complementary standards set by other levels of government. Radioactive waste is generated in all phases of the nuclear fuel cycle (Fig. 13)[(17)]. The fuel cycle encompasses the physical and chemical activities necessary

---

(17) Not all reactors employ the same fuel cycle. For example, some HWRs are fuelled with natural uranium requiring no isotopic enrichment, recovery, or recycle of spent fuel. Others use both uranium 235 and plutonium 239 in their cores and FBRs can use U235, Pu239 and U233 as fissile materials. Since the waste products of the fission reaction are similar for all fissile materials, the waste management of the fuel reprocessing steps are similar. Fig. 13 is the fuel cycle associated with the slightly enriched LWR; the predominant system until at least the year 2000.

to produce the fuel for use in the reactor; the operation of the reactor for the production of electricity; and the reprocessing of spent fuel for the recovery of re-usable material.

81. The amount and type of radiation generated in the fuel fabrication and reactor operation phases of the fuel cycle are minimal compared with the reprocessing activities. This is not to say, however, that surveillance and control will be relaxed. Well over 99 per cent of the radioactivity generated in power reactors is retained within the fuel elements until they are reprocessed. Because of this, and the fact that one fuel reprocessing plant may serve a large number of power reactors, it is at this stage of the fuel cycle that long-term management of radioactive waste becomes critically important.

82. The major objective of the high-level waste management programme is to keep the great majority of the potentially dangerous wastes isolated from the public sufficiently long to allow them to lose their activity through decay. The techniques used to accomplish this vary depending on the geological conditions in the various countries where fuel reprocessing is carried out.

83. The major radioactive wastes which have some public health implications and which arise in the course of normal fuel reprocessing operations can be broadly classified according to their physical state and level of radioactivity. The management of these wastes is accomplished by three widely accepted principles:

a. dilute and disperse for low-level liquid and gaseous wastes;

b. delay and decay for intermediate and high level liquid and gaseous wastes, particularly those waste streams that contain short-lived radionuclides; and

c. concentrate and contain the intermediate and high level solid, liquid and gaseous wastes.

84. It is in the storage and disposal of intermediate and high level solid, liquid, and gaseous wastes that no clear policy has been formulated. This is in part due to the variation of geological conditions throughout the world. World attention is being focused on this problem and the prospects for the implementation of storage and disposal techniques are promising. Some of these techniques are illustrated in Fig. 14: The History of a Nuclear Fuel Rod.

85. Presently, intermediate level solid and liquid wastes are treated by insolubilization in asphalt. High level liquid wastes are converted to insoluble solids by high temperature calcination or fusing in glass. Intermediate and high level liquid wastes are also stored in tanks while solid wastes can be deposited in vaults or caverns, or other deep geological formations. The ocean has also been used as a disposal medium. The extent to which oceans and other deep geological formations will be utilized will depend upon both national and international regulations and agreements. A more futuristic proposition for waste management is the transmutation (transformation by neutron bombardment) of radioactive fission products to yield non-radioactive nuclides. The success of this scheme, however, depends on the availability of a surplus supply of neutrons which can be provided only by fusion reactors.

86. In conclusion, suggested ways of disposing of intermediate and high level solid, liquid, and gaseous wastes include solidifying and burying them in salt mines; storing them in guarded, near-surface mausoleums for later retrieval; burying them in Antarctic rocks or permanent ice; pouring them into subterranean caverns and allowing them to melt themselves permanently into rocks. Other possibilities include disposal in the oceans and shooting the wastes into space.

SOME OTHER NUCLEAR ENERGY ROLES

87. Electricity is not the sole end-product envisioned for nuclear power. Other possibilities include:

a. the production of desalinated water;

b. process heat for the production of chemicals, fertilizers, synthetic fuels, etc;

c. high temperature gases for the direct reduction of iron ore; and

d. the production of hydrogen and oxygen by the electrolytic decomposition of water.

88. Nuclear reactors must be used for these applications. In fact, their realization may best be achieved by the construction of nuclear parks called NUPLEXES. These parks would encompass most of the fuel cycle activities (except for U_3O_8 production) and would transmit energy to the centres of consumption via hydrogen. A positive advantage would be that intensely radioactive fission products and plutonium 239 (used in the manufacture of nuclear bombs) would not have to be transported via long distance and would therefore not be vulnerable to clandestine diversion. NUPLEXES could be located in arid regions to provide water for irrigation. Communities could be built around them.

89. Fissile material can also be used in the production of peaceful nuclear explosive devices. Such devices could find application in the release of gas from otherwise difficult sources. The release of oil from tar sands and oil shales could also be accomplished by nuclear stimulation. Construction of canals, deep-water harbours, in-situ combustion of coal, and mining of non-fuel minerals are other applications. However, the number of nuclear explosive devices required to realize these applications may be prohibitive (Ref 33).

REACTOR SAFETY AND SITING

90. Much has been said of the potential danger of nuclear reactors. Armageddon-like scenarios have been depicted wherein nuclear reactors suddenly go out of control and are destroyed by mushroom-cloud explosions. These are gross exaggerations. Fissionable fuel in reactors is arranged in such a way that a nuclear bomb-like explosion could never occur. Fissile fuel has a TNT equivalence of 1,000,000 lbs of TNT for every pound of nuclear fuel when used as a nuclear bomb. In a reactor one pound of nuclear fuel is equivalent to one pound of TNT.

91. The probability of a calamitous nuclear reactor explosion is very remote and has been estimated at one for every one billion years of reactor operation. Considering the benefits to be derived from nuclear power, the damage to life and property resulting from a reactor run-away accident, and the risks associated with other everyday activities, a risk-benefit analysis would quickly reveal that no undue risks need be accrued by the adoption of nuclear power as a source of energy. It is notable that the public at large have not suffered any loss of life through reactor operation and industrial accidents have been far below other industries. No other industry can claim such an enviable record. The nuclear industry has been safety conscious from its inception and has never relaxed its efforts to achieve maximum safety and reliability.

92. The siting of nuclear reactors has also come under attack. Psychologically, people do not like living near a reactor nor to have it placed near or in the centre of densely populated areas. Fear of reactor explosion and release of radioactivity is unfounded. Explosions are extremely rare and the emission of radioactivity from a power reactor over its operating life is less than that one would experience from a high-altitude (30,000 feet) return flight from Toronto to Vancouver. Physical siting concerns are associated with inadequate cooling water supplies and the location

of reactors on earthquake prone faults. The construction of reactors underground and on floating platforms off-shore are possible solutions. The American reactor constructor, Westinghouse, has already entered into a joint-venture to construct an off-shore nuclear power station.

93. Increased standardization of nuclear units and present multiple failure-protection back-up systems will increase even more the already high safety factors in nuclear reactors. A great deal of successful research and development has gone into and continues to be applied to loss of coolant accidents (LOCA) resulting from failures in the emergency core cooling system (ECCS). LOCA is more likely in LWRs which use pressure vessels than HWRs such as CANDU which employ pressure tubes, although in either system the possibility of LOCA is very remote.

THE NON-PROLIFERATION TREATY AND SAFEQUARDS

94. The 1968 Non-Proliferation Treaty was intended to limit the proliferation of nuclear weapons by freezing the number of nuclear weapon nations at five. These nations, which became known as the nuclear club, include the USA, the Soviet Union, Great Britain, France, and the People's Republic of China. The Treaty makes no provision for the limitation or reduction of nuclear arms nor does it guarantee protection against nuclear threat or attack on non-nuclear weapon states. The question of guarantee did receive attention in the UN Security Council but was merely passed as a resolution noting the "intention" of "certain powers" to meet the aid-to-the-victim obligation.

95. The Non-Proliferation Treaty also states: "Each nuclear-weapon state party to this treaty undertakes not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly,

or indirectly and not in any way to assist, encourage, or induce any non-nuclear weapon state to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices."

96. The phrase "other nuclear explosive devices" was inserted in the Treaty because the disarmament conference was aware that certain non-nuclear states wanted to develop such devices for peaceful purposes, such as the excavation of harbours and canals and the recovery of underground fuel - and non-fuel minerals.

97. The Treaty further states that each state party undertakes not to provide:

a. "source or special fissionable material"; or

b. "equipment or material especially designed for the processing of special fissionable material, to any non-nuclear weapon state for peaceful purposes, unless the source or special fissionable material shall be subject to the safeguards required by the Treaty."

98. The safeguards required by the Treaty are outlined in the IAEA(18) document: The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty in the Non-Proliferation of Nuclear Weapons.

99. The world considered the Treaty and its safeguard arrangements as a significant breakthrough in limiting the spread of nuclear weapons and a step towards disarmament and the arrest of the arms race. It was thought that the world would therefore be a more stable and secure place in which to live. Even today some hold the Treaty as the demonstration of good will, a desire for peace, equality, and justice which led

---

(18) IAEA - International Atomic Energy Agency.

to SALT (Strategic Arms Limitation Talks), MBFR (Mutual and Balanced Force Reduction), CSCE (Conference on Security and Cooperation in Europe) and the ABM (Anti-Ballistic Missile) Treaty. This euphoria was soon tarnished as it became evident that not all nations were willing to sign and/or ratify the Treaty.

100. According to the 1973 SIPRI (Stockholm International Peace Research Institute) Yearbook of World Armament and Disarmament, 33 countries will have nuclear power reactors by 1977. Of these, five are nuclear weapon states. Of the remaining 28 states, sixteen have not yet ratified the NPT. Seven of the sixteen states have failed even to sign the Treaty. More than half of the threshold - nuclear-weapon nations that will have nuclear reactors, are keeping open their option for developing nuclear weapons. Notable amongst those nations which have not even signed the Treaty are France, the People's Republic of China (both nuclear weapon states), Saudi Arabia, South Africa, Argentina, and Israel. Those which have signed but not ratified include Japan, the Federal Republic of Germany, the United Arab Republic, South Korea, Italy, Kuwait, and Turkey. Nations which have either signed, ratified or both are listed at Annex A.

101. Various reasons were voiced against becoming party to the Treaty and its safeguard arrangements:

a. inability to freely formulate and pursue national objectives and foreign policy;

b. infringement on national sovereignty arising from safeguard arrangements such as on-site inspection and the provision of nuclear material inventory data to the IAEA or other agencies such as Euratom;

c. lack of guarantee of protection against nuclear threat or attack on non-nuclear weapon states;

d. mistrust of the intentions of nuclear weapon states and the fear of clandestine nuclear weapon programmes in non-nuclear weapon states;

e. the prestige and political influence conferred by the possession or ability to construct nuclear weapons (presently denied to non-nuclear weapon states);

f. the concern of non-nuclear weapon states with the apparent lack of success in limiting strategic arms and arresting advancement in strategic arms technology;

g. the desire to profit from the peaceful uses of nuclear explosive devices; and

h. need for a viable deterrent against superior conventional military forces.

102. Any hope that remained in the spirit of an already emasculated Non-Proliferation Treaty was shattered when a complacent world awoke to the fact that India had exploded a subterranean nuclear device in the Rajasthan desert on the eighteenth of May of this year. The detonation of this 10 to 15 kiloton nuclear device made India the sixth nuclear weapon state. India stated that its explosion was for peaceful purposes and that it intended to explode more such devices so that it could acquire nuclear stimulation technology for the recovery of fuel and non-fuel minerals. Two other factors may, however, be surmised as to her reasons; her political weakness (the international prestige conferred by being a nuclear weapon state could have advantageous and stabilizing domestic political results) and the growth of China's nuclear programme. Recent reports from India indicate that she may even develop a hydrogen weapon. This development confirms beyond a doubt that the NPT circle has been totally broken.

103. "While the NPT is very specific about excluding the making of any nuclear device as a part of peaceful application of nuclear energy, existing IAEA safeguard agreements are vague enough not to exclude the making of peaceful nuclear devices. In fact a non-NPT country could conceivably make a peaceful nuclear device within the safeguard agreements and with the knowledge of the IAEA. To accomplish this, the country would only have to notify the IAEA ahead of time that it planned to divert certain spent fuel containing plutonium to make a "peaceful" nuclear device. All the IAEA could require would be inspections of the diverted material and the nuclear device."(19) Although Canada had specified in its bilateral agreement of 1956(20) with India that nuclear material could be used for "peaceful purposes" only, India's interpretation of these words did not exclude the construction of peaceful nuclear explosive devices. Canada's plans to construct nuclear reactors in Argentina and South Korea, both non-NPT countries, must now be re-examined. The rhetoric exercised by India demonstrates the frailty of any such bilateral agreement of the NPT if countries are intent upon developing a nuclear device capability.

104. Nuclear weapon or explosive device technology is no longer the secret possessed only by a few states. The information is available in unclassified form. In addition the nuclear material (enriched uranium and plutonium 239) needed for the construction of nuclear weapons is becoming more readily available and increasingly so as nuclear power production expands on a world basis. Nuclear weapons are constructed of either

---

(19) Source: Weekly Energy Report, June 10, 1974

(20) No international machinery to limit the proliferation of nuclear weapons nor complimentary safeguard arrangements existed in 1956. Any such agreements were necessarily of a bilateral nature.

highly enriched uranium (at least 95% U235) or plutonium 239. The enrichment facilities required to amass enough U235 put this beyond the reach of most non-nuclear weapon states. However, the acquisition of Pu 239 from spent reactor fuel rods or clandestine diversion is not so impossible.

105. Only 5 to 10 kilograms of Pu 239 are required to construct a weapon with an explosive power equivalent to 20 kilotons of TNT. The Nagasaki and Hiroshima bombs were of the 20 kiloton range. India, for example, has been able to produce about 100 kilograms of safeguard-free plutonium from its CIRRUS reactor. Even if safeguards could be stringently exercised (and the political will would have to exist to achieve this), plutonium losses in the reprocessing of spent reactor fuel(21) of the order of less than 0.2 to 0.5% would be almost technologically impossible to recognize. Considering the global commitment to nuclear power production, the difference between 0.2 and 0.5% for an estimated plutonium production of about 750 tons by the year 2000 would be enough to construct nearly 350 Nagasaki-size weapons. Table XV lists rough projections of plutonium production capacities for non-nuclear weapon states during the period 1975-1980. The impact of process losses is alarmingly evident. It would be difficult to determine if any of these process losses were clandestinely diverted to nuclear weapon programmes.

106. Plutonium inventory discrepancies already exist. The size of these discrepancies, MUF (material unaccounted for), is not known but there is good reason to believe it is significant. Material diversion could occur at the reprocessing plants or during transportation to and from the reprocessing plants. Thus any non-nuclear weapon nation or, for that matter, extremist/ terrorist groups intent on blackmail could proceed with the construction of nuclear weapons.

---

(21) Plutonium 239 is a by-product of nuclear reactors and is present in spent reactor fuel. Large quantities of Pu 239 will also be produced in breeder reactors.

107. Special attention has been focused on the diversion/theft dilemma in the USA. Both the GAO (General Accounting Office) and USAEC's (United States Atomic Energy Commission) Directorate of Licensing have pointed out weaknesses and improvements in the method of safeguarding nuclear materials. A report prepared by the USAEC's Directorate of Licensing and released late in April by Sen. Abraham Ribicoff (D. Conn.)[22] suggests that "the concept of a periodic measure of material balance around large flows and inventories in the current concepts of MUF and LEMUF[23] be abandoned as a basis for safeguards". The report advocates:

a. adoption of philosophy of "double contingency in measurement", with two independent individuals making redundant measurements;

b. The consideration of safeguards as an organization function, with safeguard activity as the "primary activity", if not the sole activity, "of at least one organizational position of authority in all groups which are involved in SNM (special nuclear materials), etc.

108. The recommendations of the report are extensive and also include the development of plausible diversion scenarios and periodic exercises by say the CIA and FBI to test the vulnerability of fuel cycle activities and the efficacy of response to such diversion.

---

(22) Chairman of the Subcommittee on Executive Reorganization, Senate Committee on Government Operations.

(23) Limit of error in material unaccounted for.

109. The GAO and the USAEC consider that the potential harm to the public from an illicit nuclear weapon is greater than any plausible power plant accident and that regulations to prevent such illicit acquisition are "entirely inadequate to meet the threat".

110. Thus the world has a right to be anxious about the dangerous consequences of an expanded civilian nuclear power programme. Since India's detonation on the eighteenth of May only several months have passed. During that short period of time the United States has offered reactors to Israel and Egypt (two traditionally hostile nations separated only by a tenuous cease-fire agreement and hopes of settlement at a yet-to-be-convened Geneva peace conference), India has indicated it would exchange nuclear know-how with Argentina (both are non-NPT nations), and Iran has sealed an agreement with France to exchange reactors for oil (The Shah has both announced and denied an intention to build nuclear weapons).[24]

111. It is a disquieting world in which we live. Dr. K. Subrahmanyan, director of the Institute for Defence Studies and Analysis in New Delhi, has argued that the proliferation of nuclear weapons may have positive effects on the international system by reducing the political and military advantage conferred by the possession of nuclear weapons. It might be that the US offered both Egypt and Israel nuclear aid to preempt any overtures by India.

112. Perhaps the only solution to iron-clad safeguards is that a nuclear weapon state with sufficient political, economic, diplomatic and military leverage to enforce safeguards and the

---

(24) That such an intention should even by denied by the Shah who has both signed and ratified the NPT certainly puts the last nail in the NPT coffin.

spirit of the NPT be allowed to participate in international nuclear technology agreements. Only the USA is capable of assuming that role. Neither the USSR, Japan, the UK or France have the industrial base or leverage to do this. While the USSR in particular may not enjoy the prospect of a US reactor monopoly in the world, its interests in keeping the nuclear club from expanding further may force it to accept this situation.

113. The US could exact that any nation not already possessing nuclear technology receiving such aid, ship spent reactor fuel rods to American reprocessing facilities. Reprocessed fuel and core re-loads would be provided as sealed fuel rods.

114. Another solution would be to locate both the reactor and fuel cycle activities such as enrichment and reprocessing in one central location such as a "nuclear park". Inventory control would be more effective and there would be no need to transport spent and reprocessed fuel over long distances. The transportation of such fuel is highly vulnerable to malevolent diversion.

115. Although the preceding discussion paints a picture of gloom for the nuclear industry, the expansion of nuclear power need not be retarded or arrested if effective methods of nuclear weapon material management are instituted on national and international levels. It must be noted, however, that this will not be an easy task.

TERRORISM AND NUCLEAR ENERGY

116. In addition to the diversion of nuclear weapon material for the construction of bombs, terrorist or extremist groups could sabotage nuclear power stations. They could also exercise blackmail by threatening such action or by diversion of radioactive wastes and other radioactive isotopes. Intelligence about the activities of these groups must be extensive and always current.

CONCLUSIONS

117. The use of the oil weapon as a political instrument during the Yom Kippur War of October last demonstrated the vulnerability of the industrialized nations to Middle East oil import dependency. Of all alternative energy sources, nuclear energy because of its advanced technology and industrial base, offers the most promise for reducing this dependency during the next twenty-five years.

118. Presently, the atom accounts for only one per cent of annual global energy consumption. It is unlikely that its contribution will be very substantial before 1985. By the year 2000, however, nuclear energy will provide about twenty-five per cent of the global energy requirements. Most of this will be in the industrialized nations.

119. Nuclear power reactors will be used mainly to produce electricity. Reactors could also find application in the production of:

a. desalinated water;

b. hydrogen (and oxygen) for the "hydrogen economy";

c. process heat for the direct reduction of iron ore;

d. synthetic hydrocarbon fuels; and

e. other chemicals including fertilizers via indirect processes.

120. There are a number of factors, however, which could retard the projected expansion of nuclear power programmes. Sound policies must be established and decisive action exercised now

by both government and the private sector if the role anticipated for nuclear power is to be realized. These factors are:

a. possible uranium shortages at the turn of the decade due to lack of incentives to increase the rate of exploration;

b. impending shortages in uranium production capacity and separative work (enrichment) capacities (both likely in the early eighties); and

c. insufficient availability of trained professional, skilled and semi-skilled manpower.

121. Governments at both the national and international level must improve safeguard arrangements and must, in addition, exact more stringent adherence to improved safeguards. If the question of safeguards is not more realistically and effectively addressed nuclear weapon material could find its way into the hands of extremist groups intent on blackmail and could increase the number of nations having a nuclear arsenal. Perhaps only countries with substantial political, economic, diplomatic, and military leverage should be permitted to sell reactors on the international market.

122. Radioactive waste management, reactor safety and siting, and regulatory processes should be effective in providing protection to the public at large. They should not impede the orderly and timely introduction of nuclear power. It appears that responsible and intelligent progress is being realized in these areas.

123. It is encouraging to note that the major sources of uranium ore for the western world are located in countries with stable, predictable and pro-Western governments. Fuel for the reactors of industrialized nations should therefore be politically secure.

124. Fast breeder reactors and fusion in particular are not expected to contribute significantly before 2000 A.D. Thermal spectrum reactors will provide the major portion of nuclear capacity until the year 2000.

REFERENCES

1. Merlin, H.B., Uranium - Corridor to the Future, Presentation to Annual Meeting of Eastern Ontario Association of Municipal Electrical Utilities, Oshawa, April 24, 1974, Department of Energy, Mines and Resources, Ottawa.

2. OECD/IAEA Report: Uranium Resources, Production and Demand, OECD, 1973.

3. Runnals, O.J.C., The Changing Role for Nuclear Fuels, CNA '73-604, Department of Energy, Mines, and Resources, Ottawa.

4. WASH-1139(74), Nuclear Power Growth 1974-2000, USAEC, February, 1974.

5. Uranium and the Balance of Power, World Minerals and Metals, 7, pp 15-21, May/June, 1972.

6. OECD/NEA, SEN/NELT(74)1, Paris, 11 February, 1974.

7. The National Energy Outlook, Shell (Houston), March, 1973.

8. Market Survey for Nuclear Power In Developing Countries. General Report, IAEA, September, 1973.

9. Bulletin, IAEA, 16(1/2), 1974.

10. Nuclear Power and the Environment, IAEA, 1973.

11. Nuclear Engineering International, 19(217), June, 1974.

12. WASH-1130 (Revised), Utility Staffing and Training For Nuclear Power, USAEC June, 1973.

13. DRAES 190-1 (D Strat A), Report: Canadian Nuclear Association Fourteenth Annual International Conference, 9-12 June, 1974, Montreal, 18 June, 1974.

14. Varughese, J.M., Nuclear Energy and Manpower, CNA-74-502, Ontario Hydro, Rolphton, Ontario.

15. Nellestyn, A., Les Perspectives Nucléaires et la Crise de l'Energie, Canadian Defence Quarterly, 3(3), Winter 1973/74.

16 Gilchrist, W., Uranium and Thorium Resources, Nuclear News, October 15, 1971.

17. The World Market for Commercial Nuclear Power Plant, Nuclear Engineering International, September, 1973.

18. Merlin, H.B., Nuclear Energy, Its Growth and Impact, 71-CNA-301, Canadian Nuclear Association, 11th Annual International Conference, Montreal, 1971.

19. The Economist, Uranium, p. 113, April 27, 1974.

20. Energy Facts, Prepared for the Subcommittee On Energy of the Committee on Science and Astronautics, U.S. House of Representatives, Ninety-Third Congress, First Session by the Science Policy Research Division, Congressional Research Service, Library of Congress, Serial H, November, 1973.

21. Department of Energy, Mines and Resources, An Energy Policy for Canada, Phase 1, Ottawa, 1973.

22. Advisory Committee on Energy, Energy in Ontario: The Outlook and Policy Implications, Queen's Park, 1972.

23. Uranium Enrichment: A Report of a Ad Hoc Forum Policy Committee, Atomic Industrial Forum, 1972.

24. A Study of Uranium Enrichment in Canada, The Great Plains Project, Toronto, 1972.

25. ORO-735, New Enrichment Plant Scheduling, USAEC, November, 1973.

26. Weil, G.L., Nuclear Energy: Promises, Promises, Washington, D.C., April, 1973.

27. Deutsch, R.W., Nuclear Manpower Crisis Ahead, Nuclear News, 17(8), June, 1974.

28. Wilson, E.W., Engineering Manpower Needs: A Survey, Nuclear News, 17(8), June, 1974.

29. Scientific American, Energy and Power, September, 1971.

30. The Annals of the American Academy of Political and Social Science, The Energy Crisis: Reality or Myth, November, 1973.

31. The Energy Crisis, Bulletin of the Atomic Scientists, July, 1972.

32. Huss, K.P., Knorr, K, Morgenstern, O., Long Term Projections of Political and Military Power, Mathematics, Inc., January, 1973.

33. Willrich, M., Global Politics of Nuclear Energy, Praeger Publishers, New York, 1971.

34. The Structure and Context of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, IAEA.

35. Krieger, W., The Serious Implications of Widespread Nuclear Power Development, Science Forum, 39, June, 1974.

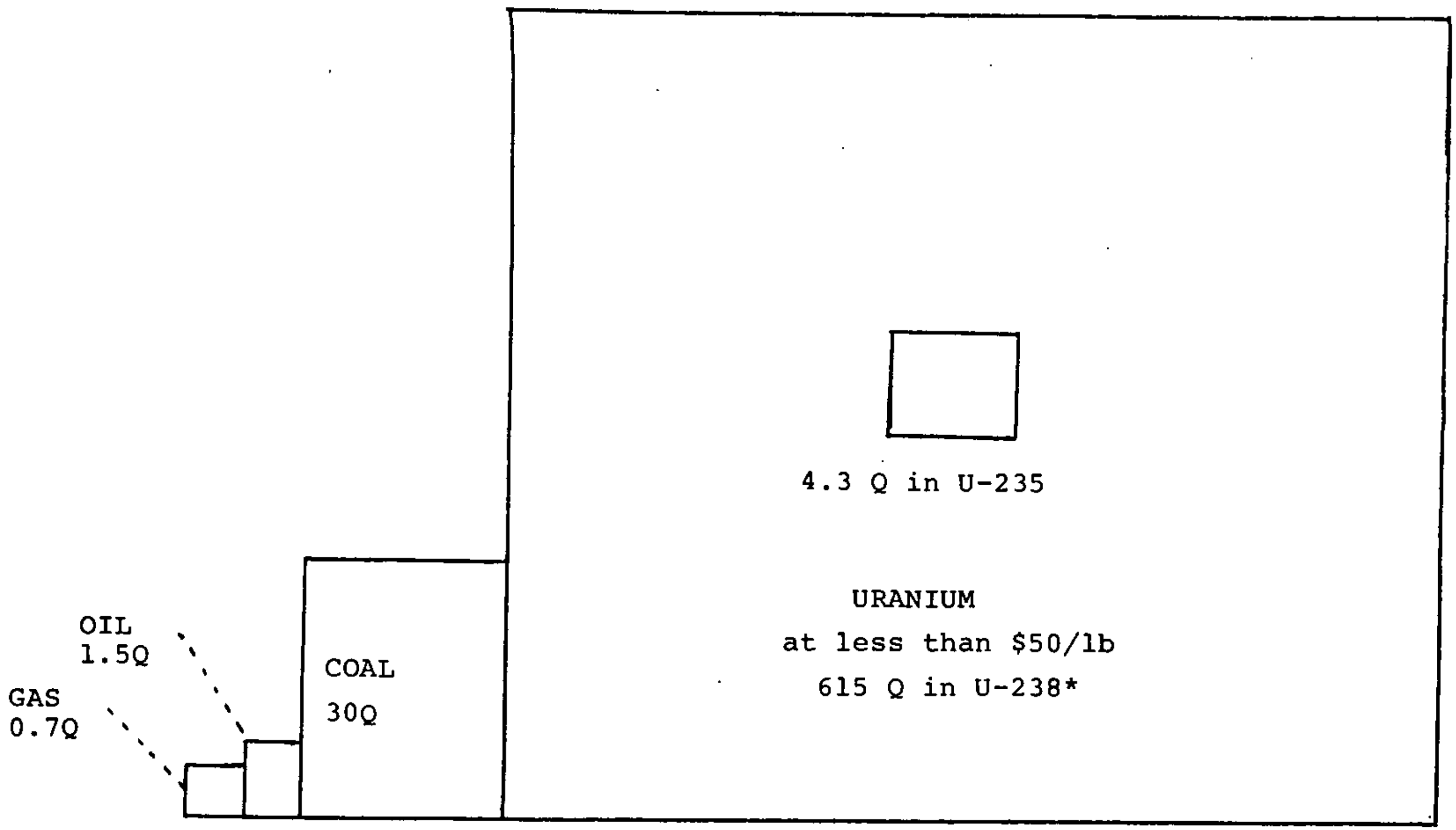
36. Solem, K.E., Safeguarding The International Atom: Some Conclusions and Suggestions Regarding Political and Scientific Effectiveness In Nuclear Management Control, Private Communications.

37. Division of Compliance U.S. Atomic Energy Commission, Report on Releases of Radioactivity From Power Reactors In Effluents During 1970, October, 1971.

38. Kubo, A.S., Rose, D.J., Disposal of Nuclear Wastes, Science, 182(4118), December, 1973.

39. Lewis, W.B., Radioactive Waste Management in the Long Term, DM-123, Fourth Draft, 1972, AECL/CRNL.

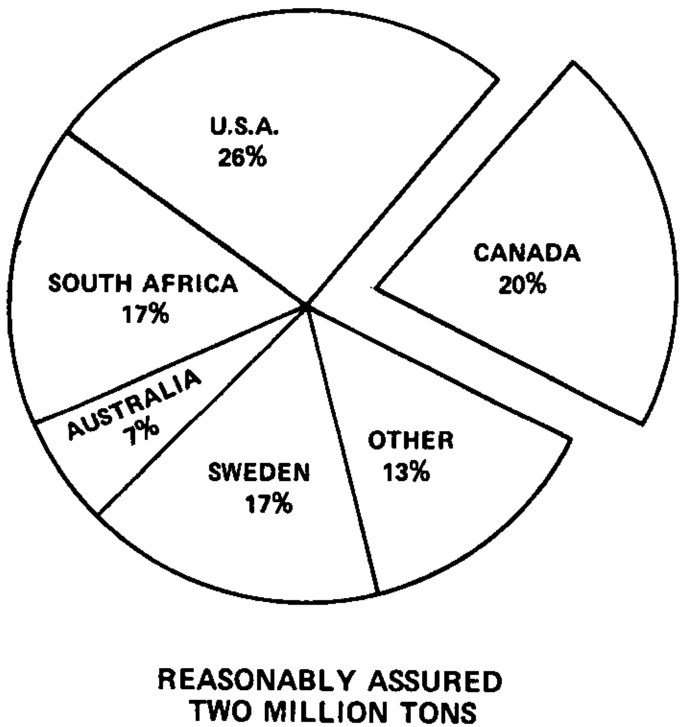
40. SIPRI (Stockholm International Peace Research Institute) Yearbook of World Armaments and Disarmament, 1973, SIPRI, Stockholm, Sweden.



* U-238 energy available when transformed into plutonium in breeder reactors

U.S. energy resources (1 Q = 10^{18} Btu)

FIGURE 1 - US Energy Resources



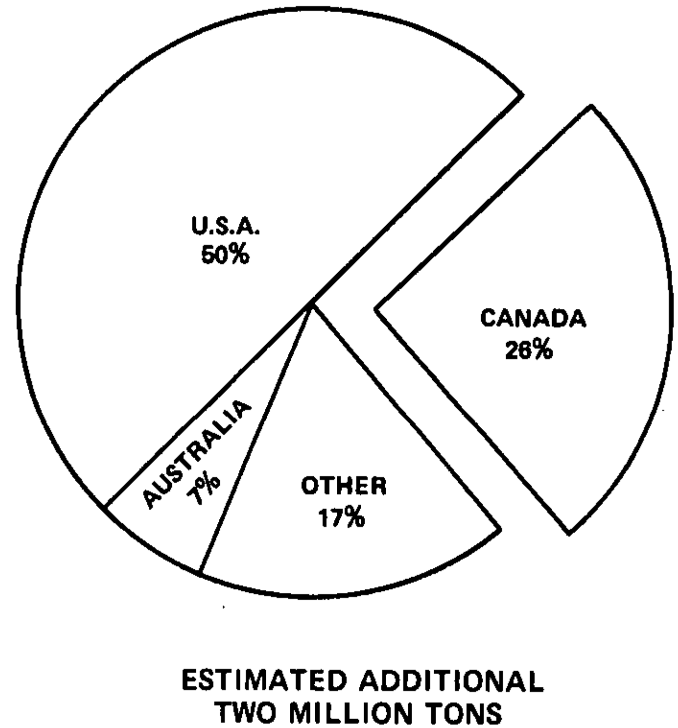
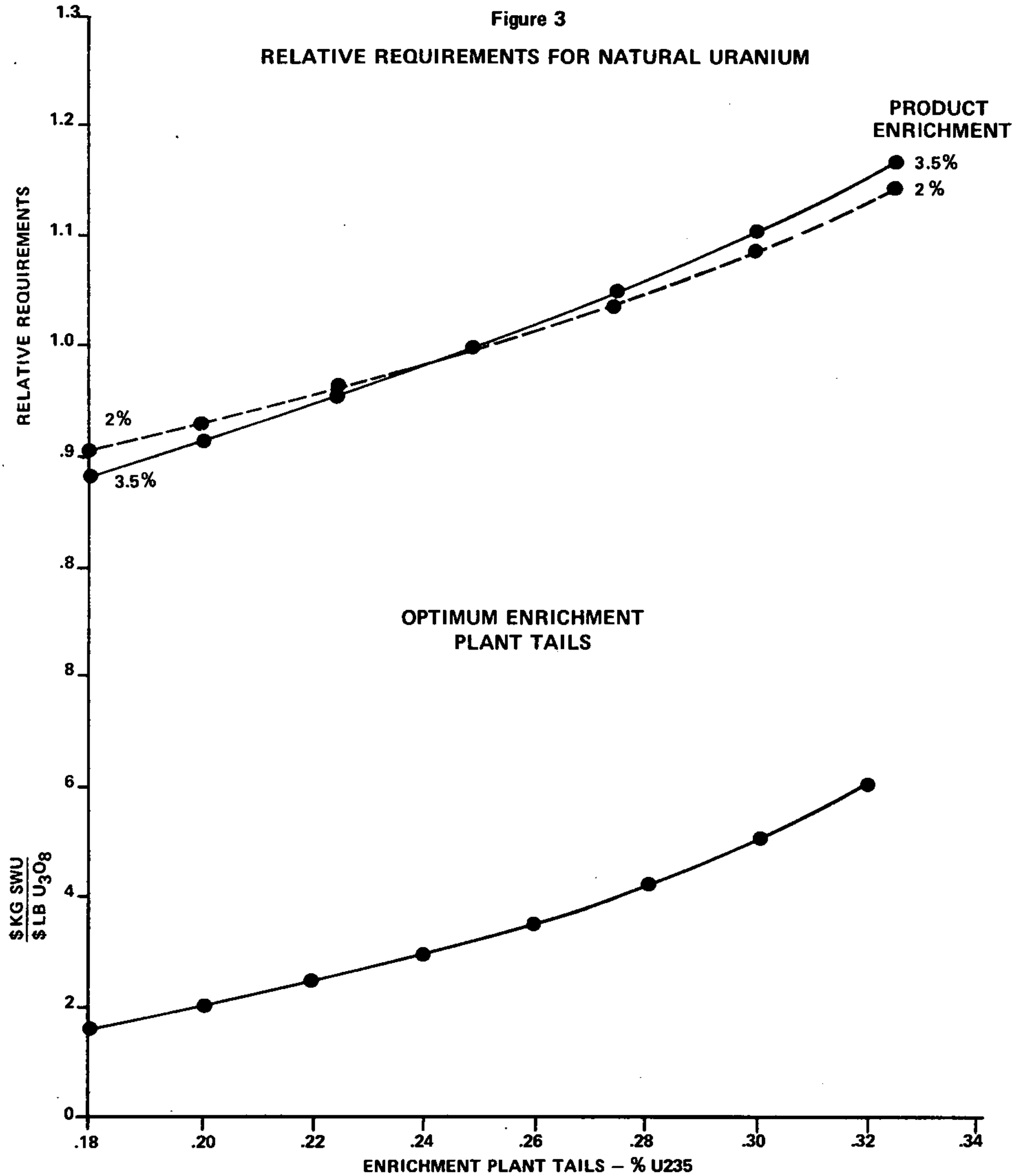


FIGURE 2 – URANIUM RESOURCES UNDER \$15/LB U_3O_8

Source: Ref 1

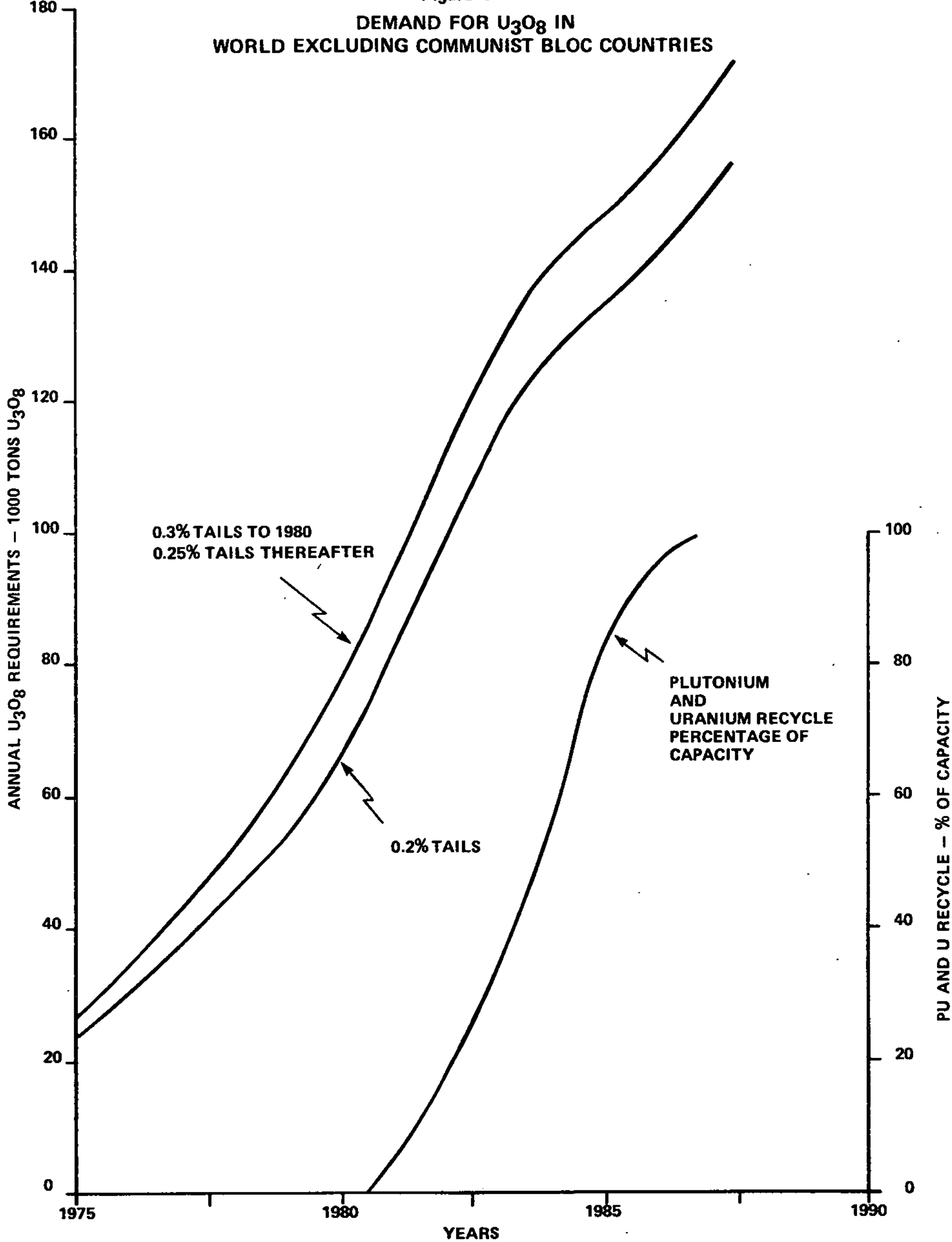
Figure 3

RELATIVE REQUIREMENTS FOR NATURAL URANIUM



Source: Ref 1

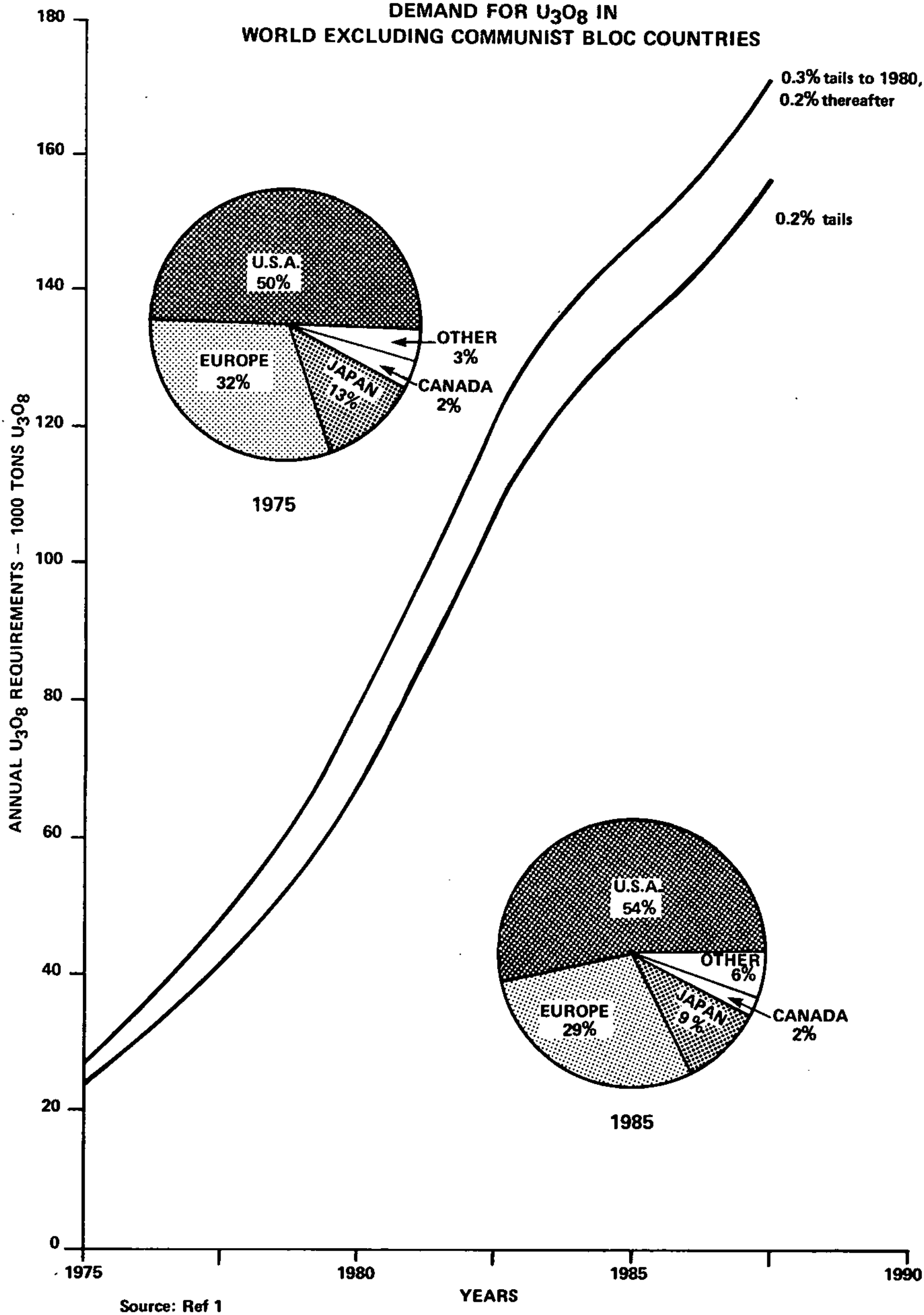
Figure 4



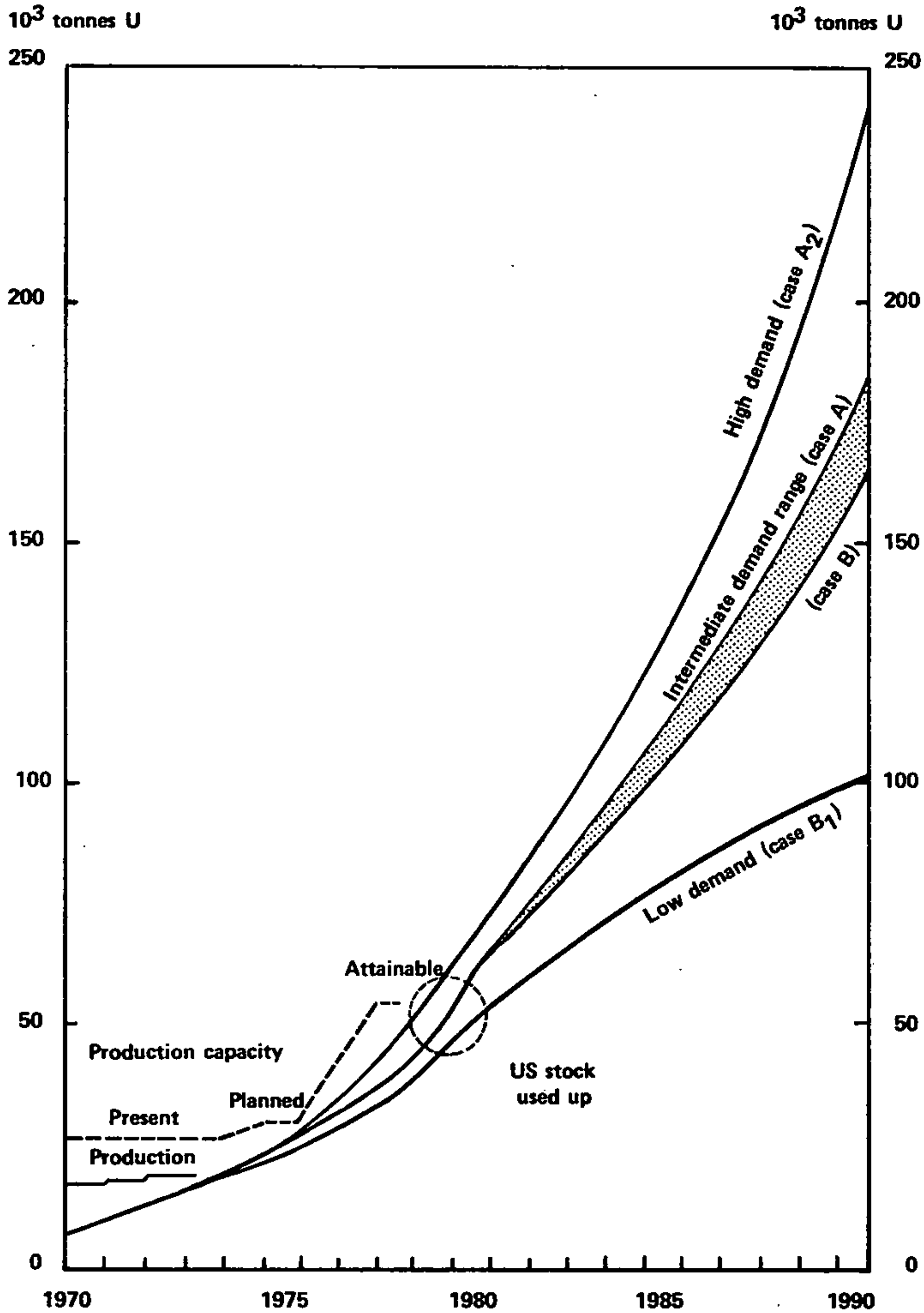
Source: Ref 1

Figure 5

DEMAND FOR U_3O_8 IN WORLD EXCLUDING COMMUNIST BLOC COUNTRIES



Source: Ref 1



Assuming recycling of plutonium in LWRs: the use of a US stock of 38,500 tonnes U to enable the existing US enrichment plants to be operated at a tails assay of 0.30% U 235 up to 1980, despite the continuing national use of a tails assay of 0.20% U 235 in all contracts for USAEC enrichment services; and the operation of all enrichment plants after 1980 at a tails assay of 0.275% U 235.

For details see Part III, 2 and Table 7.

Figure 6
ANNUAL WORLD URANIUM REQUIREMENTS

Source: Ref 2

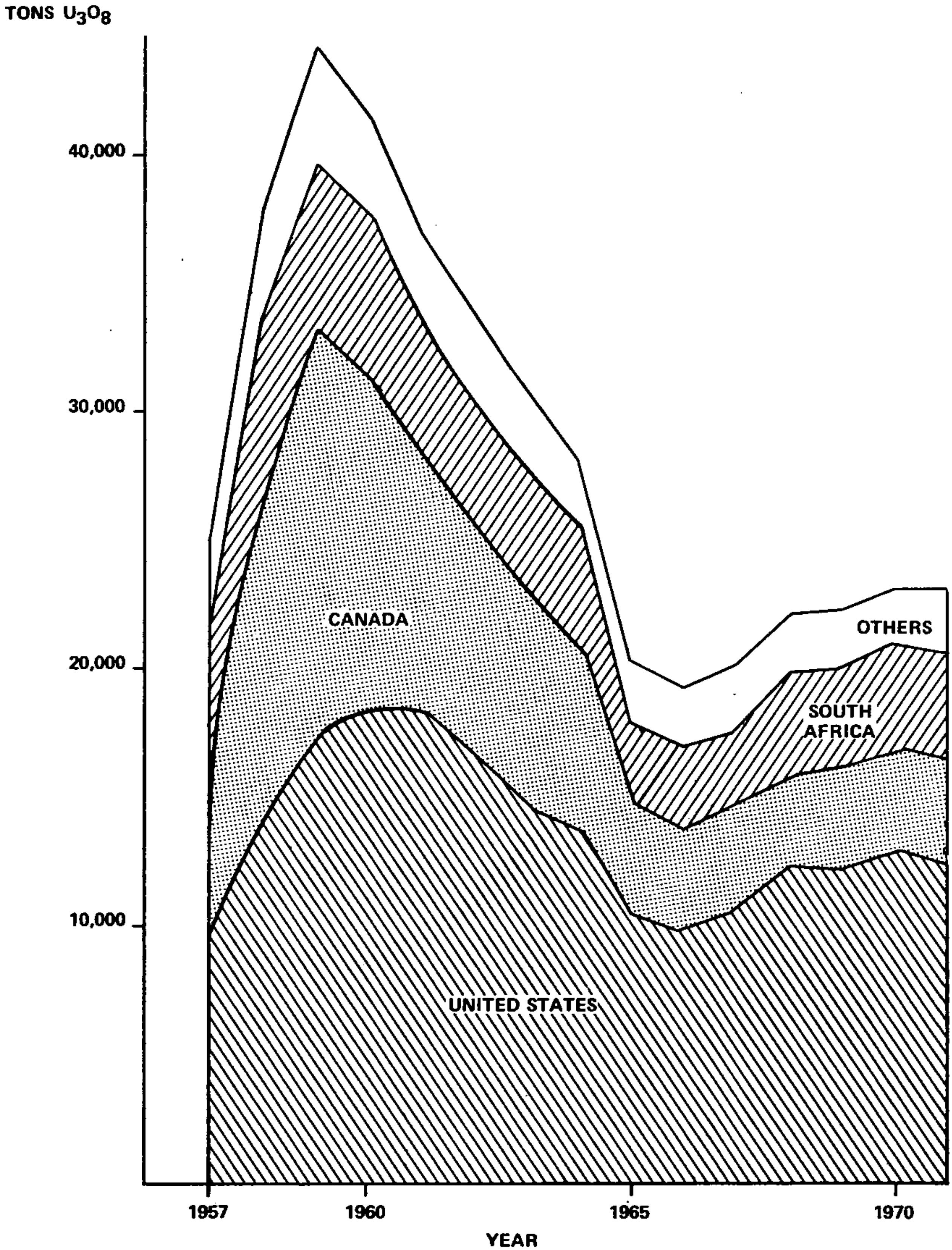
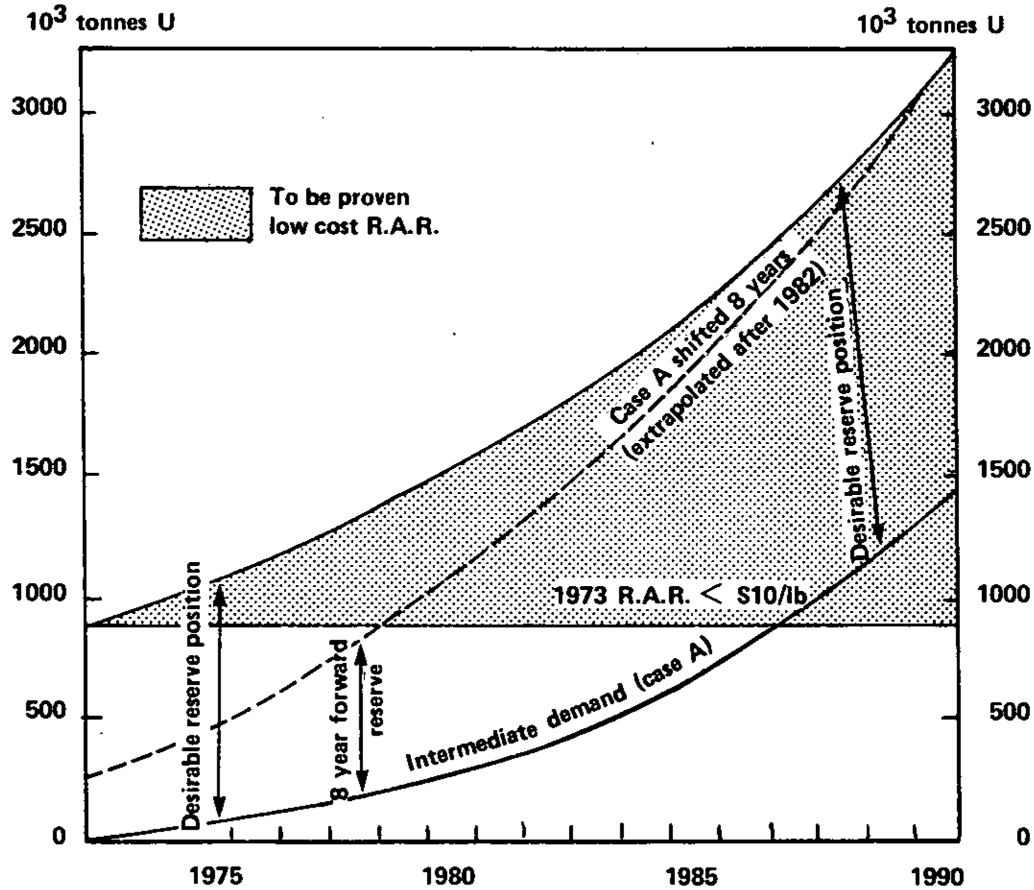


Figure 7
ANNUAL WESTERN WORLD U_3O_8 PRODUCTION, 1957–1971

Source: Ref 3



For more details see Figure 4 and Part III, 2.

Assuming recycling of plutonium in LWRs: the use of a US stock of 38,500 tonnes U to enable the existing US enrichment plants to be operated at a tails assay of 0.30% U 235 up to 1980, despite the continuing national use of a tails assay of 0.20% U 235 in all contracts for USAEC enrichment services: and the operation of all enrichment plants after 1980 at a tails assay of 0.275% U 235.

Figure 8

RELATIONSHIP BETWEEN URANIUM RESERVES AND CUMULATIVE REQUIREMENTS

Source: Ref 2

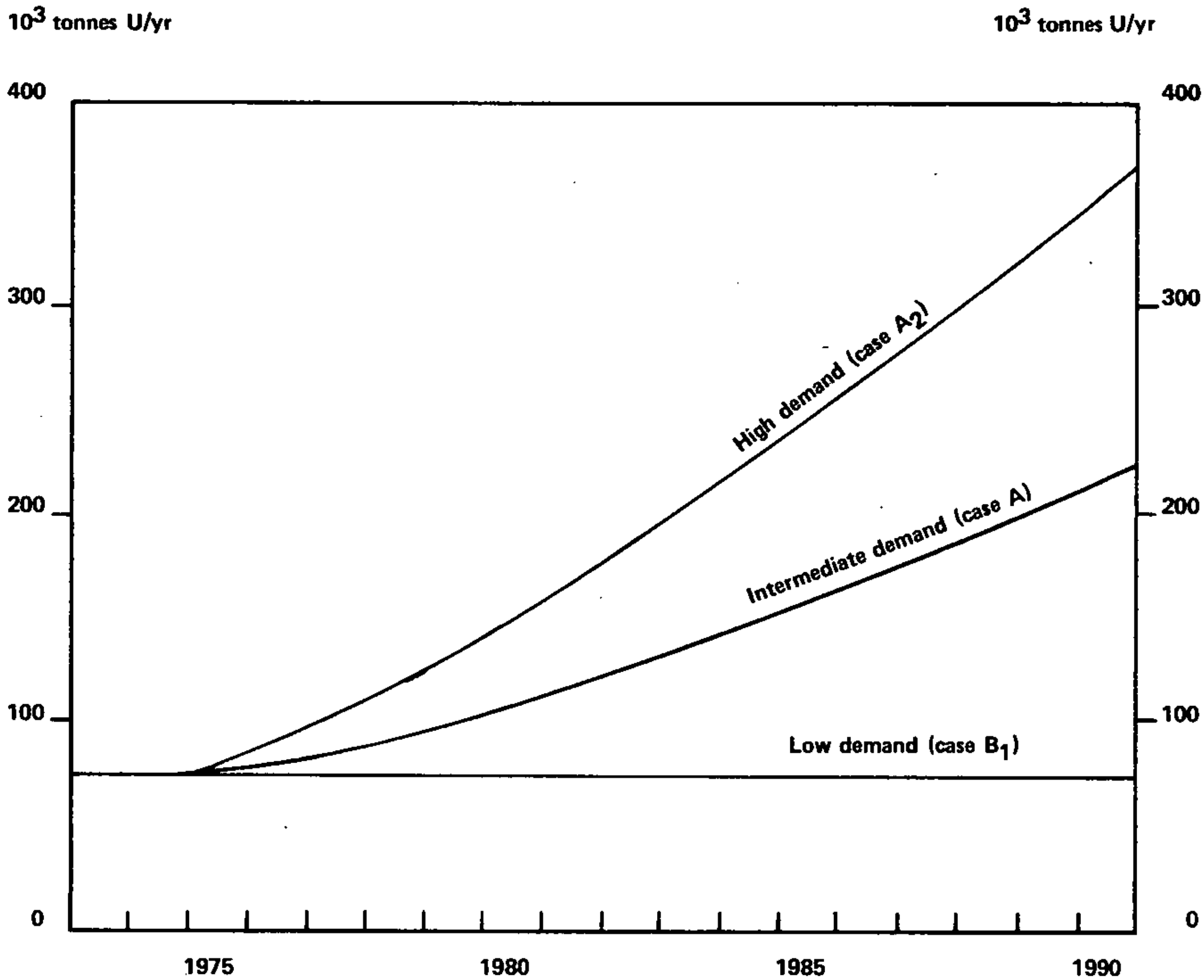


Figure 9

DESIRABLE DISCOVERY RATE FOR LOW COST R.A.R.
TO MAINTAIN AN EIGHT-YEAR FORWARD RESERVE

Source: Ref 2

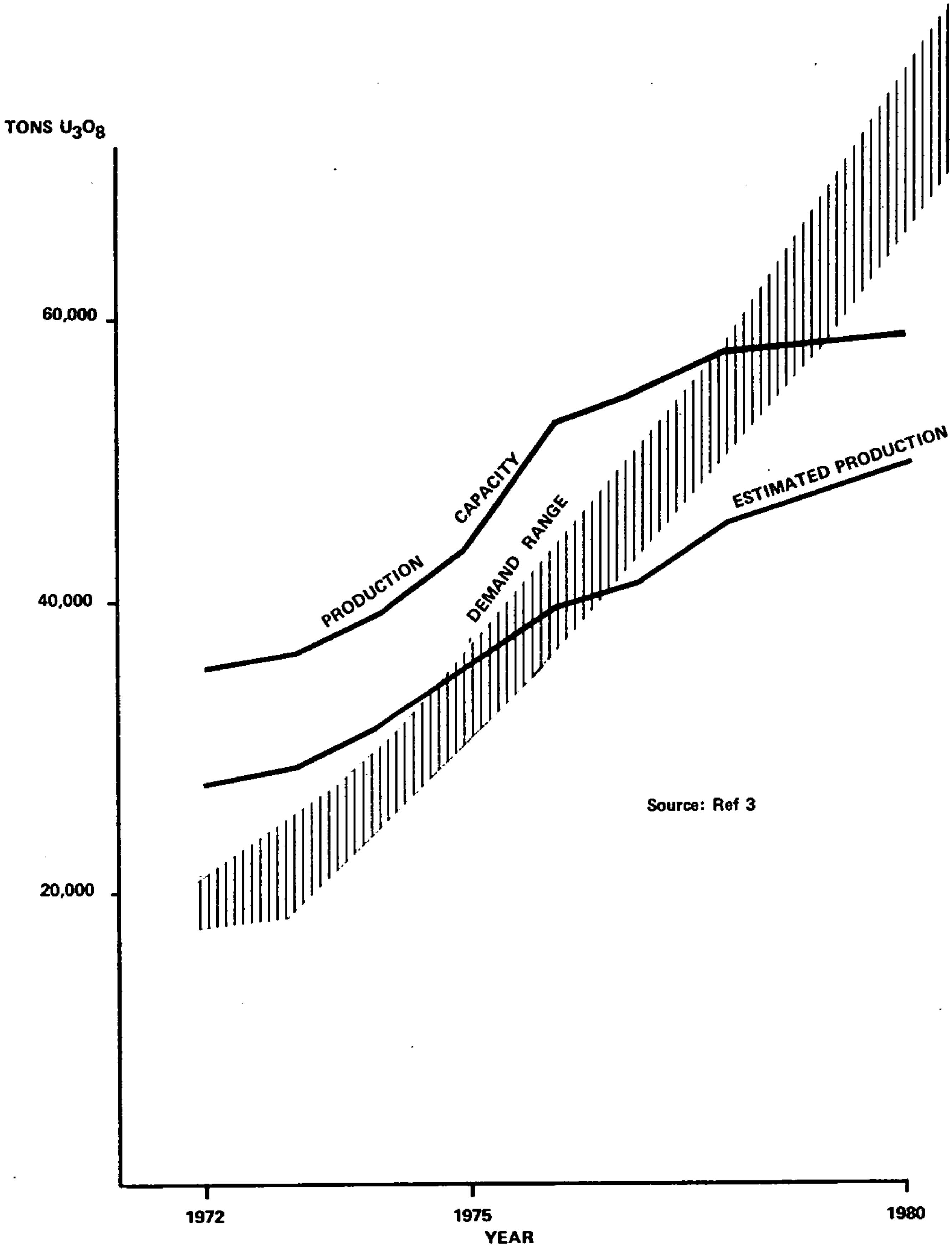


Figure 10

ANNUAL WESTERN WORLD U_3O_8 PRODUCTION VERSUS DEMAND, 1972–1980

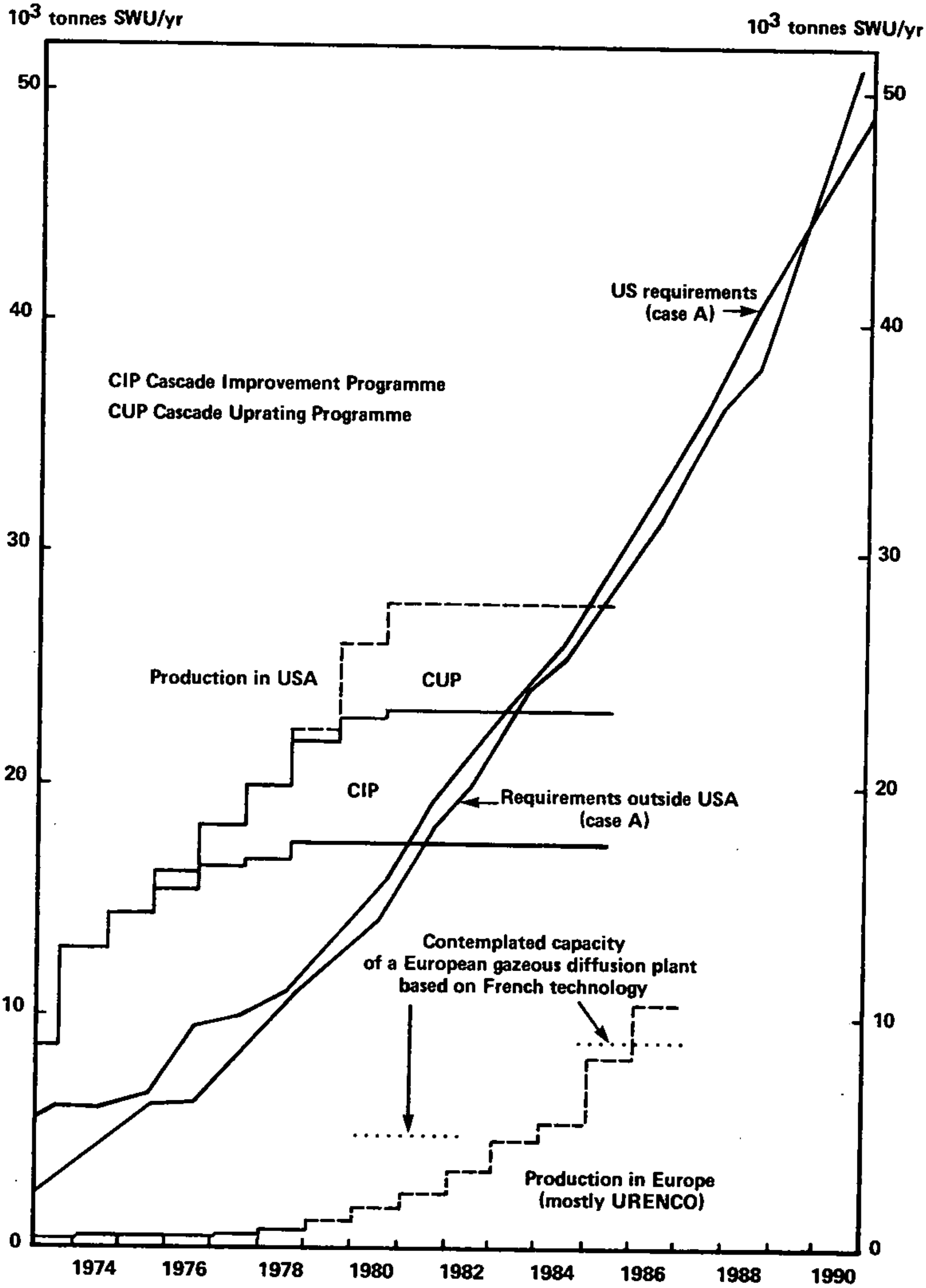


Figure 11 – Annual Separative Work Requirements and Production (0.275% tails Assay Pu Recycling)

Source: Ref 2

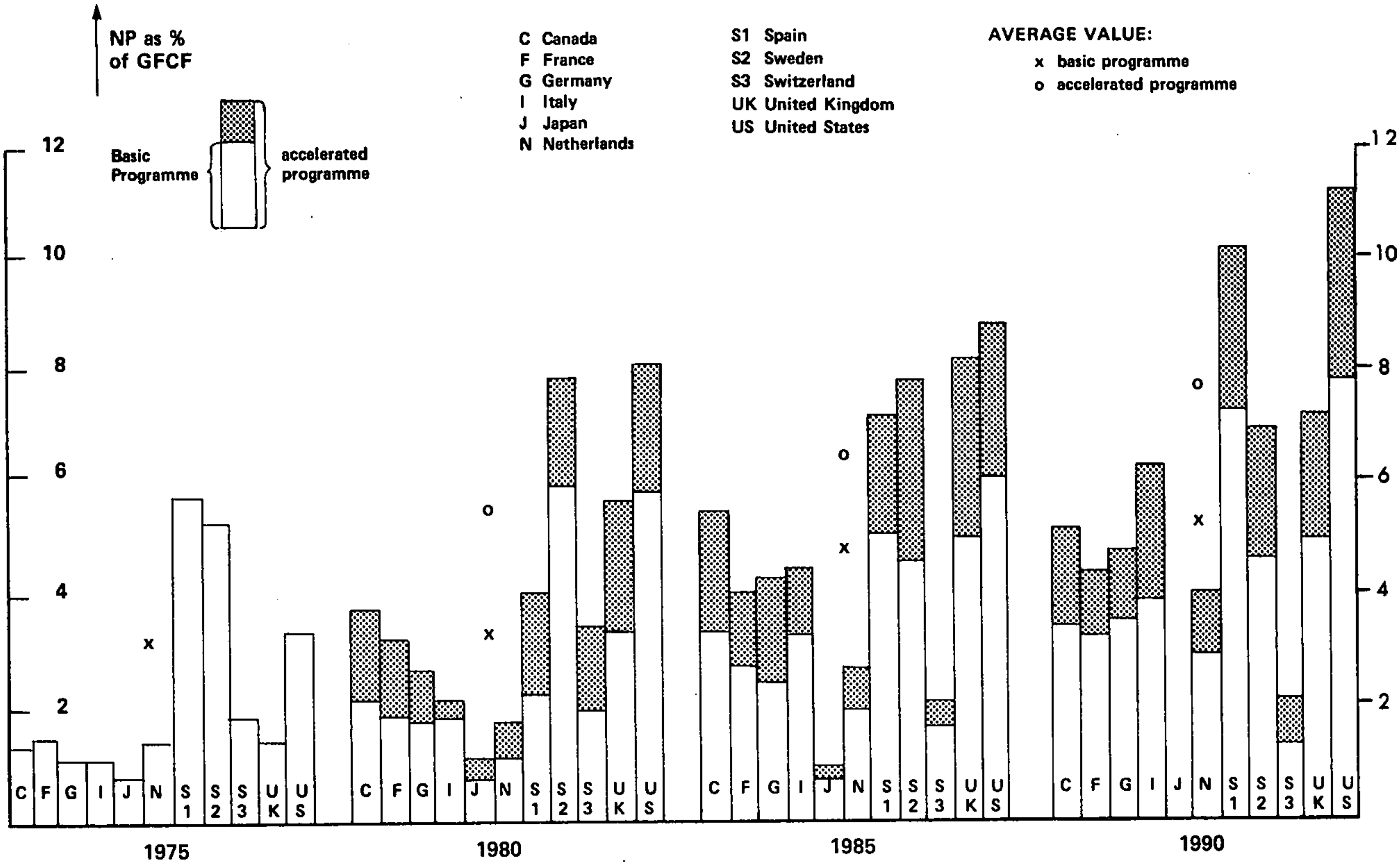


Figure 12 – INVESTMENT IN NUCLEAR POWER (NP) RELATED TO GROSS FIXED CAPITAL FORMATION (GFCF)

Source: Ref 6

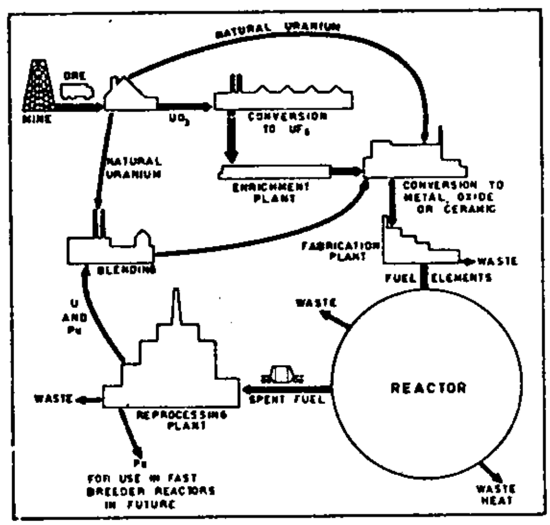


FIGURE 13 - The Nuclear Fuel Cycle

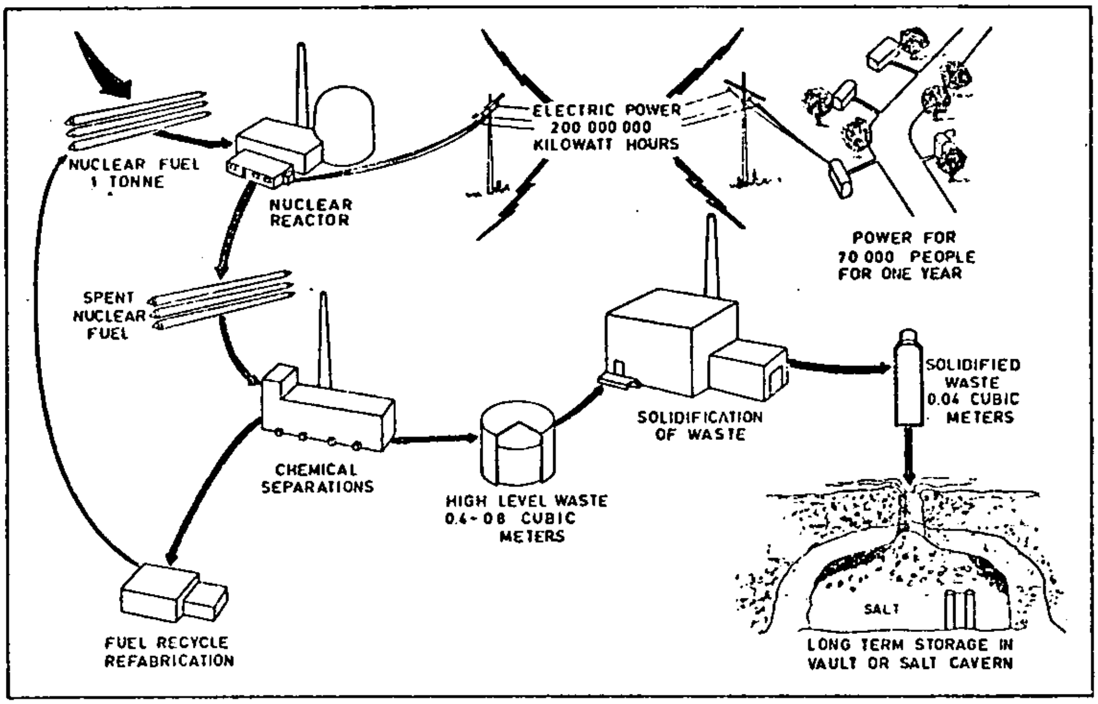


FIGURE 14 - The History Of A Nuclear Fuel Rod

TABLE I

Nuclear Electrical Capacity
(Thousands of Megawatts at End of Calendar Year)

February 1974 Forecast					WASH-1139(72)				
United States Case	**1980**	**1985**	**1990**	**2000**		**1980**	**1985**	**1990**	**2000**
A	85	231	410	850	Low	127	256	412	825
B	102	260	500	1200	Most Likely	132	280	508	1200
C	112	275	575	1400	High	144	332	602	1500
D	102	250	475	1090					
Foreign Case									
X	113	290	640	1600	* Low	143	312	600	1635
Y	140	387	780	2130	* Most Likely	161	359	724	2060
Z	157	420	900	2550	* High	173	414	850	2500

* Excludes Peoples Republic of China.

Source: Ref 4

NOTE: See para 29 for explanation of Cases A, B, C, D, X, Y, and Z; capacity factor of 75% for all types of reactors

TABLE II

WORLD NUCLEAR POWER GROWTH +

Installed Nuclear Capacity in GWe (net) at end of each year

Countries	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1985	1990
Austria							0.7	0.7	0.7	1.4	1.4	3	6
Belgium				0.4	1.3	1.7	1.7	1.7	2.3	2.3	3.0	5.5	10
Denmark											0.7	1.5	4
Finland							0.4	0.4	0.4	0.8	1.3	4.6	8
France	1.5	2.4	2.6	2.8	3.2	3.8	4.4	6.8	8.9	10.7	13.4	32.5	67
Germany	0.8	0.8	2.1	2.1	4.9	4.9	9.3	11.5	13.5	16.0	19.0	38	75
Greece											0.7	1.5	3
Italy	0.6	0.6	0.6	0.6	0.6	1.5	1.5	1.5	2.5	3.5	6.0	18	44
Netherlands				0.5	0.5	0.5	0.5	0.5	1.1	1.1	1.7	3.7	8
Norway											1.0	2	4
Portugal												2	3
Spain	0.1	0.6	1.1	1.1	1.1	1.1	2.5	4.2	6.0	6.0	8.0	12	24
Sweden		0.4	0.4	0.4	2.6	3.2	3.2	4.1	5.0	6.8	8.3	16	24
Switzerland	0.4	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.9	1.9	2.6	8	16
Turkey											0.4	1	2
United Kingdom	3.4	4.3	4.5	7.0	7.6	8.8	10.7	11.3	11.3	12.5	13.8	35	75
TOTAL EEC	6.3	8.1	9.8	13.4	18.1	21.2	28.1	33.3	39.6	46.1	57.6	134	283
TOTAL OECD EUROPE	6.8	9.8	12.3	15.9	22.8	26.5	35.9	43.7	53.6	63.0	81.3	184	373
Australia									0.5	0.5	1.0	3	6
Canada	0.2	1.2	2.0	2.5	2.5	2.5	3.3	4.0	4.8	5.5	6.5	15	31
Japan	1.3	1.3	1.8	3.1	5.2	8.6	12.6	17.3	20.6	24.5	32	60	100
U.S.A.	5.2	11.8	15	28.9	42.3	54.2	61.2	69.3	86.7	103.3	132	280	508
TOTAL OECD	13.5	24.1	31.1	50.4	72.8	91.8	113.0	134.3	166.2	196.8	252.8	542	1018
Other countries*	0.4	0.5	0.7	1.0	1.2	2.0	3.0	4.0	6.1	8.2	11.0	25	50
TOTAL	14	25	32	51	74	94	116	138	172	205	264	567	1068
Upper limit + %							1	2	3	4	5	11	20
Lower limit - %						5	6	7	8	9	10	16	25

* Countries considered: Argentina, Brazil, Formosa, India, Israël, Korea, Mexico, New Zealand, Pakistan, Philippines, South Africa, Thailand.

+ capacity factor of 70% for all types of reactors

Source: Ref 2

TABLE III

ESTIMATED WORLD RESOURCES OF URANIUM

(Data Available January 1973)

Type of Resources / Country	Price Range $[1] 10/lb U_3O_8*				Price Range $10-15/lb U_3O_8*			
	Reasonably Assured Resources (Reserves)		Estimated Additional Resources		Reasonably Assured Resources		Estimated Additional Resources	
	10^3 tonnes uranium	10^3 short tons U_3O_8	10^3 tonnes uranium	10^3 short tons U_3O_8	10^3 tonnes uranium	10^3 short tons U_3O_8	10^3 tonnes uranium	10^3 short tons U_3O_8
Argentina	9.2	12	14	18	7.7	10	23	30
Australia	71	92	78.5	102	29.5	38.3	29	38
Brazil	-	-	2.5[2]	3.3	0.7	0.9	-	-
Canada	185	241	190	247	122	158	219	284
Central African Republic	8	10.5	8	10.5	-	-	-	-
Denmark (Greenland)	5.6	7.0	10	13	-	-	-	-
Finland	-	-	-	-	1.3	1.7	-	-
France	36.6	47.5	24.3	31.5	20	26	25	32.5
Gabon	20	26	5	6.5	-	-	5	6.5
India	-	-	-	-	2.3	3	0.8	1
Italy	1.2	1.6	-	-	-	-	-	-
Japan	2.8	3.6	-	-	4.2	5.4	-	-
Mexico	1.0	1.3	-	-	0.9	1.2	-	-
Niger	40	52	20	26	10	13	10	13
Portugal (Europe)	6.4	9.3	5.9	7.7	1	1.3	10	13
(Angola)	-	-	-	-	-	-	13	17
South Africa	202	263	8	10.4	62	80.6	26	33.8
Spain	8.5	11	-	-	7.7	10	-	-
Sweden	-	-	-	-	270	351	40	52
Turkey	2.2	2.8	-	-	0.5	0.6	-	-
USA	259	337	538[3]	700	141	183	231	300
Yugoslavia	6	7.8	10	13	-	-	-	-
Zaire	1.8	2.3	1.7	2.2	-	-	-	-
TOTAL (rounded)	866	1126	916	1191	680	884	632	821

1) $ Value of March 1973: 1$ = 0.829 EMA u/a = 0.829 SDR (Special Drawing Rights). This $ value corresponds to $42.22 per fine ounce of gold.

2) Plus 70,000 tonnes U by-product from phosphates.

3) Plus 70,000 tonnes U by-product from phosphate and copper production.

* The recent increase in the price of yellowcake to $12/lb$U_3O_8$ has altered the price range classification as listed above. The $10/lb$U_3O_8$ can with qualifications be read as $15/lb$U_3O_8$ while that at $10-15/lb$U_3O_8$ could read $15-20/lb$U_3O_8$.

Source: Ref 2

TABLE IV

ESTIMATED WORLD RESOURCES OF URANIUM+
('000s. tons)

Price range/lb	$5-10		$10-15		$15-30	
	Proven ore	Est. add.	Proven ore	Est. add.	Proven ore	Est. add.
Country						
United States	300	350	150	200	200	440
Canada	200	290	130	170	100	300
Argentina	9	21	11	32	15	73
France	45	20	5	10	-	-
Spain	11	-	4	30	15	250
Portugal	10	7	-	12	-	10
Sweden	-	-	350	50	150	200
Other (Europe)	7	20	21	15	20	-
South Africa	205	15	65	35	55	70
Gabon	4	4	-	-	-	-
Morocco	6	-	11	-	8	-
Zaire	6	-	-	-	-	-
Niger	12	13	13	-	-	-
India	-	-	3	1	24	61
Japan	-	-	4	-	-	-
Australia	11	3	3	1	1	-
Total (Free World)	826	743	770	556	558	1,404

Source: Organization for Economic Cooperation and Development, and the International Atomic Energy Agency, Vienna, 1970.

+ Price qualification is same as that noted in TABLE III, however, it is not clear what the $15-30 range should now be. These are 1970 data and although the $5-10 and $10-15 resources have increased in the 1973 report, it is doubtful that the $15-30 will have changed substantially.

Source: Ref 5

TABLE V

Estimated World Resources of Thorium

Country	Reasonably Assured Resources US \$10/lb ThO_2		Estimated Additional Resources	
	Tonnes Th	Short tons ThO_2	Tonnes Th	Short tons ThO_2
Brazil	1,200	1,485	880	1,100
Canada	80,000	100,000	80,000	100,000
	(associated with RAR uranium)			
UAR (Egypt)	14,700	16,700	280,000	317,900
India	(300,000 tonnes Th, 372,000 short tons ThO_2)			
Sri Lanka (Ceylon)		extensive		
Turkey	4000 tonnes Th found, deposits can be increased if boring is continued			
USA	52,000	65,000	265,000	335,000

Source: OECD Report: Uranium: Resources, Production, and Demand, 1973.

TABLE VI

URANIUM REQUIREMENTS*

(Thousands of Short tons of U_3O_8)

	0.20% ^{235}U Enrichment Plant Tails Assay				0.30% ^{235}U Enrichment Plant Tails Assay			
	1980	1985	1990	2000	1980	1985	1990	2000
United States Case	**Annual**							
A	25.2	45.5	68.5	97.	30.3	55.2	83.5	119.
B	28.9	52.9	87.6	143.	34.8	64.2	106.6	175.
C	29.4	58.5	102.4	165.	35.5	70.9	125.	203.
D	31.5	49.8	81.5	128.	37.9	60.4	99.3	157.
Foreign Case								
X	33.3	66.4	119.	194.	39.2	78.7	142.	234.
Y	39.6	84.2	144.	259.	46.5	99.9	171.	311.
Z	54.9	97.5	169.	331.	54.9	116.	202.	400.
United States Case	**Cumulative From 1973**							
A	111.	294.	587.	1466.	134.	355.	712.	1789.
B	126.	334.	699.	1931.	152.	404.	848.	2356.
C	137.	363.	787.	2226.	165.	438.	953.	2716.
D	133.	329.	671.	1793.	161.	397.	814.	2187.
Foreign Case								
X	154.	409.	907.	2584.	179.	481.	1074.	3088.
Y	194.	520.	1120.	3293.	226.	612.	1326.	3926.
Z	208.	577.	1282.	3929.	243.	680.	1521.	4708.

* With plutonium recycle beginning in 1977.

Source: Ref 4

TABLE VII

WORLD URANIUM PRODUCTION

Countries	1969		1970		1971		1972	
	tonnes U	short tons U_3O_8	tonnes U	short tons U_3O_8	tonnes U	short tons U_3O_8	tonnes U	short tons U_3O_8
Argentina	42	55	45	60	45	60	26	33
Australia	254	330	254	330			-	-
Canada	3,430	4,450	3,530	4,580	3,830	4,980	4,000	5,200
France	1,180	1,530	1,250	1,630	1,250	1,630	1,380	1,800
Gabon	500	650	400	520	540	700	210	270
Japan	-	-	-	-	-	-	15	20
Mexico	30	40						
Niger	-	-	-	-	430	560	870	1,130
Portugal	94	122			81	105	81	105
South Africa	3,080	4,000	3,167	4,117	3,220	4,186	3,076	4,000
Spain	55	72	51	66	60	78	60	78
Sweden	29	38	14	18	8	10	7	9
USA	8,900	11,600	9,900	12,900	9,470	12,300	9,900	12,900
TOTAL	17,600	22,880	18,610	24,200	18,930	24,610	19,660	25,550

Note: No production figures were available for India; the processing capacity of the Jaduguda mill is 1,000 tonnes of ore per day, which indicates production of a few hundred tonnes U per year.

Source: Ref 2

TABLE VIII

WORLD URANIUM PRODUCTION CAPACITIES

Countries	Reasonably Assured Resources $10/lb U_3O_8 (Reserves)				Annual Production Capacities					
	1973		Net changes since 1970		1973		Planned for 1975		Attainable 1978[1]	
	10^3 tonnes U	10^3 short tons U_3O_8	10^3 tonnes U	10^3 short tons U_3O_8	tonnes U	short tons U_3O_8	tonnes U	short tons U_3O_8	tonnes U	short tons U_3O_8
Argentina	9.2	12	+ 1.5	+ 2	46	60	165	210	520	670
Australia	71	92	+ 54	+ 70	-	-	770	1,000	4,600	6,000
Canada	185	241	+ 7	+ 9	4,600	6,000	6,500	8,500	10,800	14,000
France	36.6	47.5	+ 2.6	+ 2.1	1,800	2,300	1,800	2,300	2,000	2,600
Gabon	20	26	+ 9.6	+ 12.5	600	780	600	780	1,200	1,560
Italy	1.2	1.6	0	0	-	-	92	120	92	120
Japan	2.8	3.6	+ 0.7	+ 0.9	30	40	30	40	-	-
Mexico	1	1.3	0	0	30	40	225	300	340	450
Niger	40	52	+ 20	+ 26	750	975	1,500	1,950	1,500	1,950
Portugal	7.4	9.6	0	0	114	148	114	148	170	220
South Africa	202	263	+ 48	+ 63	4,130	5,370	3,800	5,000		
Spain	8.5	11	0	0	115	150	132	171		
Sweden[2]	-	-	0	0	120	155	120	155	120	155
USA	259	337	+ 67	+ 87	14,600	19,000	14,600	19,000	26,000[3]	34,000
Yugoslavia	6	7.8	+ 6	+ 7.8	-	-	-	-	230[5]	300
TOTAL (rounded)	850	1,105	+215	+ 280	27,000	35,000	30,500	40,000	48,000[4]	62,000[4]

1) Given favourable market situation and adequate lead time.
2) Production based on resources available at $10 to 15/lb U_3O_8.
3) 1,000 tonnes by-product included.
4) Estimates for South Africa <u>not</u> included.
5) Construction of mine and concentration plant to be completed in 1976.

Source: Ref 2

TABLE IX

SEPARATIVE WORK REQUIREMENTS*

(Millions of SWU)

	0.20% ²³⁵U Enrichment Plant Tails Assay				0.30% ²³⁵U Enrichment Plant Tails Assay			
	1980	1985	1990	2000	1980	1985	1990	2000
United States Case	**Annual**							
A	14.3	28.8	45.2	71.4	11.3	23.0	36.3	57.4
B	17.8	33.1	57.4	104.4	14.1	26.4	46.0	84.0
C	17.6	35.7	66.6	121.	13.9	28.5	53.4	97.4
D	17.9	30.8	53.2	93.6	14.2	24.6	42.7	75.3
Foreign Case								
X	15.9	34.8	66.7	119.	12.6	27.5	52.8	93.6
Y	17.9	42.9	76.9	153.	14.1	33.9	60.7	121.
Z	22.6	49.6	93.7	206.	17.8	39.1	74.1	163.
United States Case	**Cumulated From 1973**							
A	62.2	173.	363.	979.	49.4	138.	290.	785.
B	71.1	197.	430.	1285.	56.4	156.	343.	1030.
C	77.0	212.	481.	1482.	61.1	169.	384.	1189.
D	73.6	194.	414.	1194.	58.4	154.	330.	957.
Foreign Case								
X	66.6	195.	463.	1444.	52.6	154.	366.	1142.
Y	86.4	249.	567.	1796.	68.2	196.	447.	1419.
Z	92.4	277.	657.	2216.	72.8	218.	518.	1752.

* With plutonium recycle beginning in 1977.

Source: Ref 4

TABLE X

REQUIREMENTS AND CAPACITIES FOR HEAVY EQUIPMENT (in GWe)

Approximate annual requirements				Capacities							
	Basic Programme		Acc. Pro.	Prestressed concrete pressure vessels		Steel pressure vessels		Steam generators		Turbine-generators	
	1974	1978	1978	1974	1978	1974	1978	1974	1978	1974	1978
France	2	3	4								
Germany	4	4	6	-		2.5-3.8		3.8		12	≦15
Italy	-	2	4	-		5-8	7-10	8-10		5-8	7-10
Spain	1	2	3	~1		-	~3	~1	~3	~1	~1
Sweden	-	2	3								
Switzerland	-	1	1	1	1	1	1	-	-	4	5
U.K.	2	2	3	1.3-2.5		-	(1.3-2.6)	1.3-2.5		1.3-2.5	
EEC*	9	12	18			20-25		10-15		20	
Canada	1	1	2								
U.S.A.	7	29	39			24	29	20	30	15	30
Japan	4	7	9	-	-	10	18	3-4	6-10	13	25
OECD*	22	56	70								

* Totals are somewhat smaller than sums of countries' figures due to rounding.

Source: Ref 6

TABLE XI

SHARE OF DOMESTIC INDUSTRIAL SUPPLY TO NUCLEAR POWER STATIONS ORDERED IN:

	1965-1968	1969-1973
Canada	50%	65% [1)]
France	large portion	large portion
Germany	large portion	large portion
Italy	-	80%
Japan	~60%	~70%
Netherlands	95%	>70%
Spain	~33%	~50%
Sweden	85%	92%
Switzerland	Unknown	
United Kingdom	100%	up to 100% [2)]
U.S.A.	100%	95-100%

1) It is aimed to achieve 90% in the future

2) Depending on future reactor programme

Source: Ref 6

TABLE XII

ANNUAL CAPITAL INVESTMENT IN NUCLEAR ELECTRICITY GENERATING CAPACITY IN 10^9 US \$ (1972)

		1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1990	1995
EEC	Basic	3.0	2.2	2.7	2.8	3.9	4.3	5.2	6.5	7.7	8.2	9.9	11.2	12.0		
	Accelerated	3.1	2.4	3.0	3.0	4.3	6.5	7.7	9.5	11.2	12.0	14.2	15.1	17.2		
OECD Europe	Basic	4.0	3.4	4.3	4.0	6.8	6.5	6.9	8.2	9.0	10.8	11.6	12.9	14.6		
	Accelerated	4.3	3.7	4.3	4.7	7.3	9.5	10.8	12.0	13.8	15.9	20.6	19.4	21.5		
North America	Basic	3.4	4.2	7.7	7.4	12.8	11.4	12.9	12.9	15.1	15.1	15.9	18.9	21.1		
	Accelerated	3.6	3.9	8.2	8.2	14.6	16.8	19.4	19.8	22.4	22.8	25.4	30.1	34.4		
Japan	Basic	1.7	2.0	1.4	1.7	3.2	1.7	2.2	2.6	2.6	3.0	3.0	3.0	3.4		
	Accelerated	1.7	2.3	1.7	1.7	3.4	3.0	3.0	4.3	3.9	4.7	5.2	5.2	4.7		
Other OECD Countries	Basic			0.2		0.2			0.4		0.4		0.4			
	Accelerated			0.2		0.2			0.4		0.9		0.4	0.4		
Total OECD	Basic	9.1	9.4	13.6	13.1	23.0	19.6	22.0	24.1	26.7	29.3	30.5	35.2	39.1		
	Accelerated	9.6	9.9	14.4	14.8	25.5	29.3	33.2	36.5	40.1	44.3	51.2	55.1	61.0		
Other Countries*	Basic	0.4	0.4	0.9	0.9	1.2	0.9	0.9	1.3	1.3	1.7	1.7	2.2	2.2		
	Accelerated	0.4	0.4	0.9	0.9	1.3	1.7	1.3	1.7	2.2	2.6	2.6	3.0	3.0		
Total	Basic	9.5	9.8	14.5	14.0	24.2	20.5	22.9	25.4	28.0	31.0	32.2	37.4	41.3	55.9	86.0
	Accelerated	10.0	10.3	15.3	15.5	26.8	31.0	34.5	38.2	42.3	46.9	53.8	58.1	64.0	86	140

*Countries considered: Argentina, Brazil, Formosa, India, Israel, Korea, Mexico, Pakistan, Philippines, South Africa, Thailand.

Source: Ref 6

TABLE XIII

CUMULATIVE INVESTMENT IN NUCLEAR CAPACITY IN 10^9 US $ (1972)

		up to 1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1990	1995
EEC	Basic	12	14	17	20	24	28	33	40	47	55	65	75	87		
	Accelerated	12	15	18	21	25	34	39	49	60	72	86	101	118		
OECD Europe	Basic	15	19	23	27	34	40	47	55	65	75	87	101	115		
	Accelerated	16	19	24	28	36	45	56	68	82	98	118	138	159		
North America	Basic	28	32	39	47	60	71	84	97	112	127	143	162	183		
	Accelerated	28	32	40	48	63	80	99	119	141	164	189	219	254		
Japan	Basic	5	7	9	11	14	15	18	20	23	26	29	32	35		
	Accelerated	5	8	9	11	15	18	21	25	29	34	39	44	49		
Other OECD Countries	Basic			0.2	0.2	0.4	0.4	0.4	1	1	1	2	2	2		
	Accelerated			0.2	0.2	0.4	0.4	0.4	1	1	2	2	2	3		
Total OECD	Basic	48	58	71	85	108	127	149	173	200	229	261	297	335		
	Accelerated	49	59	74	88	114	143	176	212	252	297	348	403	464		
Other Countries*	Basic	1	2	3	4	5	6	6	8	9	11	12	15	17		
	Accelerated	1	2	3	3	5	6	8	9	12	14	17	20	23		
Total	Basic	49	60	74	89	113	133	155	181	209	240	273	312	352	624	1019
	Accelerated	50	61	77	91	119	149	184	221	264	311	365	423	487	860	1473

* Countries considered: Argentina, Brazil, Formosa, India, Israel, Korea, Mexico, Pakistan, Philippines, South Africa, Thailand.

Source: Ref 6

TABLE 14

ENRICHMENT PLANT NATURAL URANIUM FEED REQUIREMENTS*

(Thousands of Metric Tons of Uranium)

	0.20% ^{235}U Enrichment Plant Tails Assay				0.30% ^{235}U Enrichment Plant Tails Assay			
United States Case	1980	1985	1990	2000	1980	1985	1990	2000
	Annual							
A............	17.8	33.0	49.3	73.8	21.4	40.2	60.4	91.0
B............	22.4	38.1	63.4	109.0	27.0	46.3	77.5	134.
C............	22.0	41.1	74.1	126.	26.5	50.0	90.4	155.
D............	22.2	34.8	58.5	97.2	26.7	42.4	71.5	120.
Foreign Case								
X	20.5	44.2	81.8	137.	24.6	53.2	98.9	168.
Y	23.9	54.9	94.9	177.	28.6	66.1	115.	216.
Z	30.6	64.1	116.	237.	36.6	77.1	140.	290.
United States Case	Cumulated From 1973							
A	76.7	207.	418.	1068.	92.5	251.	508.	1308.
B	88.1	235.	496.	1408.	105.2	285.	602.	1723.
C	95.5	254.	556.	1624.	115.	307.	676.	1987.
D	91.3	231.	476.	1307.	110.1	253.	579.	1600.
Foreign Case								
X	87.7	252.	585.	1745.	104.9	303.	705.	2119.
Y	115.	327.	724.	2185.	138.	392.	872.	2652.
Z	124.	365.	843.	2682.	148.	437.	1014.	3255.

* With plutonium recycle beginning in 1977.

Source: Ref 4

TABLE XV

Rough Projections of Plutonium Production Capacities, Selected Non-Nuclear-Weapon States: 1975-80

Country	Estimated installed nuclear capacity 1975-80 (Mwe)*		Estimated plutonium production capacity 1975-80** (kg per year)	
	from	to	from	to
West Germany	5,000	20,000	1,000	4,000
Japan	5,000	20,000	1,000	4,000
Canada	2,500	6,000	600	1,500
Sweden	2,500	4,000	500	800
Italy	1.400	5,000	300	1,000
Spain	2,000	5,000	400	1,000
Switzerland	1,000	3,000	200	600
India	1,200	2,000	300	500
Israel			10	
Other	5,000	15,000	1,000	3,000
Rounded total	26,000	80,000	6,000	17,000
United States	50,000	120,000	10,000	25,000

* Megawatts of electric generating capacity

** Based on 0.2 kg plutonium per Mwe per year for light water reactors and a higher figure for natural uranium reactors. Note that additional time must be allowed for extraction of plutonium.

Source: Victor Gilinsky, 'Bombs and Electricity', Environment, vol 14, no 7, September 1972.

ANNEX A

TREATY ON THE NON-PROLIFERATION OF NUCLEAR WEAPONS

List of Signatures and Ratifications

as of March 14, 1974

Sources: 1. Department of External Affairs, Ottawa, Canada.

2. Reference 40.

TREATY ON THE NON-PROLIFERATION OF NUCLEAR WEAPONS

List of Signatures and Ratifications

as of March 14, 1974

COUNTRY	DATE OF SIGNATURE			DATE OF RATIFICATION		
	London	Moscow	Washington	London	Moscow	Washington
Afghanistan	1. 7.68	1. 7.68	1. 7.68	5. 3.70	5. 2.70	4. 2.70
Australia	27. 2.70	27. 2.70	27. 2.70	23. 1.73	23. 1.73	23. 1.73
Austria	1. 7.68	1. 7.68	1. 7.68	27. 6.69	27. 6.69	27. 6.69
Barbados			1. 7.68			
Belgium	20. 8.68	20. 8.68	20. 8.68			
Bolivia			1. 7.68			26. 5.70
Botswana			1. 7.68	28. 4.69		
Bulgaria	1. 7.68	1. 7.68	1. 7.68	3.11.69	18. 9.69	5. 9.69
Burundi					acceded 19. 3.71	
Cameroon		18. 7.68	17. 7.68			8. 1.69
Canada	23. 7.68	29. 7.68	23. 7.68	8. 1.69	8. 1.69	8. 1.69
Central Africa Republic						25.10.70
Ceylon (Sri Lanka)	1. 7.68	1. 7.68	1. 7.68			
Chad		1. 7.68			11. 3.71	
China (Taiwan)			1. 7.68			27. 1.70
Columbia			1. 7.68			
Zaire Congo (Kinshasa)	17. 9.68	26. 7.68	22. 7.68			4. 8.70
Costa Rica			1. 7.68			3. 3.70
Cyprus	1. 7.68	1. 7.68	1. 7.68	5. 3.70	10. 2.70	16. 2.70
Czechoslovakia	1. 7.68	1. 7.68	1. 7.68	22. 7.69	22. 7.69	22. 7.69
Dahomey			1. 7.68			31.10.72

COUNTRY	DATE OF SIGNATURE			DATE OF RATIFICATION		
	London	Moscow	Washington	London	Moscow	Washington
Denmark	1. 7.68	1. 7.68	1. 7.68	3. 1.69	3. 1.69	3. 1.69
Dominican Republic	1. 7.68		1. 7.68			24. 7.71
Ecuador			9. 7.68			7. 3.69
El Salvador			1. 7.68			11. 7.72
Ethiopia	5. 9.68	5. 9.68	5. 9.68	5. 3.70	5. 2.70	5. 3.70
Fiji					Adhesion 29. 8.72	
Finland	1. 7.68	1. 7.68	1. 7.68	5. 2.69	5. 2.69	5. 2.69
Gabon						14. 2.74
Gambia, The	4. 9.68	24. 9.68	20. 9.68			
Germany (East)		1. 7.68			31.10.69	
Germany (F.R.)	28.11.69	28.11.69	28.11.69			
Ghana	24. 7.68	1. 7.68	1. 7.68	4. 5.70	11. 5.70	5. 5.70
Greece		1. 7.68	1. 7.68			11. 3.70
Guatemala			26. 7.68	22. 9.70		22. 9.70
Haiti			1. 7.68			2. 6.70
Holy See				acceded 25. 2.71		acceded 25. 2.71
Honduras			1. 7.68			16. 5.73
Hungary	1. 7.68	1. 7.68	1. 7.68	27. 5.69	27. 5.69	27. 5.69
Iceland	1. 7.68	1. 7.68	1. 7.68	18. 7.69	18. 7.69	18. 7.69
Indonesia	2. 3.70	2. 3.70	2. 3.70			
Iran	1. 7.68	1. 7.68	1. 7.68	5. 3.70	10. 2.70	2. 2.70
Iraq		1. 7.68			29.10.69	
Irish Republic	4. 7.68	1. 7.68	1. 7.68	4. 7.68	2. 7.68	1. 7.68
Italy	28. 1.69	28. 1.69	28. 1.69			
Ivory Coast			1. 7.68			6. 3.73
Jamaica	14. 4.69	14. 4.69	14. 4.69	5. 3.70	5. 3.70	5. 3.70
Japan	3. 2.70	3. 2.70	3. 2.70			

COUNTRY	DATE OF SIGNATURE			DATE OF RATIFICATION		
	London	Moscow	Washington	London	Moscow	Washington
Jordan			10. 7.68			11. 2.70
Kenya			1. 7.68		11. 6.70	
Khmer						acceded 2. 6.72
Korea (south) Rep.			1. 7.68			
Kuwait	22. 8.68	15. 8.68	15. 8.68			
Laos	1. 7.68	1. 7.68	1. 7.68	5. 3.70	20. 2.70	5. 3.70
Lebanon	1. 7.68	1. 7.68	1. 7.68	15. 7.70	15. 7.70	20.11.70
Lesotho			9. 7.68			20. 5.70
Liberia			1. 7.68			5. 3.70
Libya	18. 7.68	23. 7.68	19. 7.68		15. 7.70	
Luxembourg	14. 8.68	14. 8.68	14. 8.68			
Malagasy Republic			22. 8.68			8. 10.70
Malaysia	1. 7.68	1. 7.68	1. 7.68	5. 3.70	5. 3.70	5. 3.70
Maldives Republic			11. 9.68			7. 4.70
Mali		15. 7.69	14. 7.69		10. 2.70	5. 3.70
Malta			17. 4.69			6. 2.70
Mauritania			?			
Mauritius			1. 7.68	14. 4.69	25. 4.69	8. 4.69
Mexico	26. 7.68	26. 7.68	26. 7.68	21. 1.69	21. 1.69	21. 1.69
Mongolia		1. 7.68			14. 5.69	
Morocco	1. 7.68	1. 7.68	1. 7.68	30.11.70	27.11.70	16.12.70
Nepal	1. 7.68	1. 7.68	1. 7.68	3. 2.70	9. 1.70	5. 1.70
Netherlands	20. 8.68	20. 8.68	20. 8.68			
New Zealand	1. 7.68	1. 7.68	1. 7.68	10. 9.69	10. 9.69	10. 9.69
Nicaragua	1. 7.68		1. 7.68			6. 3.73
Nigeria	1. 7.68	1. 7.68	1. 7.68	27. 9.68	14.10.68	7.10.68
Norway	1. 7.68	1. 7.68	1. 7.68	5. 2.69	5. 2.69	5. 2.69
Panama			1. 7 68			

COUNTRY	DATE OF SIGNATURE			DATE OF RATIFICATION		
	London	Moscow	Washington	London	Moscow	Washington
Paraguay			1. 7.68	5. 3.70		4. 2.70
Peru			1. 7.68			3. 3.70
Philippines	1. 7.68	18.7.68	1. 7.68	16.10.72	20.10.72	5.10.72
Poland	1. 7.68	1. 7.68	1. 7.68	12. 6.69	12. 6.69	12. 6.69
Rumania	1. 7.68	1. 7.68	1. 7.68	4. 2.70	4. 2.70	4. 2.70
San Marino	29. 7.68	21.11.68	1. 7.68	10. 8.70	20. 8.70	31. 8.70
Senegal	26. 7.68	1. 7.68	1. 7.68	15. 1.71	17.12.70	22.12.70
Singapore	5. 2.70	5. 2.70	5. 2.70			
Somali Republic	1. 7.68	1. 7.68	1. 7.68	5. 3.70		12.11.70
Southern Yemen		14.11.68				
Sudan		24.12.68			22.11.73	31.10.73
Swaziland	24. 6.69			11.12.69	12. 1.70	16.12.69
Sweden	19. 8.68	19. 8.68	19. 8.68	9. 1.70	9. 1.70	9. 1.70
Switzerland	27.11.69	27.11.69	27.11.69			
Syria		1. 7.68	1. 7.68		24. 9.69	
Thailand				acceded 7. 12.72		
Togo			1. 7.68			26. 2.70
Tonga				bound 7. 7.71		
Trinidad & Tobago	22. 8.68		20. 8.68			
Tunisia	1. 7.68	1. 7.68	1. 7.68	26. 2.70	26. 2.70	26. 2.70
Turkey	28. 1.69	28. 1.69	28. 1.69			
U.S.S.R.	1. 7.68	1. 7.68	1. 7.68	5. 3.70	5. 3.70	5. 3.70
U.A.R.	1. 7.68	1. 7.68				
United Kingdom	1. 7.68	1. 7.68	1. 7.68	27.11.68	29.11.68	27.11.68
U.S.A.	1. 7.68	1. 7.68	1. 7.68	5. 3.70	5. 3.70	5. 3.70
Upper Volta		11. 8.69	25.11.68			3. 3.70
Uruguay			1. 7.68			31. 8.70
Venezuela			1. 7.68			

COUNTRY	DATE OF SIGNATURE			DATE OF RATIFICATION		
	London	Moscow	Washington	London	Moscow	Washington
Viet-Nam (South)			1. 7.68			10. 9.71
Yemen A.R.		23. 9.68				
Yugoslavia	10. 7.68	10. 7.68	10. 7.68	5. 3.70	5. 3.70	4. 3.70

BACK END PAGE

Unclassified

Security Classification

DOCUMENT CONTROL DATA – R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATING ACTIVITY Operational Research & Analysis Establishment Department of National Defence	2a. DOCUMENT SECURITY CLASSIFICATION Unclassified 2b. GROUP III

3. DOCUMENT TITLE

The Impact of Energy on Strategy - Nuclear Energy

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, middle initial)

Nellestyn, Andrew (Maj.)

6. DOCUMENT DATE September 1974	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS 40
8a. PROJECT OR GRANT NO.	9a. ORIGINATOR'S DOCUMENT NUMBER(S) ORAE Memorandum No. M54	
8b. CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)	

10. DISTRIBUTION STATEMENT

PUBLIC AVAILABLE

11. SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY

13. ABSTRACT

The use of the oil weapon as a political instrument during the Yom Kippur War of October last demonstrated the vulnerability of the industrialized nations to Middle East oil import dependency. Nuclear energy alone possesses the technoligy and industrial base to lessen this dependency during the next twenty-five years. Presently the atom accounts for only one per cent of annual global energy consumption. It is unlikely that its contribution will be very substantial before 1985. By the year 2000, however, nuclear energy could provide about twenty-five per cent of the global energy requirements. In order to achieve the 2000 A.D. target, governments and the private sector must today establish policies and implement programmes to avoid the uranium ore, uranium enrichment capacity and manpower shortfalls predicted to occur in the first half of the eighties. These shortfalls if not surmounted could severely impede the orderly and timely expansion of the nuclear industry. In addition, governments at both the national and international level must improve safeguard arrangements and exact more stringent adherence to improved safeguards. It is encouraging to note that the major sources of nuclear fuel, i.e. uranium ore, are located in countries with stable, predictable, and pro-Western governments. Fast breeder reactors and fusion in particular are not expected to contribute significantly before 2000 A.D. Thermal spectrum reactors will provide the bulk of nuclear capacity.

DSIS
70-241

Security Classification

KEY WORDS

Nuclear Energy
Uranium Resources
Requirements
Capital Investment
Developing Countries
Manpower

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the organization issuing the document.

2a. DOCUMENT SECURITY CLASSIFICATION: Enter the overall security classification of the document including special warning terms whenever applicable.

2b. GROUP: Enter security reclassification group number. The three groups are defined in Appendix 'M' of the DRB Security Regulations.

3. DOCUMENT TITLE: Enter the complete document title in all capital letters. Titles in all cases should be unclassified. If a sufficiently descriptive title cannot be selected without classification, show title classification with the usual one-capital-letter abbreviation in parentheses immediately following the title.

4. DESCRIPTIVE NOTES: Enter the category of document, e.g. technical report, technical note or technical letter. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the document. Enter last name, first name, middle initial. If military, show rank. The name of the principal author is an absolute minimum requirement.

6. DOCUMENT DATE: Enter the date (month, year) of Establishment approval for publication of the document.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the document.

8a. PROJECT OR GRANT NUMBER: If appropriate, enter the applicable research and development project or grant number under which the document was written.

8b. CONTRACT NUMBER: If appropriate, enter the applicable number under which the document was written.

9a. ORIGINATOR'S DOCUMENT NUMBER(S): Enter the official document number by which the document will be identified and controlled by the originating activity. This number must be unique to this document.

9b. OTHER DOCUMENT NUMBER(S): If the document has been assigned any other document numbers (either by the originator or by the sponsor), also enter this number(s).

10. DISTRIBUTION STATEMENT: Enter any limitations on further dissemination of the document, other than those imposed by security classification, using standard statements such as:

    (1) "Qualified requesters may obtain copies of this document from their defence documentation center."

    (2) "Announcement and dissemination of this document is not authorized without prior approval from originating activity."

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document, even though it may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall end with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (TS), (S), (C), (R), or (U).

The length of the abstract should be limited to 20 single-spaced standard typewritten lines; 7½ inches long.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a document and could be helpful in cataloging the document. Key words should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context.