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REGIONAL NUCLEAR FUEL CYCLE CENTRES

IAEA STUDY PROJECT

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ABSTRACT

The Study Project on Regional Nuclear Fuel Cycle Centres (RFCC) was initiated by the International Atomic Energy Agency in 1975 to examine the economic, safety, safeguards and security aspects of a multinational approach to planning and establishment of nuclear fuel cycle facilities as contrasted to a wholly national approach. The Study has concentrated on what is referred to as the "back-end" of the fuel cycle covering transport, storage, processing and recycle activities starting from the time the spent fuel leaves the reactor storage pools and through all steps until the recycled fuel is in finished fuel elements and shipped to the reactor.

Specific features of large regional fuel cycle centre established on a multinational basis vis-a-vis smaller fuel cycle facilities set up on a national basis have been evaluated. Methodology for assessment of alternative strategies for fuel storage, reprocessing, and recycling of plutonium has been developed, characteristic data on material flows and cost factors have been generated, and an analytic system has been developed to carry out such evaluations including appropriate sensitivity analysis. Studies have also been made on institutional and legal, organizational, environmental, non-proliferation and safeguards, physical security and other essential aspects related to the development of the RFCC concept.

The results of the Study are indeed very encouraging. In some areas, specifically non-proliferation and safeguards considerations, waste management aspects, and economics, considerable advantages are expected to be gained by the RFCC approach to fuel cycle activities, as contrasted to the alternative of States setting up their own smaller national plants. In other areas, such as in the case of health, safety and environmental aspects, physical protection considerations and nuclear materials control, operational advantages would result from the co-location of facilities and from the intergovernmental structure envisaged for an RFCC.

The material developed during the course of this Study would enable any group of interested Member States to examine and work out alternative strategies pertinent to their present and projected nuclear fuel cycle needs, as well as evolve institutional, legal and other appropriate frameworks or agreements for the establishment of fuel cycle centres on a multinational cooperative basis.

1. INTRODUCTION

There is an increasing need for detailed planning of the entire nuclear fuel cycle, especially with regard to the storage and reprocessing of spent fuel and the subsequent recycle of recovered fissionable materials. The Study Project on Regional Nuclear Fuel Cycle Centres (RFCC) was initiated by the International Atomic Energy Agency in 1975 to examine the economic, safety, safeguards and security aspects of a multinational approach to planning and establishment of nuclear fuel cycle facilities as contrasted to a wholly national approach, and to develop a methodology whereby Member States might evaluate alternative strategies and make decisions together in order to meet their fuel cycle requirements.

A study effort of this nature is necessarily extensive and complex, covering as it does not only the quantifiable technical and economic considerations of the entire back-end of the fuel cycle, but at the same time requiring evaluation of the broader and qualitative non-proliferation, environmental, institutional and legal aspects. The Agency was fortunate to receive the generous support of various Member States and international and national organizations who provided expert consultants and other resources. Appreciation is also expressed for the financial support given by the United Nations Environment Programme, the International Bank for Reconstruction and Development, and the Government of the United States of America.

This paper is based upon the 1977 Report of the IAEA Study Project[1/] which provides a more extensive discussion of the considerations involved as well as presenting background data and other information pertinent to a complete understanding of the RFCC concept.

2. OBJECTIVES, SCOPE AND ORGANIZATION

The primary objective of the Study was to evaluate the relative merits and drawbacks of multinational fuel cycle centres versus national facilities, taking into account the amount of spent fuel expected to be removed from power reactors over the next 25 years. In this regard, a goal of the Study Project was to provide a forum whereby interested countries and other entities could work out alternative strategies pertinent to their present and projected nuclear fuel cycle requirements, as well as develop appropriate legal, institutional and organizational arrangements for establishing multinational fuel cycle centres.

As shown in Figure 1, the Study Project was organized into three broad categories of effort:

(a) Studies were carried out to analyse and evaluate some of the important considerations in any decisions to participate in an RFCC, as well as to determine the merits, problems and possible forms of such a multinational enterprise. These studies covered non-proliferation and

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1/ Regional Nuclear Fuel Cycle Centres: 1977 Report of the IAEA Study Project (Vols. I and II) International Atomic Energy Agency, Vienna, 1977, STI/PUB/445, ISBN-No. 92-0-159177-2 safeguards; institutional and legal aspects; organization and administration; financial; health, safety and environment; nuclear materials control; and physical protection.

(b) Studies of process steps involved in an RFCC were carried out to develop process flow models and characteristic cost data for each step, including spent fuel storage, reprocessing, mixed oxide (MOX) fuel fabrication, waste management, and transport of spent fuel and radioactive wastes. Nuclear power generation and spent fuel discharge projections were obtained from on-going programmes of the Agency.

(c) Mathematical models and computer programmes were developed for economic analysis of alternative strategies for spent fuel management by reprocessing and recycle, using large multinational fuel cycle centres as against smaller national facilities, or possibly by storing spent fuel on a long term basis without reprocessing. These models and programmes were based on the above studies of spent fuel management processes, and the data developed in those studies were used in carrying out illustrative strategy evaluations and sensitivity analyses.

As the technical and economic data, as well as the socio-political factors, with respect to spent fuel management are in a constant state of change, it was necessary that the relevant data reflect current conditions in Member States and hence could serve as "characteristic data" for general economic studies. Accordingly, contributions to all areas of the Study were obtained through meetings of experts from many Member States, and the information thus generated was compiled through the process of consensus. The studies were later harmonized by other groups of experts and by the Agency Secretariat. Thus, the findings of the Study represent a synthesis, rather than the direct views of individual experts or study groups.

3. CONCEPT OF THE RFCC

The RFCC concept envisages several countries joining together to plan, build and operate facilities necessary to service the back-end of the nuclear fuel cycle. Such a concept is broad enough to cover spent fuel from the time it leaves the nuclear power reactor through all subsequent steps including radioactive waste management until recycled fuel in the form of mixed oxide fuel elements is ready for use in a reactor, as shown in Figure 2.

The multinational grouping of participants in an RFCC would be formed on the basis of mutual needs and interests, and would not necessarily be limited by geographical considerations. This became evident during the early phase of the Study when it was found that the variation in spent fuel transport cost as a function of shipping distances to the RFCC would not be very significant in relation to the total fuel cycle cost.

The RFCC approach does not necessarily require the construction of entirely new facilities; existing or planned national installations could serve as the initial core of an RFCC. This would be particularly useful as one or more participants bringing in the needed technological and financial resources could help in early implementation of the concept and ensure commercial viability of such a multinational venture.

The schedule of construction and operation of an RFCC would begin with the immediately-needed facilities, such as spent fuel receiving and storage, followed by the reprocessing plant and other facilities. The optimum scope and timing would vary, depending upon the size and growth of the nuclear power programmes, the reactor types involved, the economic value of the recovered uranium and plutonium, and the specific requirements of the participants. Economies of scale favour reprocessing plants having annual capacities of about 1000 metric tons or more of spent fuel per year. This, in turn, requires that the combined nuclear power programmes of the participants be such that large-scale facilities can be effectively utilized.

A projection of world[2/] reprocessing capacity for oxide fuel is presented in Figure 3 which also shows the expected annual quantity of spent oxide fuel that would be generated[3,4/]. Similarly, cumulative data are presented in Figure 4. It is seen that the existing and planned spent fuel reprocessing capacity in the world will not be adequate during the next decade to process the irradiated fuel from the nuclear power reactors in operation during that period. Further, it is uncertain whether the planned reprocessing capacity will be installed as indicated, as many of the plans are considered to be rather optimistic. A significant shortfall in fuel reprocessing services available during the next decade appears to be unavoidable, as the lead time for establishing new reprocessing capacity is about ten years. Therefore, most countries will have to arrange for substantial capacity for storing their spent fuel.

There is a growing realization in a number of States that specific arrangements should be made for appropriate disposition of the spent fuel generated in their power reactors. Some States are considering new alternatives to reprocessing based on non-proliferation considerations. Other States consider reprocessing to be necessary to recover the energy and economic values remaining in the spent fuel. Still others consider the reprocessing of spent fuel as an essential step in the management of radioactive wastes, i.e. it is desirable to separate the highly radioactive wastes from the spent fuel and to convert them into solidified form, which would be more amenable to long-term storage or ultimate disposal, rather than leave these wastes in the spent fuel. Under the circumstances explained above, the nuclear fuel cycle situation will be different for each State.

As regards the need for fuel cycle services, even though there are only five countries at present which have spent fuel generation rates exceeding 50 t/a, i.e. about 2000 MW(e) LWR generating capacity, there will be about 25 countries in this category by 1990, as shown in Table 1. Many of these countries will find it difficult to arrange for suitable disposition of their spent fuel; in fact, some are even seriously concerned that, in the absence of any definite plans for the disposition of their spent fuel, there may be licensing difficulties for their new power stations.

2/ Countries with Centrally Planned Economies (C.P.E.) are not included.

3/ "Reprocessing of Spent Nuclear Fuels in OECD Countries", NEA/OECD, Paris (January 1977).

4/ IAEA Estimate, Division of Nuclear Power and Reactors (February 1977).

Unless some other approach appears possible, a number of these countries will have to consider seriously plans for establishing the essential fuel cycle services on a national basis. The RFCC concept would meet the fuel cycle needs of States on an economical and assured basis through multinational cooperation and participation in joint projects. When individual countries perceive incentives to join an RFCC, they then have less incentive for establishing their own national facilities, which would thereby reduce the problem of the spread of reprocessing capability around the world.

4. RESULTS AND CONCLUSIONS

The results of the Study Project on Regional Nuclear Fuel Cycle Centres are indeed very encouraging. Certain elements of this Study which will now be reviewed, specifically non-proliferation and safeguards considerations, waste management aspects, and economics, show that there are considerable advantages to be gained by the RFCC approach to fuel cycle activities, as contrasted to the alternative of States setting up their own smaller national plants. In other areas, such as in the case of health, safety and environmental aspects, physical protection considerations and nuclear materials control, substantial operational advantages are expected to result from the co-location of facilities and from the intergovernmental structure envisaged for an RFCC. No major disadvantages are expected to result in any area due to the RFCC approach.

4.1 Non-Proliferation and Safeguards Considerations

A paradox of our time is that nuclear technology, which promises so much for peaceful purposes in meeting the present and future energy needs of the world, remains also a major contributor to programmes of a military nature. Indeed, with this in mind, the IAEA was established with the objectives as stated in its Statute that it "....seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity, throughout the world" and that it ensure to the extent possible that assistance provided through its auspices "...is not used in such a way as to further any military purpose". Non-proliferation and safeguards considerations therefore constituted one major portion of the RFCC Study.

Present methods which have been used to further non-proliferation objectives include the Non-Proliferation Treaty and other treaties; the application of Agency safeguards; controls on the transfer or use of nuclear materials imposed by national, bilateral, multilateral and other requirements; similar controls on the transfer and use of certain sensitive technologies; arrangements of an industrial or commercial nature applying to nuclear research and development activities; and the application of requirements for the physical protection of nuclear materials and facilities.

Despite this extensive array of non-proliferation approaches, there is a growing concern that gaps exist now or may develop in the immediate future and that such gaps will require harmonization of actions at the multinational or international level for their solution. This situation has arisen mainly owing to the anticipated large-scale use of nuclear power in many nations by the end of this century, and the expectation of widespread possession of large quantities of nuclear material and an increasing number of commercial nuclear fuel cycle facilities which might at some future time be diverted to non-peaceful activities, if control measures are inadequate.

In particular, concern is addressed to the reprocessing of spent fuel from nuclear power plants and to the separated plutonium recovered from this fuel. Both fuel reprocessing facilities and recovered plutonium may be diverted from peaceful uses, and this has led some to suggest that the fuel needs of nuclear power be met with newly-mined uranium and that spent reactor fuel not be reprocessed but placed in storage. However, this raises several problems; the spent fuel must be stored safely until final disposal; also the plutonium contained in spent fuel that is in storage may be of some concern since small reprocessing plants can be constructed and operated with data available in the open literature. Thus, the solution to this proliferation problem cannot be attained merely by discouraging reprocessing or the spread of national reprocessing facilities. A constructive solution must be sought whereby legitimate interests in obtaining a well-managed nuclear fuel cycle programme can be reconciled with concerns about proliferation. There are a number of ways of meeting these interests, including the utilization of commercial services offered by nuclear supply states, the taking of equity shares in national facilities, or the establishment of multinational fuel cycle centres. While none of these provide a complete solution, they do, in varying degrees, resolve some of the concerns about present non-proliferation measures applicable to nuclear energy programmes for peaceful purposes.

The Regional Nuclear Fuel Cycle Center concept offers a number of advantages in meeting non-proliferation objectives, the most important being reduction in the number of national facilities constructed. In addition, the intergovernmental agreements envisaged for the RFCC (1) would enhance controls on the transfer and use of nuclear materials and restricted technologies, and provide for physical protection requirements for the facilities; (2) would provide for the adequate siting of reprocessing and fuel fabrication facilities, and (3) could define limitations on certain activities of the participants that might otherwise be detrimental to the non-proliferation objectives of the RFCC.

Further, the urgency for embarking on national reprocessing programmes is reduced since the RFCC concept offers States the opportunity to meet their needs for spent fuel storage and reprocessing in a timely and economic manner. To the extent that the RFCC conveys to the public a greater assurance of adequate control over nuclear materials and facilities than would wholly national facilities, it helps to allay concern in some countries about proliferation. In this regard, if the IAEA were to be given an advisory role on the intergovernmental body of the RFCC, this would serve to keep the activities more open and hence more acceptable internationally.

The RFCC concept includes the application of full IAEA safeguards to its activities. Significant interest has developed in the possibility of the IAEA exercising authorities granted in its Statute to require deposit of special fissionable materials in excess of on-going national needs, and some have suggested this authority might also extend to spent fuel storage. A determination in this regard is yet to be made. Such activities might be implemented in connection with the RFCC.

4.2 Radioactive Waste Management Considerations

Another major portion of the RFCC Study deals with considerations of radioactive waste management. It is probable that, with a steady increase in nuclear power growth, there will be many years of accumulated spent fuel in storage before an RFCC commences reprocessing. It is assumed that for early RFCCs, the spent fuel will have decayed for at least five years before reprocessing. On this basis, high-level liquid radioactive waste may be taken to solidification shortly after reprocessing, thus reducing the duration of storage and the quantities of waste in liquid form in tanks.

Approximately 70% of the total capital cost of waste management is attributable to the solidification plant for the high-level liquid waste and the cost of disposal in a geological formation. The RFCC concept on a large enough scale provides a substantial economic advantage in overall waste management operations because the costs per tonne of fuel processed are lower by a factor of 4 to 6 than in national facilities of smaller size.

There would be major economic and operational advantages from location of the RFCC at the geological disposal site. However, the time required to select a suitable geological site for disposal and the possible different requirements for siting of the facilities for reprocessing and fuel fabrication may make such co-location unfeasible. Nevertheless, whether the disposal site is co-located or is at an auxiliary site, the multinational participation would facilitate harmonization among the participants of national approaches to waste management.

4.3 Economic Considerations

Economic evaluations carried out during the RFCC Study show that the unit costs of fuel reprocessing, mixed-oxide fuel fabrication, and waste management are sharply reduced as one goes to larger-capacity facilities. This is illustrated in Figure 5, which shows that the unit total cost of reprocessing and recycle operations using a 1500-t/a reprocessing plant is about 40% lower than with a 500-t/a reprocessing plant. The effects of economies of scale are further illustrated in Figure 6, which shows the levellized net total cost of spent fuel storage, reprocessing, recycle and waste management using different size reprocessing plants. The capacities of the associated facilities were matched to the respective reprocessing plant.

The results shown in Figure 6 indicate that the unit cost of reprocessing plus recycle, including waste management costs, is much lower in large-scale facilities than in smaller facilities. Indeed, it is only in the large-scale facilities that the levellized net unit cost of reprocessing and recycle operations becomes negative; that is, that the present-worth of recycle credits are greater than the present-worth of costs. Thus, these results confirm that there are substantial economic incentives for many countries to consider participation in RFCCs of sufficiently large size.

The RFCC concept offers the opportunity for countries with small nuclear power programmes to realize these economies of scale by joining with other countries and jointly utilizing plants of larger size than could be utilized alone by such countries. The economic benefits of such joint participation was investigated by analyzing a model RFCC providing service to six model participating countries. General economic parameters and assumptions used in this analysis are listed in Table 2.

The financing arrangements for a multinational RFCC cannot be predicted at this time due to the many uncertainties involved. However, many experts suggest that the governmental involvements in such a venture could lead to financial guarantees and relief from taxes. In this eventuality, the funds could come principally from government-insured bonds carrying relatively low interest rates. This, combined with possible exemption from revenue, income and property taxes, could lead to a fixed charge rate lower than customarily used for commercial chemical and nuclear projects.

This view of the financing arrangements was taken as the base assumption in the economic analyses. It was assumed that all funds would bear an interest rate of 10%/a, and that the facilities would be amortized over 20 years using sinking fund depreciation. In addition, small percentages were included for interim replacements and property insurance. With these assumptions, the fixed charge rate on capital investments is about 12.5%/a, which was taken as the base value in the economic analyses. However, in order to allow for varying conditions in different Member States, such as private financing with different costs of money, provision for taxes and profit, and different amortization periods, sensitivity analyses were carried out with fixed charge rates up to 25%/a. In all cases, the discount rate was held fixed at 10%/a, which is consistent with general practice in many Member States.

The economic benefits of RFCC participation by a typical model country are illustrated in Figure 7, which shows the cumulative net cost (investment plus operating costs, minus recycle value of recovered fuels) for a country having a nuclear power programme growing from about 9000 MW(e) in 1980 to 33,000 MW(e) in 2000 and to 45,000 MW(e) in 2020.

In Strategy A, the country shares in an RFCC in which reprocessing with a 1500-t/a plant begins in 1989, and a second 1500-t/a reprocessing plant begins reprocessing in 1997 to keep pace with increasing service needs. This model country provides about 36% of the total amount of spent fuel received at the RFCC, with the remaining 64% coming from the other participants. It is assumed, therefore, that 36% of the RFCC investment and operating costs would be assessed to this country and that 36% of the credits from recycle of recovered uranium and plutonium would be distributed to this country.

In Strategy B, the country is assumed to establish a national reprocessing and recycle programme to meet its own needs, with reprocessing beginning in 1989, as in Strategy A. In this case, the national nuclear power programme can only support a 750-t/a reprocessing plant in 1989. A second 750-t/a plant is needed in 2006, to meet increasing national service needs.

In Strategy C, it is again assumed that the country establishes a national reprocessing and recycle programme. However, this strategy is optimized in terms of reprocessing plant size and start-of-service date.

The result of the optimization study indicates that it is desirable to delay start of reprocessing to 1996, at which time a 1500-t/a reprocessing plant could be supported by the spent fuel accumulated in storage plus the annual discharges in future years.

The results displayed in Figure 7 show some interesting comparative aspects of these three possible strategies for this single country:

a. The required total direct investment (capital plus operating costs) in fuel cycle facilities is lowest [see Figure 7(A)] when the country shares proportionately in establishing a multinational RFCC. In this case the total investment reaches its maximum value of about US$730 x 10^6 in 1990, immediately after the reprocessing and recycle facilities begin service.

   If the country should pursue a national programme, the total direct investments in fuel cycle facility capital plus operating costs will reach about US$1.2 x 10^9 in Strategy B and about US$1.8 x 10^9 in Strategy C. The higher investment in Strategy C results primarily from the need for increased fuel storage and purchases of additional natural uranium and enrichment services, due to delaying reprocessing and recycle until 1996. This higher investment is eventually offset by the economies of scale of the larger reprocessing plant, and the net result is that Strategy C is more economical in the long term than Strategy B.

b. Including interest charges compounded at 10%/a, as shown in Figure 7(B), the investment share in the RFCC option would be recovered by about 2003, through the fuel cycle benefits from uranium and plutonium recycle. The investments in smaller national recycle facilities would not be recovered until about 2015 in the case of Strategy C, and much later in the case of Strategy B. That is, investments in large-scale RFCC fuel recycle facilities would be offset by recycle benefits significantly more quickly than would investments in smaller national recycle facilities.

c. Similar analysis performed for countries with nuclear power programmes smaller than in this example show that the relative benefits of RFCC participation would be even greater when compared with the costs of smaller national programmes. This is due to the very much higher relative costs of small reprocessing and recycle facilities. The investment in recycle facilities may be reduced by a factor of 3 - 4 by sharing in a large-capacity RFCC instead of building smaller national facilities.

Sensitivity to Changes in Cost Parameters

Sensitivity studies were carried out to determine the degree to which the RFCC economics would be changed by changes in costs of the major facilities or by changes in economic parameters, such as the price of natural uranium. Results from these sensitivity studies are presented in Figure 8.

<u>Base Case.</u> The first bar in Figure 8 shows the net total cost of reprocessing

and recycle using the base assumptions listed in Table 2 and the base costs developed in this Study for storage, reprocessing, fabrication and waste management facilities. It may be seen that, with these base cost data and with 12.5%/a fixed charge rate, there is a net benefit of about US$35/kg of spent fuel; with 25%/a fixed charge rate there is a net cost of about US$110/kg of spent fuel.

Uranium Price. The economic benefits from reprocessing and recycle of uranium and plutonium are influenced by the price of natural uranium. As noted earlier, this Study used US$40/lb U_3O_8 as the base uranium price. As shown in Figure 8, changing to US$30/lb U_3O_8 would increase the net cost of RFCC recycle operations by about US$42/kg, since the value of the recovered uranium and plutonium is less at the lower natural uranium price. A change to US$50/lb U_3O_8 would decrease the net cost of RFCC recycle operations by about the same amount

Reprocessing Plant. The most costly single facility in the model RFCC is the fuel reprocessing plant, and its cost is not known with great accuracy. Cost estimates developed by this Study Project were considered to have an accuracy within ± 20%. The results in Figure 8 show that a 20% change in reprocessing plant capital cost would change the levellized net cost of the RFCC by about US$20/kg and US$40/kg spent fuel for fixed charge rates of 12.5%/a and 25%/a, respectively.

MOX Fuel Fabrication Plant. The capital cost of MOX fuel fabrication plants, as developed by expert consultants to the Agency, were considered to have an accuracy within ± 20%. The results shown in Figure 8 show that a 20% change in MOX plant costs would change the levellized net cost of the RFCC by about US$4/kg and US$8/kg of spent fuel, for fixed charge rates of 12.5%/a and 25%/a, respectively.

Waste Management Facility Costs. Sensitivity studies were also carried out with the capital costs of all waste management facilities changed by plus and minus 20% from the estimated base costs. Figure 8 shows that a 20% change in these costs would change the levellized net cost of the RFCC by about US$4/kg and US$8/kg of spent fuel, for fixed charge rates of 12.5%/a and 25%/a, respectively.

Economics of Long-Term Storage Alternative

Among the options for spent fuel management is the alternative of storing the fuel for the present, delaying until some future date the final decision whether to reprocess the spent fuel or to place it in ultimate disposal. This alternative has been examined in the economic evaluations, and some comparisons are given of the relative economics of reprocessing and recycle vis-a-vis long-term storage without reprocessing. At the present time, decisions have not been made on the most suitable mode for long-term storage of spent fuel elements, nor on the extent to which the fuel must be prepared or encapsulated prior to being placed in storage. Hence, costs for long-term storage are not well established at this time.

The storage facility costs estimated by expert consultants were based on water-filled storage basins for LWR fuel. For long-term spent fuel storage without reprocessing, there would be economic incentive to develop more efficient and less costly facilities. Therefore, it is important to assess the sensitivity of spent fuel management choices to variation in the costs of long-term storage facilities. The base cost of storage facilities was taken as the lowest estimate developed in the Study, although some of the consultants were of the opinion that costs of water-basin storage could be higher by a factor of two. Sensitivity studies were carried out with storage facility capital costs reduced to 50% of the selected low estimate for water-basin storage. Results from this sensitivity analysis of long-term storage costs are presented in Figure 9.

The results shown in Figure 9(A) indicate a generally favourable picture for the economic viability of the RFCC recycle option with 1500-t/a reprocessing plants and with fixed charge rates applicable in many Member States. With uranium costing US$30/lb U_3O_8, the RFCC recycle option would be cheaper than the base-cost storage option for fixed charge rates below about 22%/a; if uranium should cost US$50/lb U_3O_8, the RFCC option would be cheaper for fixed charge rates below about 35%/a. The sensitivity results with 50% lower capital costs for long-term storage facilities show that at US$30/lb U_3O_8 the 1500-t/a RFCC recycle option would be cheaper than long-term storage if the fixed charge were about 16%/a or lower. At US$50/lb U_3O_8, the RFCC recycle option is cheaper at fixed charge rates below about 26.5%/a.

The economic viability of the recycle option becomes much less favourable with smaller capacity reprocessing plants, as shown in Figure 9(B) for 750-t/a reprocessing plants.

These results show that the economic decision regarding fuel recycle versus long-term storage of spent fuel would depend strongly on the size of the RFCC and also on the price of uranium and the economic conditions under which the recycle or storage facilities would be financed. This decision would also be affected by additional obligations encountered at the end of the storage period, either to reprocess the stored spent fuel or to dispose of it as a waste.

Summary of Economic Evaluations

The results presented in this section show that significant economic savings can be obtained through the economies of large-scale operations in the RFCC, when compared to the alternative of smaller national reprocessing, recycle and waste management programmes. These results indicate that countries with small to moderately large nuclear power programmes, and having need to reprocess their spent fuel, would have strong economic incentive to form multinational ventures of sufficiently large size for reprocessing, MOX fuel fabrication and waste management.

5. IMPLEMENTATION OF THE RFCC CONCEPT

In considering implementation of the RFCC concept, the Study has addressed a number of areas of interest to those States who may now or in the future wish to evaluate such an approach in terms of their interests and needs. Of particular interest would be the possible institutional and legal arrangements that may be considered by the Member States.

There has been an increasing use, during the last 30 years, of intergovernmental/multinational ventures in fields involving sophisticated technology, high financial needs and national policy interests. The multinational approach has been utilized for ventures with an industrial/commercial orientation in the nuclear field, such as Eurochemic, EURODIF and URENCO, and a variety of institutional arrangements has been used for these ventures.

Because the RFCC involves activities in a field in which Governments have played a strong role and which would be of potential economic-political importance, it is highly likely that sponsoring States would wish to reach some agreements, of a general or more specific nature, on various questions that will be involved in the organization and operation of an RFCC. This would lead to a two-tier organizational structure with an operating enterprise (which could include both governmental and non-governmental representation) having full authority for management of commercial and technical operations, but subordinate to an intergovernmental tier within the framework of the formalized intergovernmental agreements. Nevertheless, experience of the three substantial multinational industrial ventures mentioned above indicates that it is feasible for interested Governments to establish an industrial/commercial project with considerable management autonomy and, at the same time, have the venture responsive to the interests of Governments.

Results from the RFCC economic evaluations indicate that the financing share of a sponsoring State would be lower by a factor of up to 2 to 3 in the case of its participation in a large-scale RFCC than it would be if that State were to establish smaller national fuel cycle facilities. This saving through sharing in economies of scale provides a strong incentive for potential sponsoring States to solve any problems involved in financing such a multinational enterprise. It is to be noted that the total cost of the RFCC facilities is less than 10% of the total cost of the nuclear power plants that would be serviced by the RFCC. Therefore, it would appear that if financing of the nuclear power plants in the sponsoring States is feasible, then obtaining this additional financing for the RFCC should not pose a major obstacle to RFCC implementation.

As of now, the scope of the economic uncertainties involved, as well as strong national policy interests in the back-end of the fuel cycle, make it likely that Governments would play a particularly active role in the financial arrangements through direct supply of funds, provision of loan guarantees, approval of electric power rate adjustments, as well as through enactment of regulatory and fiscal measures. Beyond this stage, however, the distribution of responsibilities in securing additional financing and the sharing of risks and benefits may assume a variety of forms, as has been the experience with joint ventures in the uranium enrichment field.

In the course of this Study, the IAEA has acquired additional capability to assist Member States in analysing how potential groupings of RFCC participants might select the most suitable strategies and organizational framework to meet their mutual interests and needs regarding the back-end of the nuclear fuel cycle. The IAEA could provide in the organizational stage a forum for initial discussions among potential RFCC participants, could give guidance to Member States on economic evaluation of different fuel cycle strategies and on detailed study and evaluation of specific RFCC proposals prior to an implementation decision, and could assist Member States in negotiations prior to establishing institutional-legal arrangements for an RFCC. These are appropriate activities for the Agency as the necessary expertise and Secretariat infrastructure for assistance and evaluation are already available.

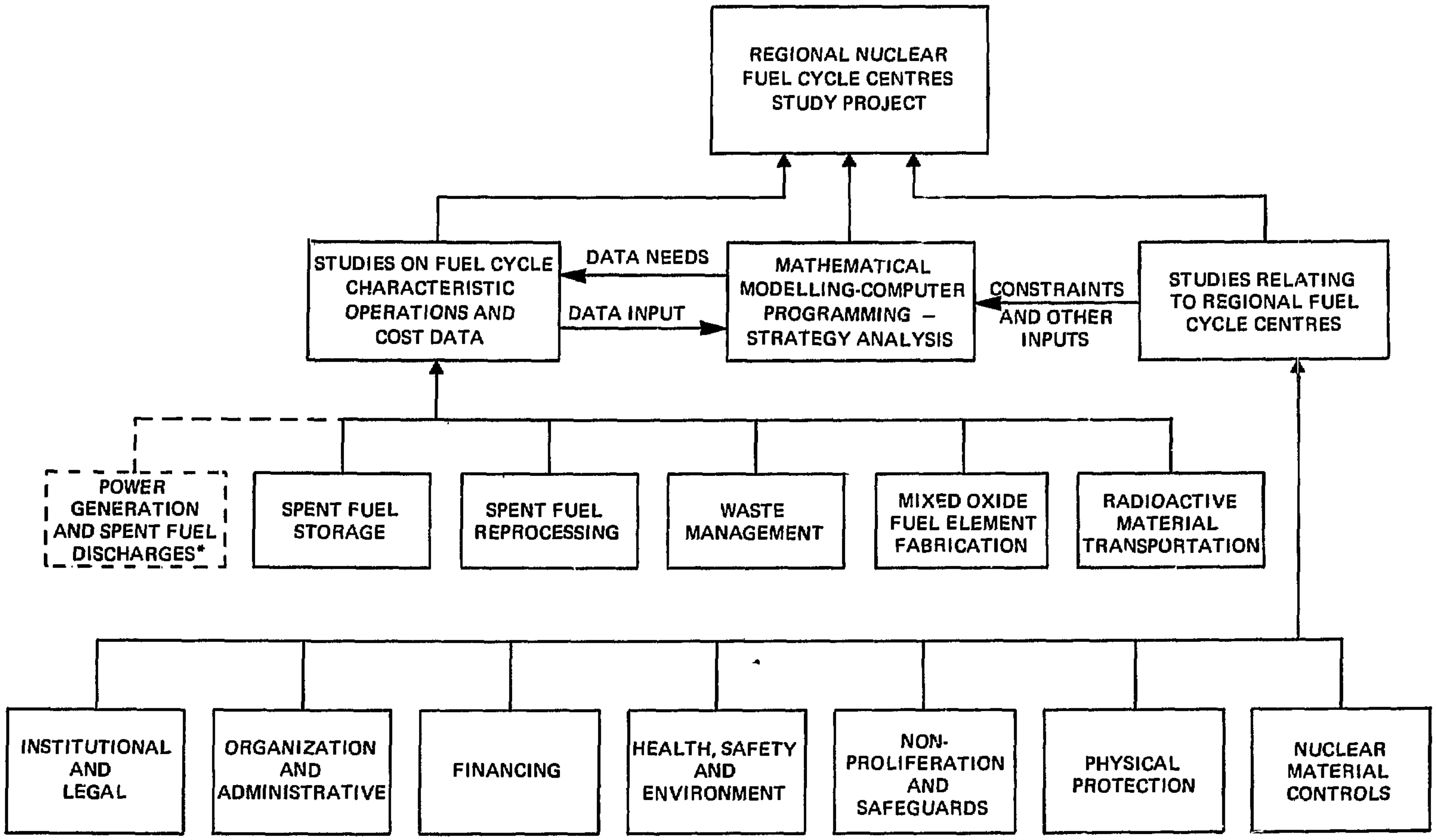
Decisions regarding problems associated with the back-end of the fuel cycle cannot be taken in isolation and are inevitably related amongst nations. The Agency would most appropriately be involved in a role with the Member States that enhances the credibility and effectiveness of safeguards and of the Non-Proliferation Treaty. In this regard, the RFCC concept, combining technological and control activities on an equitable basis, offers the world community a rational framework well-suited to attaining the objectives of non-proliferation and safeguards, while developing solutions to problems associated with reprocessing and recycling of fissile fuel materials. Moreover, it offers all States the opportunity to work together in planning nuclear fuel cycle strategies which would meet their needs on a timely and economic basis.

TABLE I. NUMBER OF COUNTRIES THAT MAY REQUIRE FUEL REPROCESSING SERVICES IN THE WORLD excluding Centrally Planned Economies (for LWR and HWR oxide fuel)

Annual quantity of spent fuel (t/a)	1976	1980	1985	1990
>500	1	1	5	6
50–500	4	10	14	19
<50	10	8	11	21
Total	15	19	30	46

TABLE 2. ECONOMIC CONDITIONS USED IN ECONOMIC ANALYSIS OF MODEL RFCC

Item	Value
Planning horizon	to 2010
Base year for costs	end 1976
Interest and discount rate	10%/a
Fixed charge rate	12.5%/a - 25%/a
U_3O_8 price	US$40/lb
Separative work price	US$100/SWU
UO_2 fuel fabrication	US$150/kg
Earliest date to begin reprocessing	1989
Spent fuel storage	as needed



* Input obtained from on-going programmes of the IAEA's Division of Nuclear Power and Reactors.

Fig. 1. Organization of the Study Project.

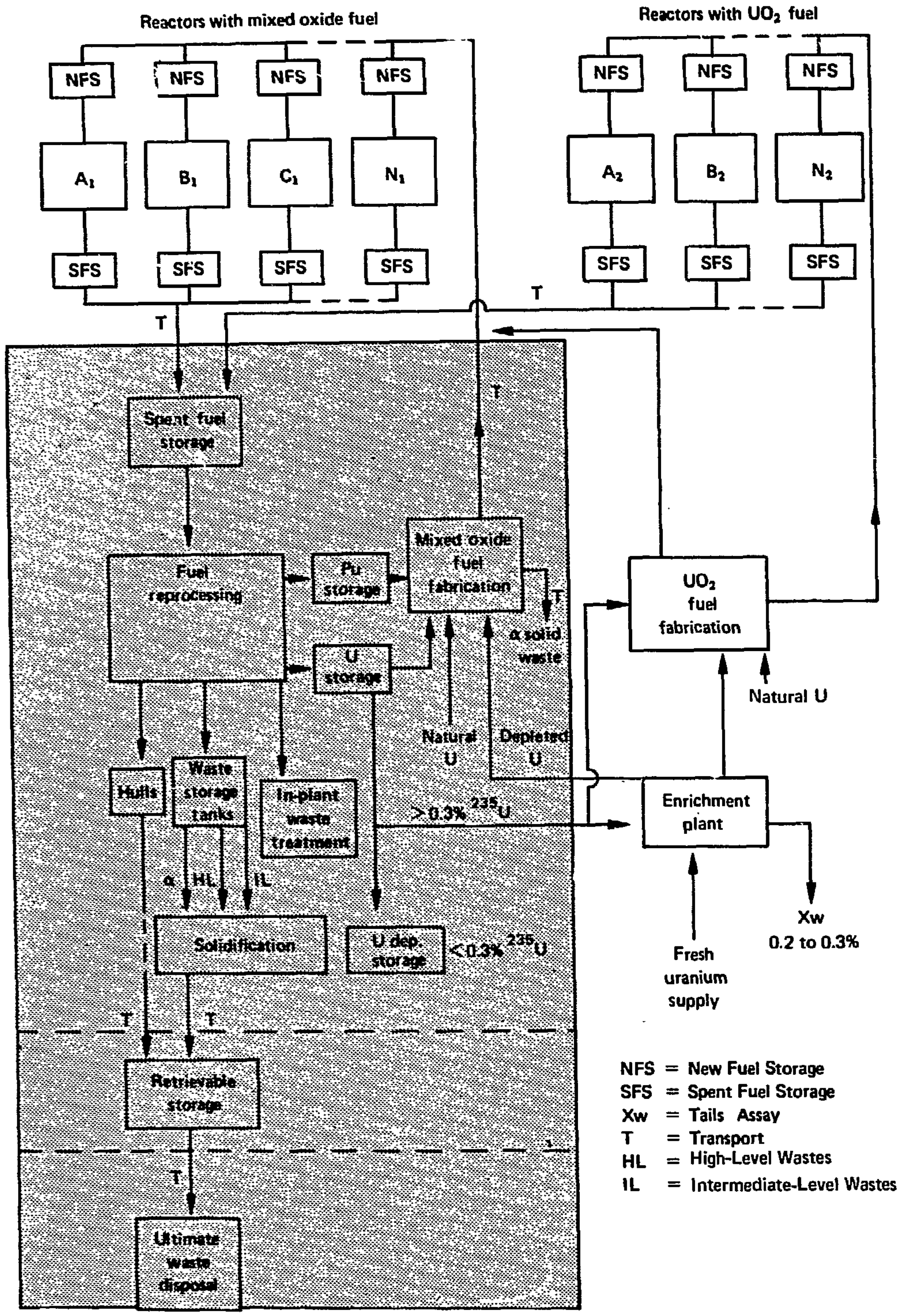


Fig. 2 Concept of the Regional Nuclear Fuel Cycle Center

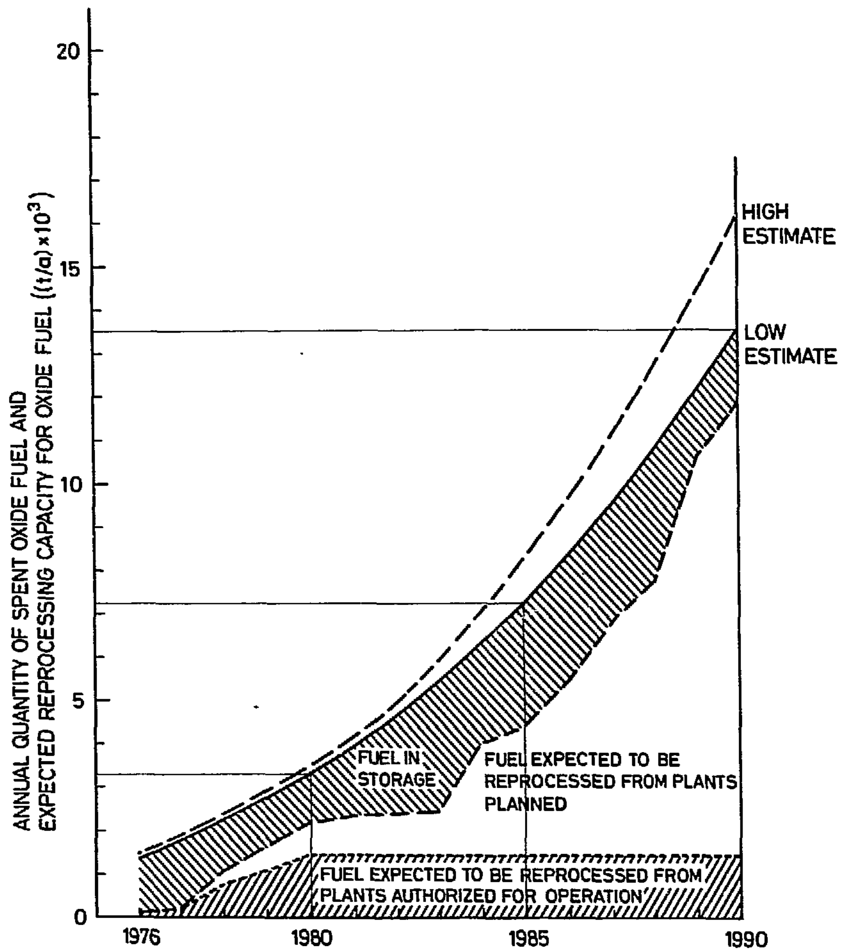


Fig.3. Annual Quantity of Spent Oxide Fuel and Expected Reprocessing Capacity for Oxide Fuel in the World Excluding C.P.E.

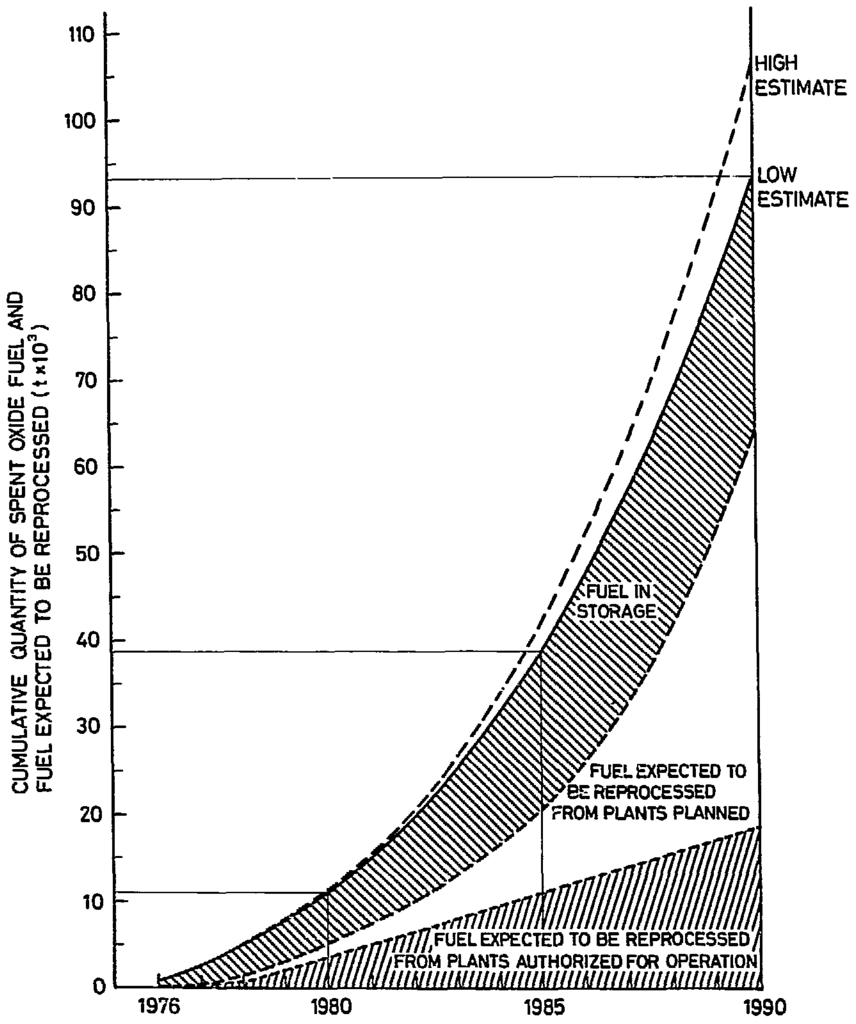


Fig.4. Cumulative Quantity of Spent Oxide Fuel and Fuel Expected to be Reprocessed in the World Excluding C.P.E.

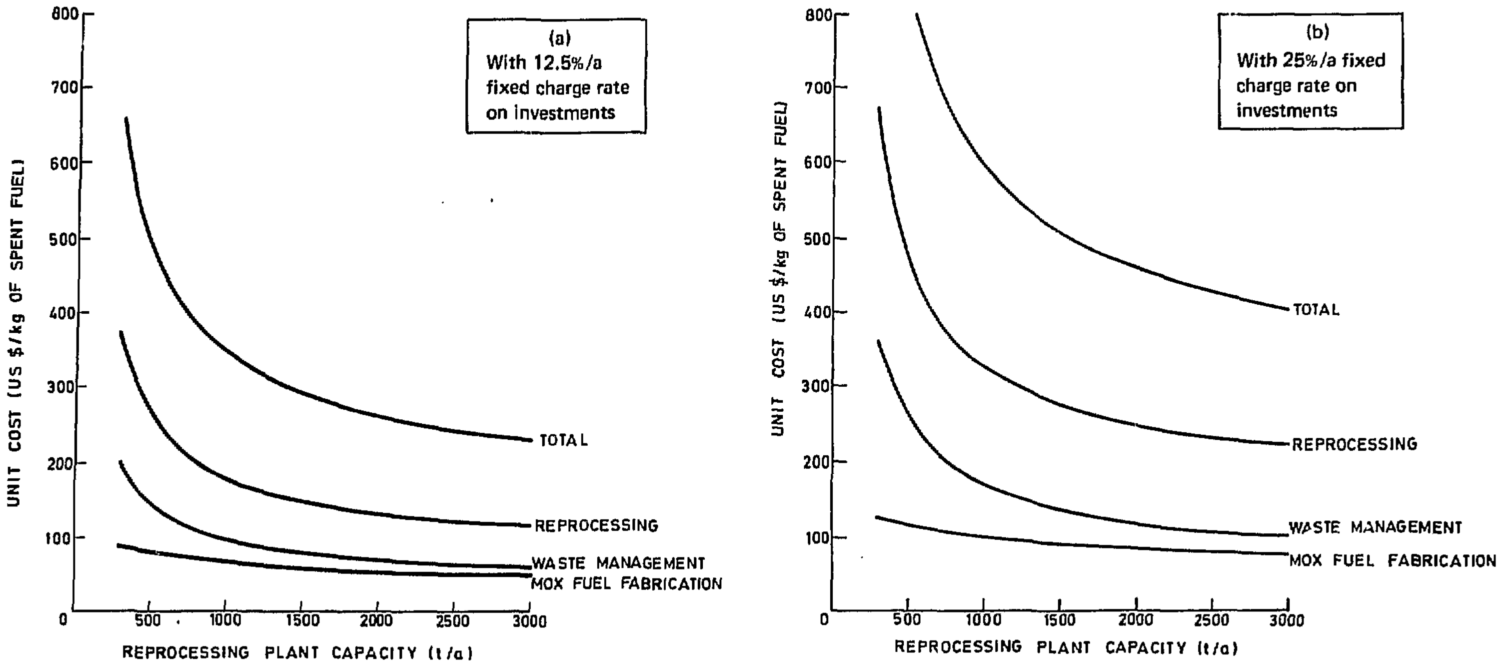


Fig.5. Economy-of-scale effects on unit costs of reprocessing, MOX fuel fabrication and waste management (all costs are per kilogram of spent fuel reprocessed).

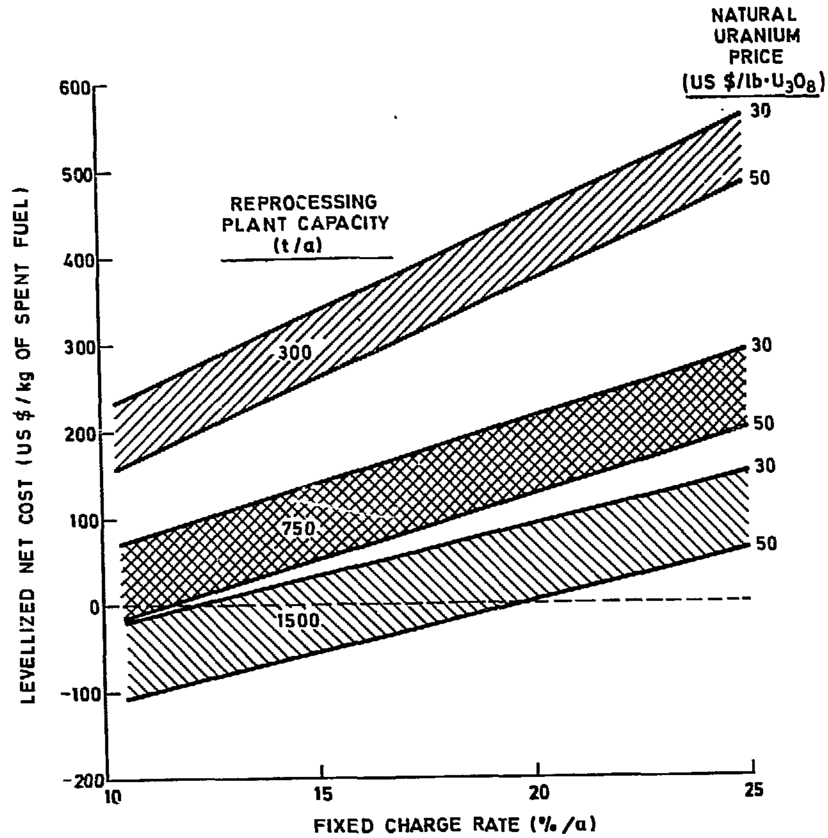


Fig.6. Sensitivity of reprocessing plus recycle costs to economies of scale, fixed charge rate, and natural uranium price.

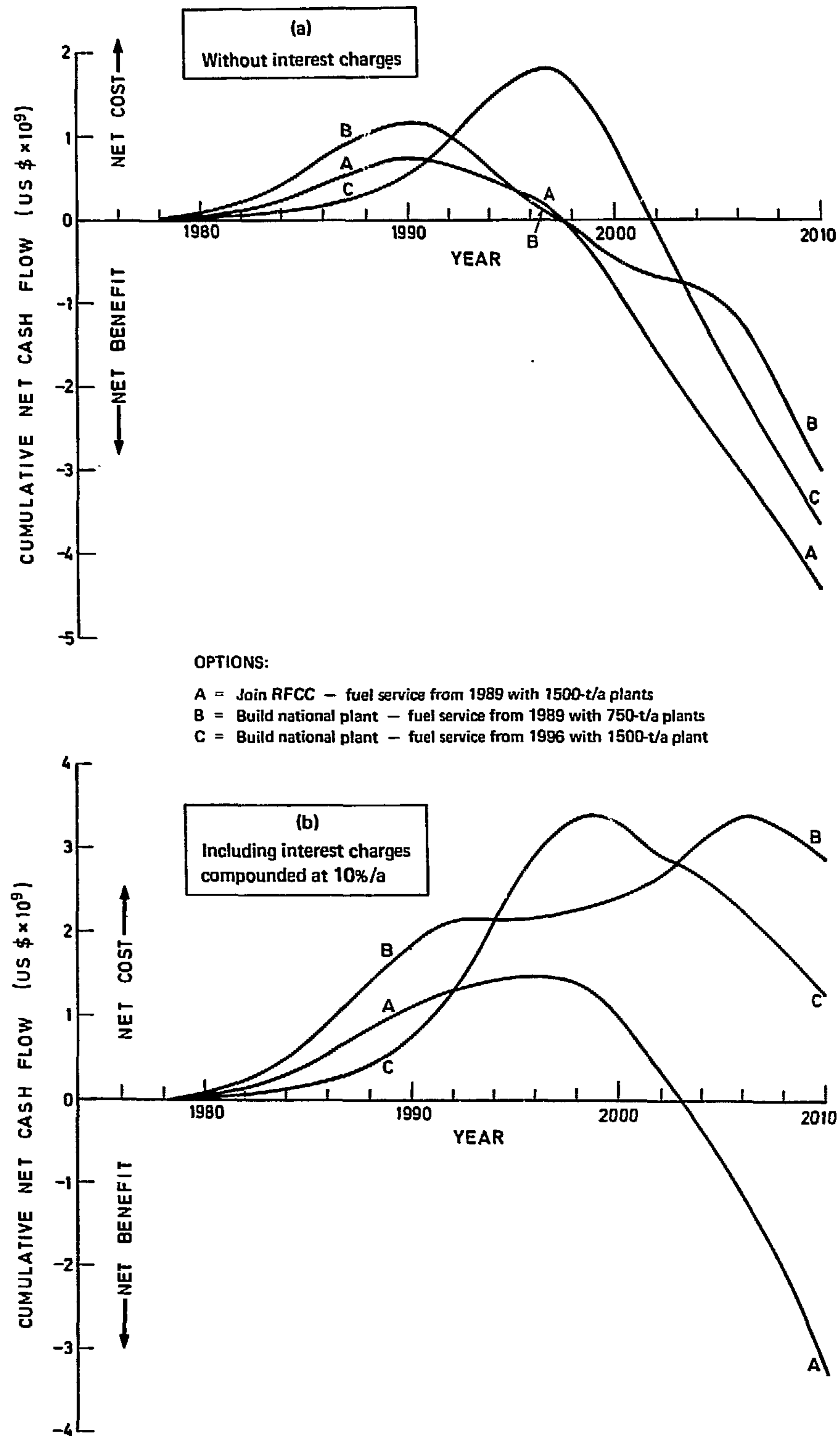


Fig.7. Comparative investments and returns for alternative options for Country No.6.

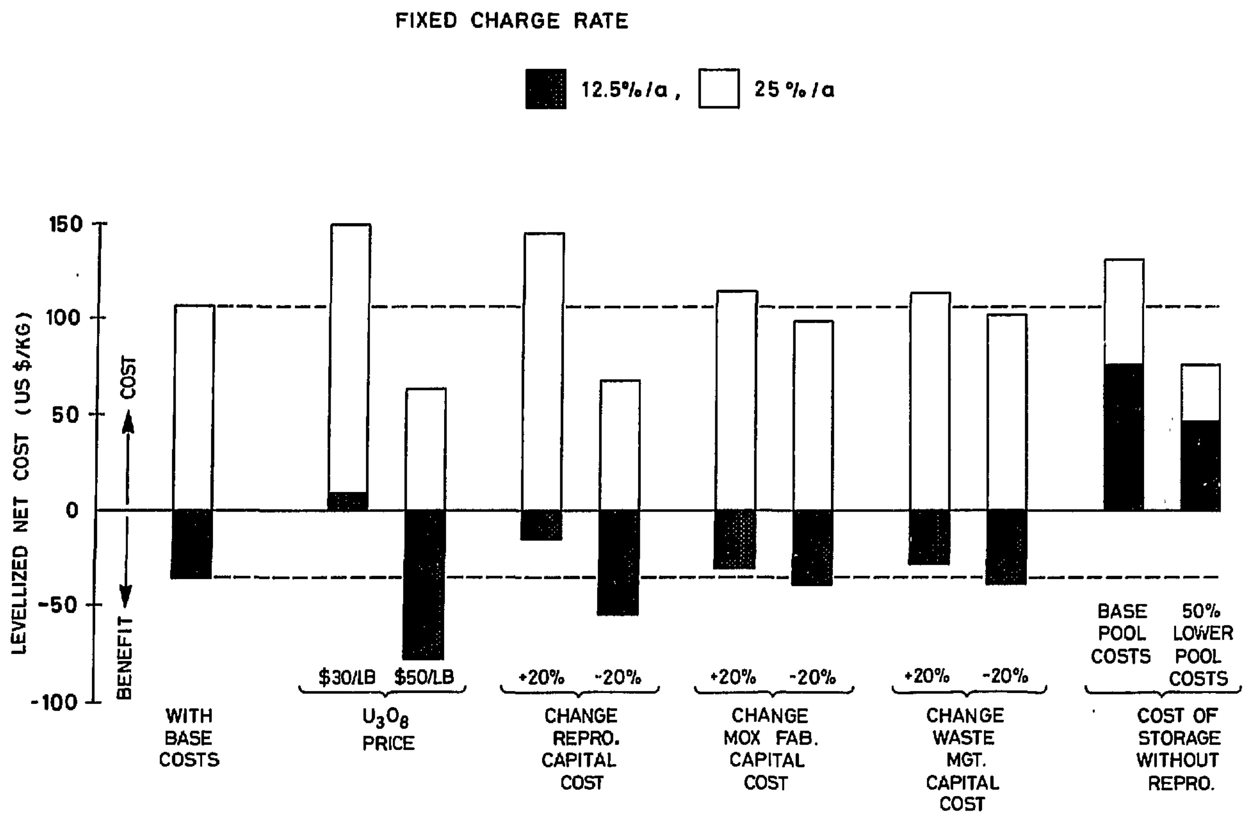


Fig. 8. Summary of Sensitivity Analysis for RFCC with 1500-t/a Reprocessing Plants.

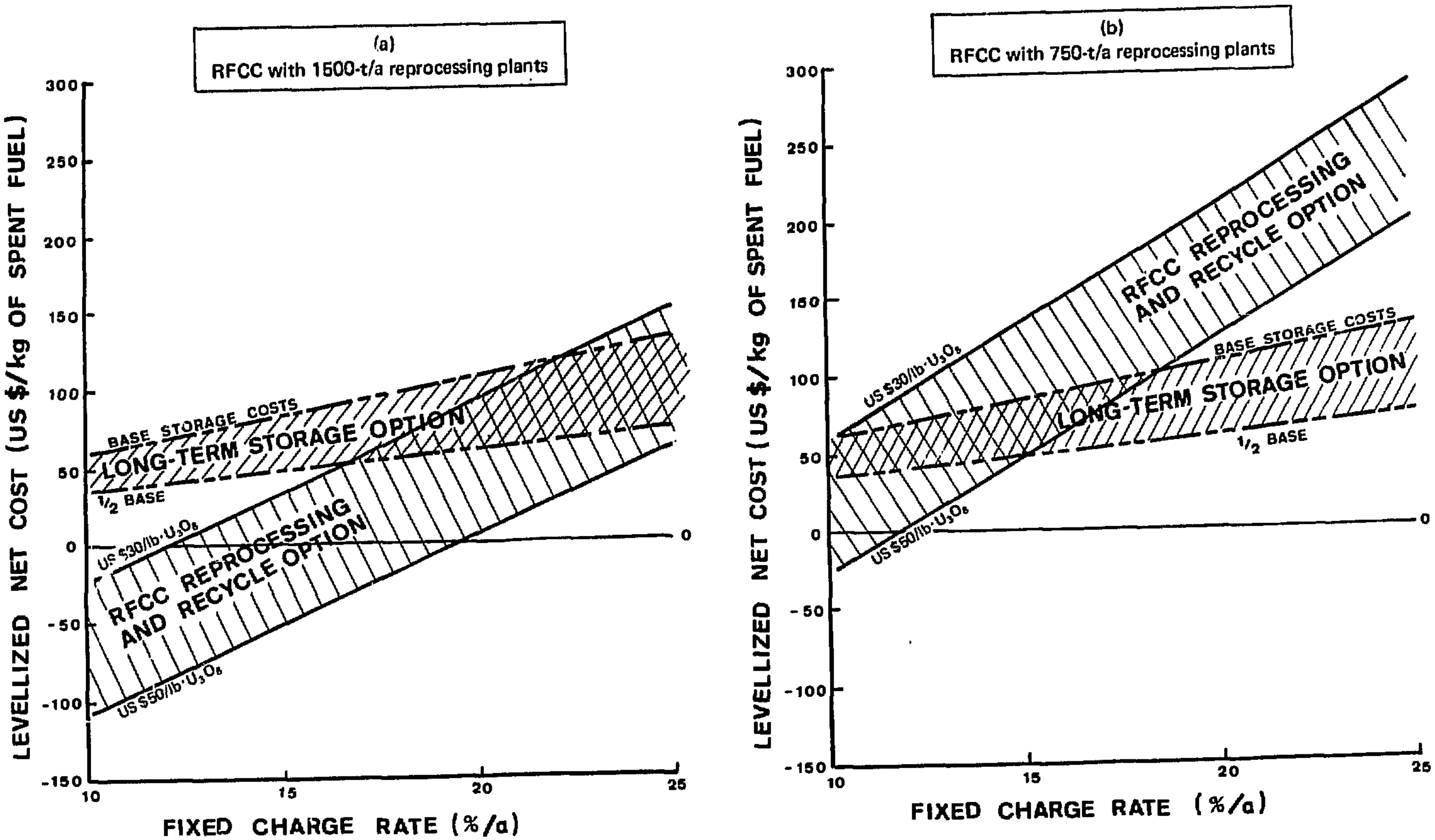


Fig.9. Economic comparison of long-term storage and RFCC reprocessing-recycle.