KfK 2997
Juli 1980

Saudi Arabia a Technically Developing Country and the Question of Introducing Nuclear Power During 1980-2000

A. R. Melibary
Institut für Neutronenphysik und Reaktortechnik

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE
Institut für Neutronenphysik und Reaktortechnik

KfK 2997

Saudi Arabia
a Technically Developing Country and the Question of Introducing Nuclear Power During 1980-2000

by
Abdul Rahman Melibary

Doctoral Thesis approved by the Fakultät
für Maschinenbau der Universität Karlsruhe

Kernforschungszentrum Karlsruhe GmbH, Karlsruhe

Kernforschungszentrum Karlsruhe GmbH
ISSN 0303-4003

Abstract

In this investigation, the possibility of introducing nuclear power during 1980-2000 to the oil exporting country Saudi Arabia is examined in view of generating the required electricity and desalted water during this period by using the nuclear fuels uranium and thorium.

The investigation is carried out in a general framework by means of coupling the prevailing conditions in the country with the special requirements of the nuclear power industry in areas as the grid size, fuel cycle material demand and cost, and siting conditions.

Concerning the grid size, the demands for both electricity and desalted water during 1980-2000 are projected. The energy requirement for desalination using the Multi Stage Flash (MSF) distillation process is determined. The suitable nuclear unit sizes for the cases "power-only" and "dual production" are determined.

Concerning the fuel cycle material requirement, different fueling alternatives using uranium and thorium are selected for the Pressurized Water Reactor (PWR), Candu Pressurized Heavy Water Reactor (Candu-PHWR), High Temperature Gas Cooled Reactor (HTGR) systems, and compared with respect to total ore requirements, annual ore requirements for 1980-2000, and reprocessing requirements. The energy generating cost of the selected alternatives with PWR and Candu-PHWR systems is determined. The total nuclear fuel expenditure for the energy growth during 1980-2000 and reactor life time of 30 years is determined and compared with that for oil.

Concerning siting requirement, heavy load transport to the central part of the country is investigated. The thermal efficiency of each reactor when cooled directly by sea water is determined. Wet cooling and dry cooling tower characteristics, water requirements, and costs are determined for selected sites near Jeddah, Riyadh, and Dahran.

It is shown that nuclear units in the range 600-1300 MW(e) can be introduced starting from 1985, thorium fuel is not economical, local uranium needs not to be mined during 1980-2000, local reprocessing is not economical, the Candu-PHWR presents no significant advantage to the country, no constraint concerning the transportation of heavy loads to the central part is foreseen, the application of dry cooling towers for all inland siting is imperative and dry cooling towers with an Advanced Reactor System, e.g. Fast Breeder Reactor and High Temperature Helium Turbine Reactor, will result in the best operation conditions in the country.

Concerning the selection of a reactor system in the future, an Advanced Reactor System should be prefered on the basis that the industrialization of the country will highly benefit from the advantages associated with these reactors. However, if at time of selection only the Proven Reactor Systems (PWR, Candu-PHWR, Magnox) will be available, and the material requirement (e.g. enrichment for PWR, heavy water for Candu-PHWR) can be secured, the first choice should be the PWR on the basis of having world wide records of experiences in operation and maintenance and larger option of suppliers.

Saudi-Arabien, ein technisches Entwicklungsland und die Frage der Einführung der Kernenergie während der Jahre 1980-2000

Zusammenfassung

In dieser Arbeit wird die Möglichkeit, die Kernkraft in den Jahren 1980-2000 in ein Öl-exportierendes Land wie Saudi Arabien mit Hilfe der Kernbrennstoffe Uran und Thorium einzuführen, untersucht, und zwar im Hinblick sowohl auf die Erzeugung des Elektrizitätsbedarfs als auch auf die von entsalztem Wasser.

Die Untersuchung wird unter der Voraussetzung ausgeführt, daß die Bedingungen, die in bestimmten Regionen des Landes vorherrschen, mit den speziellen Anforderungen der Kernenergie-Industrie verbunden werden. Beispiele sind Netzgröße, der Materialbedarf für den Brennstoffzyklus, die Kosten und schließlich die Standortbedingungen.

Hinsichtlich der Netzgröße wird der Bedarf sowohl für Elektrizität als auch für entsalztes Wasser während des Zeitraums von 1980-2000 abgeschätzt. Der Energiebedarf für Entsalzung mittels der MSF-Methode (Multi Stage Flash) wird bestimmt. Die geeignete Größe für nukleare Einheiten wird für die Fälle "Power Only" und "Dual Production" bestimmt.

Bezüglich des Materialbedarfs für den Brennstoffzyklus werden verschiedene Alternativen mit Uran und Thorium ausgewählt, und zwar für den Druckwasserreaktor, den Candu-Druckwasserreaktor mit schwerem Wasser, für den Hochtemperaturreaktor mit Gaskühlung,

und in Beziehung gesetzt zu dem totalen Erzbedarf, dem jährlichen Erzbedarf für 1980-2000 und dem Bedarf an Reprocessing. Die Energieerzeugungskosten werden für ausgewählte Alternativen mit Druckwasserreaktor und Candu-System bestimmt. Die totalen Kernbrennstoffausgaben für das Energiewachstum während 1980-2000 und einer Reaktorlebensdauer von 30 Jahren werden angegeben und mit denen für Öl verglichen.

Hinsichtlich der Standortanforderungen werden die Transportmöglichkeiten für schwere Lasten zu zentralen Teilen des Landes untersucht. Der thermische Wirkungsgrad jedes Reaktors bei direkter Kühlung durch Seewasser wird bestimmt. Die Charakteristiken von Kühltürmen mit Naßkühlung und Trockenkühlung, die Wasseranforderungen und Kosten für ausgewählte Standorte bei Jeddah, Riad und Dahran werden angegeben.

Es wird gezeigt, daß nukleare Einheiten im Bereich 600 bis 1300 MWe von 1985 ab eingeführt werden können, daß Thorium-Brennstoff nicht ökonomisch ist, daß im gleichen Zeitraum das Uran nicht aus lokalen Uranminen (ökonomisch) gewonnen werden kann, daß lokales Wiederaufarbeiten nicht ökonomisch ist, daß der Candu-Reaktor keinen signifikanten Vorteil für das Land bietet, daß keine Begrenzung der Möglichkeit des Transports von schweren Lasten zu zentralen Teilen des Landes vorausgesehen wird, daß die Anwendung von Trockenkühltürmen für alle Inlands-Standorte erforderlich ist und schließlich, daß Trockenkühltürme in Verbindung mit einem fortgeschrittenen Reaktorsystem, z.B. dem schnellen Brutreaktor oder dem Hochtemperaturreaktor mit Heliumturbine die besten Betriebsbedingungen im Lande ergeben werden.

Was die Auswahl eines Reaktorsystems in der Zukunft anlangt, so sollte ein fortgeschrittenes System bevorzugt werden, weil die Industrialisierung des Landes am meisten von den Vorteilen gewinnen wird, die mit diesen Reaktoren verbunden sind. Wenn indessen zu gegebener Zeit nur die erprobten Reaktorsysteme (Druckwasserreaktor, Candu-Reaktor oder Mangnox-Reaktor) verfügbar sein sollten und die Materialerfordernisse (z.B. angereicherter Brennstoff, Schwerwasser) sichergestellt sind, dann sollte die erste Wahl der Druckwasserreaktor auf der Basis der Tatsache sein, daß weltweite Erfahrungen bezüglich seines Betriebs und seiner Instandhaltung vorliegen und wegen der großen Auswahl von Anbietern.

PREFACE

The present work is of a bit different character as the usual topics that have been treated by our chair. It is a thesis in which aside of special know-how more general knowledge was necessary than for a purely nuclear technological topic. The dissertation was brought to us by the candidate, who has made in the United States his "master degree" in nuclear engineering, and by his government.
In view of the situation in Saudi Arabia where no nuclear technology exists and not even a sufficiently educated reservoir of technical experts is available we came to the idea of the dissertation as it is now. The wish of the Saudi Arabian government to orient themself on nuclear technology, to educate slowly a reservoir of experts and perhaps also to aquire one or the other small nuclear reactor is understandable. The country has probably major deposits of uranium ore. Despite of the large stocks of oil, perhaps the greatest in the world, also Saudi Arabia knows that these deposits are limited. At the same time they have the intention to approach modern technologies and it becomes apparent that atomic energy in this respect offers a certain fascination, to which a technological developing country likes to open itself.

The present work develops a certain scenario from which one could start. The scenario does not ask to be followed either with respect to the technical details or with respect to the time range or with respect to the valuation of the reactors. The question of mining the own uranium ores is not treated in the frame of the work.

The reader should be convinced that the author is well aware of the problems of introducing modern nuclear technology in Saudi Arabia. This was one of the goals of the work.

I wish to the author as well as to his country that the work contributes towards finding the beginning for handling nuclear energy, - a task that might be infinitely more difficult than is known to most of the developing countries at the beginning of their work in the strange field. Here we have several examples - cases in which was started with a certain enthusiasm and great economical effort, and in which we often now see the problems of the way followed.

My advise is to proceed carefully in Saudi Arabia. Whether nuclear energy is introduced until the year 2000 or whether it takes much more time or whether the plans are postponed is an open question. This work shall contribute to make clear the complexity of the process. It shall give a frame for a possible way to proceed and it shall enable the responsible persons to see as many aspects of the problems as possible.

Professor Dr. Karl Wirtz
University of Karlsruhe and
Karlsruhe Nuclear Research Center

February 1980

ACKNOWLEDGMENTS

On January 8, 1976 His Excellency Ahmed Zaki Yamani granted me his personal permission to perform this research in Germany. A year earlier, the prominent scientist Professor Dr. phil. Karl Wirtz accepted to supervise it personally. Both dignitaries promised to support the work, each on his own capacity. Both maintained the promise and faith.

In addition, I am deeply indebted to Professor Dr. rer.pol. Rolf Funck (Leiter des Instituts für Wirtschaftspolitik und Wirtschaftsforschung, Fakultät für Wirtschaftswissenschaften, Universität Karlsruhe), Professor Dr.Ing. Heinrich Schoof (Fakultät für Raumplanung, Universität Dortmund), and Professor Dr.Ing. A. Bayer (Institut für Reaktortechnik, Universität Karlsruhe). They have evaluated the work and recommended it for the Ph.D. degree.

I extend my special thanks to those who offered valuable advises and suggestions. These are Professor Dr.Ing. Walter Köhler of INTERATOM, Professor Dr.Ing. S. Wittig (Leiter des Instituts für Thermische Strömungsmaschinen, Fakultät für Maschinenbau, Universität Karlsruhe), Dr. J. Bogen of BBC, Dr. V. Heinzel, and Abd El Maksoud of Egypte.

I am grateful to those who endowed me with their moral support, namely Dr.Ing. G. Keßler (Leiter des Instituts für Neutronenphysik und Reaktortechnik, Kernforschungszentrum Karlsruhe), Priv.Doz. Dr.Ing. K. Rehme, Professor Dr.Ing. U. Müller (Leiter des Instituts für Reaktorbauelemente, Kernforschungszentrum Karlsruhe), Priv.Doz. Dr.Ing. P. Jansen (Universität Karlsruhe), Dr.Ing. H.-J. Zech, and Dr.Ing. B. Goel.

Last not least, I am specially grateful to all my colleagues and members of the Institut für Neutronenphysik und Reaktortechnik.

Abdul Rahman Melibary
Nuclear Engineer
Ministry of Petroleum and Mineral Resources
Jeddah, Saudi Arabia

Table of Contents Page

1. Introduction 1

2. Saudi Arabia: A Presentation of the Country

2.1 Location 6

2.2 Governmental Development Plans 6

2.3 Technical Status

2.3.1 Universities 8

2.3.2 Research Centers 9

2.3.3 Science and Technology 9

3. Electricity and Water Demand Projection Scenarios : 1980-2000

3.1 Introduction 11

3.2 Electricity Demand Projection Scenarios: 1980-2000

3.2.1 Construction of two National Electricity Districts 12

3.2.2 Population Growth Scenarios for the Electricity Districts 13

3.2.3 Detection of the Average Growth Ratio 16

3.2.4 The Scenario for Electricity District A 20

3.2.5 The Scenario for Electricity District B 26

3.3 Water Demand Projection Scenarios: 1980-2000

3.3.1 Water Consumption Pattern During 1970-75 29

3.3.2 Formation of the Scenarios 31

3.4 Summary 36

Table of Contents (Continued) Page

4. Determination of the Nuclear Unit Sizes

4.1 Introduction 38

4.2 The Sizes for Power-Only Stations 39

4.3 Desalination 40

4.3.1 Thermodynamic Effect of Dual Production 41

4.3.2 Economic Incentives for Nuclear Desalination 42

4.3.3 Methods of Desalination 43

4.3.4 Desalination Practice in Saudi-Arabia 44

4.3.5 Desalination Energy Requirement for the Case of (MSF) Process 46

4.3.6 Performance Ratio, Flash Range, Water Yield 49

4.4 The Sizes for the Dual Production Plants 52

4.5 Conclusion 55

5. Investigation on Fuel Cycle Alternatives for the Energy Growth Scenarios: 1980-2000

5.1 Introduction 58

5.2 Present ore Utilization Practices 59

5.3 Possible Future Practices 66

5.4 Total U_3O_8 Requirements for the Energy Growth Scenarios (1980-2000): A Comparison between Alternatives 67

5.5 Comparison of the Annual U_3O_8 Requirement for the Period 1980-2000 only with World Uranium Supply and Demand 74

5.6 Reprocessing Requirements 76

5.7 Possible Economical Benefit when Replacing Oil with Nuclear Fuels 79

5.7.1 Nuclear Fuel Cycle Cost for 1000 MW(e) Unit Size 80

5.7.2 The Total Nuclear Fuel Cycle Expenditure for the Energy Growth Period 1980-2000 and Reactor Lifetime of 30 Years 86

Table of Contents (Continued) | Page

5.7.3 The Total Oil Expenditure for the Energy Growth Period 1980-2000 and Supply Lifetime of 30 Years 88

5.7.4 The Magnitude of the "Monetary Gain" 90

5.8 Conclusion 98

6. Investigations on Siting Requirements of a Nuclear Power Station

6.1 Introduction 101

6.2 General Siting Considerations

6.2.1 Availability of Land, Land Size, Accessibility for Heavy Loads 102

6.2.2 Heavy Loads Transport to the Central Region 104

6.2.3 Heavy Components of a Nuclear Power Station 105

6.3 Condenser Cooling Requirements and Estimation of Reactor Efficiency at Locations along the Red Sea and the Gulf

6.3.1 Cooling Systems Alternatives 108

6.3.2 Meteorological Conditions in the Country 109

6.4 Application of the Direct Cooling Option 109

6.5 Cooling Towers

6.5.1 Thermodynamics, Meteorological Effects 117

6.5.2 Determination of the Characteristics for Wet Cooling Towers and Dry Cooling Towers with PWR and HTGR at Three Locations near Jeddah, Dahran, Riyadh 121

Table of Contents (Continued) Page

6.5.2.1 The Case of PWR System 122

6.5.2.2 The Case of HTGR System 128

6.6 Conclusion 129

7. Conclusion and Recommendation

7.1 Why Consider Nuclear Power ? 132

7.2 The Choice of the Reactor Type: A Comparison of Alternatives 135

7.3 What Alternatives are Available to Saudi Arabia ? 140

7.4 What Proven Reactor System Should be Selected ? 143

7.5 Recommendations about Procedures 153

Explanation of Abbreviations 159

References 161

Tables 172-208

Figures 209-271

1. Introduction

A distinctive feature of this work in terms of its timing is the fact that it is performed at a time preceding the country's decision on whether to remain for the next couple of decades on its tradtional energy supply sources, namely oil and gas, or whether a new alternative should be adopted.

The argument for continuing on the traditional path is based on the following three points:

- The country has large reserves of petroleum (e.g. over one third of the world's reserves), and hence there can be no concern over resource scarcity at least for the foreseeable future.

- The local consumption of petroleum is relatively modest, and it is seen that the consumption in the coming years will not increase so drastically as to hinder the exporting position of the country.

- The shift to a new energy alternative, e.g. nuclear fuels, can result in reliance on foreign suppliers, and thus subject the country's power industry to policy oscillations that may take place in the supplier's country.

These rather conservative points are so far taken for granted in the country. They actually represent the opinions held by most of the small and misorganized electricity generating companies, which are in the first place reluctant to face the new obligations that can arise with the advent of an alternative energy source.

In contrast, the argument for developing a second alternative in the country is supported by a number of intellectuals (inside and outside the country), and very specially by certain well organized governmental authorities such as Water Desalination Organisation (WDO), Ministry of Petroleum and Mineral Resources (MP & MR), and Ministry of Central Planning (MCP).

The supporting points here are:

- In Saudi Arabia, a member of the free world community, the planning for the development of its future energy system must be correlated with the electricity supply capacity of the market in the free world, especially since the technical status of the country is not advanced enough to support and maintain any energy system, conventional or otherwise, which may be diminishing in Europe and USA.

  That is, if a given energy alternative (e.g. nuclear power) is growing to domination in those countries which are the main supplier of Saudi Arabia, then the inspection of this alternative is only a natural step which must be fully taken into consideration.

- Saudi Arabia is a major oil producing country. But, unfortunately oil revenues constitute the main source for foreign currency. On top of this, the potential industries for the next 10-30 years are also of the energy intensive type (e.g. refinaries, petro-chemicals, fertilizer industries, aluminium, steel, etc.)

  Thus, there is a somewhat paradoxical situation, where oil becomes both the means through which government finances the country's economical and social developments (through oil exporting), and is the principle means for national income diversification (through energy intensive industries). This situation, therefore, is sufficient for inspecting the possibility of developing a second source of energy in the country.

- Not only electricity generation constitutes the market for energy, another area which looks forward to a very dependable energy source is fresh water production from the sea (e.g. desalination).

However, while the above mentioned points are persuasive to a large extent, they have never been so far tested in close interactions with the conditions in the country.

And thus, it is well recognized that these points must first be subjected to several investigations before they can be crystallized properly.

Accordingly, this work aims to initiate such studies. However, the effort will here be concentrated on the field of nuclear power (only), as the alternative to consider. This is so for two reasons:

- Nuclear power is actually the only large scale energy alternative at least for the next 15-30 years to come. The worldwide prediction is that in the course of 1980-95 the share of electricity generated by nuclear fuels will reach up to 50%.

- On top of this, the country has large quantities of uranium. If the technology is made available, then uranium should be be considered the first candidate for replacing petroleum or simply as the second energy source in the country.

The Objective of the Work

An investigation considering the introduction of a totally new energy source to the country must be obligated to confine its objectives to those fundamental areas which can lead to the right conclusion (e.g. feasible or not feasible).

But, since nuclear power is the alternative considered here, casting light on all fundamental questions through such a "first effort" investigation is recognized from the start not possible for two reasons.

Firstly in connection with the situation in the country:

Well organized 5 year development plans are executed in the country. But, while these plans place a special emphasis on the target of diversifying the national income (e.g. through energy intensive industries), there are no plans for diversifying the country's energy system itself (except for few researches on solar energy).

Thus, progresses all along such a transitional state of the country a "vacuum" as far as the development of the energy system is concerned.

With respect to nuclear energy this "vacuum" means the total absence of a conceptual view of how nuclear power may exist in the country. And hence, the country is deprived of "nuclear intelligence" concerning with collection of background information and data evaluation and updating.

Secondly in connection with nuclear power:

The shift to nuclear power does not resemble the case of replacing coal fired stations with oil fired ones. It is more or less similar in nature to the adaption of hydro stations, where certain requirements and constraints can dictate differently from country to country, or even from one location to another within the boundary of a country.

Therefore, due to both the absence of "nuclear intelligence" in the country and the special nature of nuclear power (as requiring detailed investigations for each location separately), this "first effort" investigation aims at formulating the general lines of knowledge through which for the first time a "nuclear thought" for the country can be visioned.

Saudi Arabia is a Developing Country having two distinctive features:
(1) Being an oil producing country
(2) Having arid climate

Keeping this in mind, the objective of this work is divided into two parts:

First, to find out is it possible to introduce nuclear power plants during the period of study?

Second, if the answer is YES, then: What type of the different reactor systems should be selected?

A distictive feature of most of the oil countries is the small grid size made of small units due to low population density and low electricity consumption per capita. Opposing to this, a NPP is only economical in large sizes.

This means that one can get the answer YES only if there is sufficiently large energy market in the country.

The criteria for selecting a reactor type must be seen from the above mentioned two features of the country, namely having large oil supply but in arid climate.

That is, since oil is abundant locally, the consideration of nuclear fuels raises questions on resources:
How much in prices?
Where to get it?

Answers to these questions can be provided only by comparing the NFC alternatives of the different reactor systems in view of the ore requirements for the future energy growth.

The arid climate raises the important question of how much water must be supplied daily as make-up water for reactors cooled with wet cooling towers?
And how large is the cost penality when using the alternative of dry cooling towers?

2. Saudi Arabia A Presentation of the Country

2.1 Location

The Kingdom of Saudi Arabia is bounded to the West by the Red Sea and the Gulf of Agaba; to the East by Muscat and Oman, Qatar, and the Arabian Gulf; to the North by Jordan, Iraq, and Kuwait; to the South by Yemen, Aden, and Hardramout (see Fig. 1).

The total area of Saudi Arabia is 2149690 km^2. The distance between the coasts and the boundaries are as follows:

Western Coast	=	(over)	1770 km
Eastern Coast	=		483 km
N. Boundaries	=		1368 km
S. Boundaries	=		1287 km

2.2 Governmental Development Plans: Goals and Strategies

Starting from 1970 the government of Saudi Arabia has organized development plans to be executed in 5 year periods. The first of these was implemented during 1970-75. Table 1 attempts to summarize some highlights of this plan.

By the end of 1980 the implementation of the country's second 5 year plan will be terminated. The development strategies for this plan consist of 3 key elements, these are:

1) Diversification of the economic base through emphasis on increasing agricultural and industrial products:
   This strategy lays out the fundamentality of future economic self-sufficiency as oil revenue gradually declines, and therefore, large investments are to be made in industrial

ventures based on natural gas and mineral resources. Investment in other industries will be encouraged. Agricultural products will be stimulated.

2) Rapid development of the country's manpower resources: Features of such development include:

   a. Increasing the number of both Saudi and non-Saudi citizens in the labor force

   b. Raising the productivity of the labor force by education and training and creating a productive work environment

   c. Shifting manpower out of the agricultural sector into other sectors with expanding opportunities for employment at higher levels of productivity and income

3) Development of the economic regions of the country by wide distribution of productive investment based on the distinctive physical and human resources of each region.

This strategy is intended to distribute the wealth, at present generated by the country's oil revenues, to all sectors of the country, which is divided into 5 socio-economic study sectors as shown in Figure 2.

Accordingly, the strategies for each region are designated as follows:

Central Region

Continued development of Riyadh as the administrative capital of the Kingdom; the development of industry not requiring large quantities of water; the development of large scale agricultural projects in rural areas.

Eastern Region

Major development of hydrocarbon based industry and agricultural development in areas of high potential

Western Region

Pipeline transfer of hydrocarbons for the formation of a second industrial growth pole; continued development of commercial, pilgrimage, and tourist activities of the main cities; agricultural development in rural areas.

South Western Region

Agricultural development; domestic tourism in the highlands; industry as feasible, minerals development.

Northern Region

Agricultural development; minerals development; industry as feasible.

2.3 Technical Status

2.3.1 Universities

There are already 3 well established universities which are located in the three most dynamic regions, namely the central, the western and the eastern regions. The oldest and largest of the 3 universities is the University of Riyadh at Riyadh (central region). It consists of 10 departments with an enrollment distribution as follows (as of 1976):

Education	17%
Science and Eng.	20%
Commerce	19%
Arts	19%
Agriculture	13%
Medicine	12%

The second university is located at Jeddah, the King Abdul Aziz

University. It consists as of now 6 departments and the enrollment distribution is as follows:[1]

Islamic Laws	29%
Education	33%
Science	2%
Economics	22%
Arts	14%

The third university is the University of Petroleum and Minerals at Dharan (eastern region). This institution is specialized in preparing the technical manpower for the petroleum and mineral industry of the country. It is also expected to become the site for a research complex including solar and nuclear energy.

2.3.2 Research Centers

Even prior to the implementation of the 5 year plans, the needs for local researches pertaining to subjects of vital importance to the well-being of the country have been recognized.

Some of the well planned research centers are in the field of water production and transportation, agriculture, petroleum, minerals, and industrial studies. Table 2 summarizes the activities carried out at some of the centers in these fields.

2.3.3 Science and Technology

The emphasis in the development of science and technology in the country is based on the selection, transfer, and management of existing foreign technology. But this in itself is constrained by two major obstacles. Firstly, much of the technology transferred from foreign countries is actually created to meet needs and conditions different from those existing in Saudi Arabia.

---

(1) Recently King Abdul Aziz University established an Engineering College

For this reason it was concluded that some modification must be carried out to most of the transferred technology. Such modification, however, calls for locally developed techniques and firmly established policies. Secondly, there are very few Saudis trained in research and those experienced in research management are extremely scarce.

Very recently, a Council for Science and Technology was established. It is an independent body which reports directly to the Council of Ministers. Its delegated function is to formulate and continuously update a Science and Technology Plan setting the priorities for various R&D targets.

This plan assigns the priority to research targets with potential for increasing value added to exported oil products or decreasing the country's dependence on revenues generated by exporting low value added hydrocarbons. Such research targets will necessary include:

1) Economically upgrading saline, brakish or sewage water through utilization of alternative sources of energy, e.g. nuclear, solar etc.

2) Further development of microbiological methods of producing proteins from hydrocarbons for animal feed or for supplementing the present low protein diet of the citizens.

3) Estimating in each research area the probability of technical success and the availability of scarce resources, especially trained manpower, coupled with the socio-economic impact of applying the results.

The backbone of this plan is the joint venture R&D agreements with foreign organizations abroad, which calls for the invitation of competent foreign organizations to set up laboratories in Saudi Arabia, and sending young Suadi graduates for training abroad.

3. Electricity and Water Demand Projection Scenarios: 1980 - 2000

3.1 Introduction

At the start of the second 5 year plan in 1975, electricity generation in the country was in the hands of private companies operating with small units. There were 261 stations, having a total installed capacity of only 1256 MW(e).

In addition these small units were not interconnected to a grid, but rather each was operated to satisfy the needs of a community nearby its location. This was a setback which imposed an unbalanced distribution of electricity such that every city has always suffered either from a shortage or excess at one suburb or another.

This situation, in turn, gave rise to the need for generating electricity individually as required by establishments such as hospitals, refinaries, cement complexes and road cross-overs. The immediate effect of which was the birth of an "unorganized" generation of electricity, which only contributed to further maldistribution.

In fact this predicament is much reflected in those data reported by the Statistical Year Books (ref. 2), whereas only figures supplied by companies operating in major cities are compiled, and thus failing to indicate the actual consumption in the country.

However, in order to come out of this dilamma the Ministry of Central Planning (MCP) carried out a comprehensive survey for the year 1975 which enabled drawing a program for the erection of modern electrical grids, with the first step being the interconnection of all existing and new plants and reducing the number of units as much as possible.

In addition, the MCP made forecasts for both electricity and water requirements for the year 1980. These were conceived in close connection with the development program during 1975-80 and development potentialities at each sector of the country. Large expansions in the installed capacities were foreseen.

Further, from 1980 to 2000 four more 5 year plans will be executed. The parallel expansion of the installed capacities, however, will depend on the strategy followed at the execution of each of the 5 year plans. Therefore, a definite forecast for the period 1980-2000 cannot be made in advance.

In this part of the work, the following are to be performed:

- Detect the consumption trends up to 1980
- Construct scenarios in terms of development possibilities
- Project electricity and water requirements (1980-2000) in accordance to the scenarios

3.2 Electricity Demand Projection Scenarios ; 1980 - 2000

3.2.1 Construction of Two National Electricity Districts

The erection of one national electrical grid was concluded highly impossible due to the vast distances between the main consuming areas (e.g. Riyadh - Jeddah: 1061 km; Dammam - Jeddah: 1528 km). Consequently, electrical grids were envisaged in terms of regional connections. In Figure 3 the MCP depicts the conception of two large national grids, one connecting the eastern sector with the central; the other connecting the Mecca province with the south-western sector.(1)

(1) The figure also depicts an example of local interconnection (e.g. Medinah with Yenbu); such interconnection will be applied in future to the northern part of the country, as electricity demand grows.

The scenarios developed in this work consider the two large conceptual grids. These are named here as:

(1) Electricity District A (abbreviated as: District A) comprising,

1) Riyadh Province (Riyadh city, Al-Kharj, Khurays, etc.)
2) Qasim Province
3) Eastern Province (Dammam, Khobar, Qatif, Al-Hasa)

(2) Electricity District B (abbreviated as: District B) comprising,

1) Mecca Province (Mecca, Jeddah, Tayif, etc.)
2) Assir Province
3) Jizan Province

(Note: These two grids covered in 1975 over 76% of the total population in the country)

3.2.2 Population Growth Scenarios for the Electricity Districts

The rate of the population growth during 1980-2000 cannot be expected to be uniform throughout the different provinces, because although development of the country involves all of its different parts, the degree of such development, however, must be necessarily higher at high potential areas than at the rest.

The highest potential area for extensive population concentration, especially during 1980-90 (the periods for the third and fourth of the five year plans), is the eastern province, where the construction of a chain of hydrocarbon based industries are well expected. Next are Riyadh city and Jeddah.

Published figures for the population growth are different from source to source. The figure used currently by some agencies in the country is 3.2% yearly growth rate, while reference 4 uses 1.7% and reference 5, 2.8 - 3%.

Using these published figures, the following population growth rate scenarios are made out of a balance considering the potentialities of the provinces involved in the respective electricity districts:

District A

Eastern Province :	1975 - 1985 :	3.2%
	1985 - 1990 :	3.0%
	1990 - 1995 :	2.5%
	1995 - 2000 :	2.0%
Riyadh Province :	1975 - 1980 :	3.0%
	1980 - 1990 :	2.5%
	1990 - 2000 :	2.0%
Qasim Province :	1975 - 2000 :	2.0%

District B

Mecca Province :	1975 - 1980 :	3.0%
	1985 - 1990 :	2.5%
	1990 - 2000 :	2.0%
Others (Jizan, Assir)	1975 - 2000 :	2.0%

The reasons for selecting this population growth rate scenario are:

1) The figure 3.2%, used only in connection with the eastern province, is reasoned out to account for population mobilization to this province from the least potential ones

(e.g. south-western, Qasim, northern provinces) during the three consecutive 5 year plans (1970-85). During the fourth 5 year plan the effect of mobilization is thought to slow down progressively until the year 2000.

2) The figure 3.0% is used for both Riyadh and Mecca provinces, but in the case of the Riyadh province for a 5 year period only. This is so because unlike the Mecca province [1] the development potential of the Riyadh province is centered around Riyadh city only. Further, since the Riyadh province is treated as a whole, a 5 year period growth at the rate of 3.0% is reasoned sufficient.

3) For the areas least potential in development during 1980-2000, the figure 2.0% is used as the minimum population growth ratio. The figure 1.7% given in reference 4 is found not fully representative, because it was estimated in the absence of the more dependable population censuses which have appeared since 1975.

Accordingly, the follwoing values are used:

	No. of Population $(10)^6$	
	District A	District B
1975	2.358	2.987
1980	2.723	3.396
1985	3.107	3.860
1990	3.534	4.325
1995	3.935	4.775
2000	4.342	5.272

These values will be applied in the following electricity demand projection scenarios

(1) Mecca and Jeddah are twin cities. Both represent centers of development.

3.2.3 Detection of the Average Growth Ratio

The growth ratio (GR) in a given society describes its economical and social activities. Quantitatively, it is expressed as the ratio of the percentage increase in the Gross National Product ($GNP_{incr.}$) to the percentage increase in the yearly electricity consumption ($P_{incr.}$). To determine this ratio, therefore, both (%) $GNP_{incr.}$ and (%) $P_{incr.}$ must first be determined.

1) Average Growth Ratio (GR) for the Period 1966-1975

Percentage Increase in Yearly Electricity Consumption, (%) $P_{incr.}$

Figure 4 presents the plot of (%) $P_{incr.}$ during 1966-75, as reported by the Statistical Year Books. This shows, since the start of the first 5 year plan (1970), the (%) $P_{incr.}$ went lower than the period before.

That is, of course, a contradicting situation, because logically the execution of the development plan must be accompanied by a larger consumption of electricity than before. The only interpretation for such a contradiction is seen through the limitation of the data source, in that the electricity consumed by the private companies which have participated in the implementation of the plan must not have been registered.

The (%) $P_{incr.}$ during 1973-74 was only 4.8% compared to 16.4% for the immediate preceding period (1972-73). The reason is possibly due to the long shut down of the desalting plant at Jeddah in 1973, which produced simultaneously some 50 MW(e).

In conclusion, the average value for (%) $P_{incr.}$ during 1966-74 is determined to be 20% at an average load factor (L.F.) of 33.31%

Yearly Percentage Increase in the Gross National Product, (%) $GNP_{incr.}$

The values used for the percentage increase in the GNP are those tabulated in ref. 4, which is the only available source for such information covering the period from 1970-2000. Values for the period prior to 1970 are not explicitly stated in the reference. However, they can be deduced from similar information.

Accordingly, the following values for (%) $GNP_{incr.}$ are considered:

1965 - 70 = 7.6% (deduced) (1)

1970 - 75 = 8.5% (stated in ref. 4)

Yearly Average Growth Ratio (GR)

Using the above determined values of (%) $P_{incr.}$ and (%) $GNP_{incr.}$, the GR for the period 1966-74 is determined as presented in Figure 5. The cycling appearance of the actual curve must be associated with the fluctuation of the oil income of the country, which is mainly dependent on the world wide economical situation. The influence of which is much pronounced at the end of the curve, probably referring to the years of the oil boom.

The 1974 data was additionally influenced by the slow increase in the electricity consumption (1973-74), due to the plant shut down as mentioned earlier.

The cyclic nature of the curve makes the reading of the average value impossible and therefore it was smoothed out, from which the average GR value is read to be (0.599 or 0.6).

(1) The calculation is based on the following data /4/,
For 1967: GNP/cap = 335 US Doll. Population = 6.99×10^6
Yearly (GNP/cap) Incr. = 6.10% Yearly Popu.Incr.=1.7%

2) Average (GR) for the Period: 1975-80

For this period the (%) $GNP_{incr.}$ is known, namely equal to 8.3%. Thus one needs to determine the (%) $P_{incr.}$.

Figure 6 presents 5 plots [(1)]: Curve a depicts the projected electricity generation growth during 1975-80 for the total country. Its largest three components are also individually presented.[(2)]

Curve e is also for the total country. Its first part (1968-74) is plotted from recorded data. The data for the last part is deduced from knowing the (%) $GNP_{incr.}$ =8.3%, aver. GR = 0.599, and hence, (%) $P_{incr.}$ = 13.86%.[(3)]

From this follows:

1. The value of electricity consumption in 1975 according to curve e is 13.86 x 10^8 and accroding to curve a is 24.20 x 10^8 KWh/y. This explains the comprehensive nature of the data represented by curve a.

2. The 1980 projection for the eastern sector constitutes the largest components (63% of the total). There are two reasons for this. Firstly, it includes the shares of the oil companies. Secondly, at this sector the governmental efforts are so intensified with the targets of diversifying the national economy primarily based on hydrocarbon down line products.

Now in reference to the curves a through d, the following average

---

(1) Curves a through d are in accordance with the 1975 survey of the MCP. Curve e is in accordance with the Statistical Year Books.

(2) Two other components of curve a, namely the projections for the south western and the northern sectors are not presented, because of their negligible values.

(3) For the entire curve e, average (%) $P_{incr.}$ = 16.8%

values for the (%) $P_{incr.}$ and GR are obtained:

	Average (%) $P_{incr.}$	Average (GR)
Total Country	33 %	0.25
Eastern Sector	37 %	0.22
Central Sector	23 %	0.36
Western Sector	27 %	0.31
Combined 3-Sectors	29 %	0.30

The following discussion considers the values associated with the combined 3 sections. The average GR value for the period 1975-1980 is lower than that for the earlier period. It is depressed by a factor of 2 (0.298 compared to 0.599).

This, however, must be natural, since the average percentage increase in the yearly electricity consumption for the period 1975-80 is nearly twice as much as determined in reference to curve e (e.g. 29% compared to 16.8%).

This means the value for (%) $GNP_{incr.}$ for the period 1975-80 given in ref. 4 is not valid any more, because it is based on growth trends up to 1968 only and does not include the additional income resulting from the oil price increases since 1973. Thus, new values of GNP must be applied.

In the absence of the publication of such new values, however, one can only rationalize that the nearly double increase in (%) $P_{incr.}$ must have been paralleled by a similar increase in the (%) $GNP_{incr.}$ (e.g. 8.3 to 16.6%), which then gives for GR = (0.166)/(0.29) = 0.572, much closer to the value obtained for the earlier period.

Thus, with 0.572 growth ratio deduced from 1975-80 projection, and 0.599 determined from recorded statistics, the average GR for 1968-1980 is established here as 0.586 (or 0.6).

3.2.4 <u>The Scenario for Electricity District A</u>

In order to come out with a reasonable projection, two boundary values must be applied.

First: The growth ratio determined earlier as the base value for calculating the increase in electricity consumption during 1980-2000.

Second: The electricity consumption per capita in an industrialized country (e.g. U.S.A.) as a limit value not to be exceeded at any time.

Selecting a limit value is seen as very necessary, because in the main part of the district, namely the eastern province, the electricity development projection during 1975-80 already accounts for a sharp development such that the installed capacity in 1980 will reach some 4.5 fold that in 1975. More expansion of the installed capacity will be necessary as consecutive development plants proceed, but how much expansion is a question which can be answered realistically only in the light of the outcomes of the programs. Thus a limit value must be applied.

Further, taking U.S.A. as an example is only having it on the optimistic side, since one cannot actually predict a real comparison to exist between the future industrialization of District A with that in the U.S.A.. The only justification, however, is that high availability of oil and gas at almost transport free cost leads to the expectation of higher electricity consumption per capita in this district.

<u>First Trial:</u>

The percentage increase in the yearly electricity consumption is found by calculation as follows:

	(%) Pincr.
1980 - 85	25.6%
1985 - 90	23.9%
1990 - 95	22.2%
1995 - 2000	20.1%

Now before establishing these growth values (1), the resulting future electricity consumption per capita must be tested against the limit-value in order to assure their applicability. This is shown in Figure 7. Nummercically it is expressed as follows:

	Electricity Consumption (2) Per Capita (KWh/y)/cap 10^3	
	District A	USA(ref.4)
1980	7.92	14.0
1985	22.04	17.0
1990	56.80	21.75
2000		31.00

This shows that in 1980 the consumption per capita of the district would be equivalent to the US 1970 value. This means that at the start there will be a gap period of 10 years between the values of the district and the USA, in favor of the latter.

Buth within the 5 year consumption expansion period, the consumption per capita of the district will be tripled reaching what would be reached by USA in 1990. That is, the gap period became shorter by 5 year but turned in favor of the district.

(1) The values are obtained by using the (%) increase in GNP values given in reference 4, but corrected with the factor 2, and the average growth ratio established in this work: 0.586

(2) Yearly Electricity Consumption (in 1980) = 21.56×10^9 KWh/y

Within the next 5 year period, the consumption per capita of the district will be more than doubled, exceeding the US value of the year 2000 by a factor of 1.8 times.

In terms of the expansion in installed capacity, it is as follows:

	Installed Capacity (1) MW(e)
1980	3692
1985	11553
1990	33872

That is, within 10 year period the grid must be expanded by a factor of 10, a procedure that unlikely will take place.

Second Trial

The first trial clearly indicated that the values of the average growth ratio from 1980 - 2000 must be somewhat lower than from 1968 - 1980, and consequently a lower percentage in the increase of the yearly consumption can be obtained. To do so, the combination used in this second trial is as follows:

% increase in GNP values without correlation with the factor 2. Average growth ratio determined by using the values representing the growth trends as determined earlier by the two different data sources, namely 0.599 and 0.298.

Accordingly,

	(%) $P_{incr.}$
1980 - 85	16.7%
1985 - 90	15.6%
1990 - 95	14.5%
1995 - 2000	13.1%

(1) Installed Capacity = (Year Average Demand × 1.5)

The resulting electricity consumption per capita is tested again against the USA values (Figure 7). Numerically, it is compared as follows:

	Electricity Consumption Per Capita (KWh/y)/cap 10^3	
	District A	USA(ref.4)
1980	7.92	14.0
1985	15.02 (1)	17.0
1990	27.26	21.75
1995	48.18	25.9

(1) corresponds to US-1982 Value

It should be noticed that the only effect of applying a lower percentage increase in the yearly consumption rate in this trial over the one before is that the starting 10 year period gap will be by 1985 lowered to a 3 year period, still shifted toward the US values. By 1990, however, the gap will be already overtopped.

Conclusion

The percentage increase in the yearly electricity consumption rates as calculated in the second trial are the lowest values that can be obtained from averaging the past trend based on the two different data sources. These values must be used as the base values for future projection, yet their application must be conditioned in order to remain within the limit values selected in this work.

Now to have a feeling of how to do such a conditioning, one must look back at the effect of the 75-80 projection on the consumption per capita.

In 1975 the consumption per capita of District A was 2.14×10^3 (KWh/y)/cap. It was equivalent to US 1945 value. In 1980 it will be pushed up to 7.92×10^3, leveling with the US 1970 value. Thus a gap of a 25 year period was shortened within 5 years.

Therefore, one rationalizes that after experiencing such a rapid jump up, it seems logical to maintain this 10 year period gap from 1980 to 2000 unchanged or narrowed progressively, subject to development strategies as conceived below:

After executing the country's fourth 5 years plan which will terminate by the end of 1990, there can be two strategies.

(1) Either hydrocarbon based industries will reach saturation.
(2) Or it will need one or two more 5 year plans to reach saturation level.

In the first strategy the development programs will shift from 1990 on from District A to District B, in order to prepare for the exploitation of the mineral resources as a means of enhancing the national economy after the year 2000. In the second strategy the intensive effort will remain on the side of District A.

The effect of these two strategies are accounted for in the projection scenarios as designated into three cases:

Case A

In this case the consumption per capita values at District A are maintained within the starting 10 year period gap from 1980 up to the year 2000. This case represents the possibility of reaching saturation in hydro-carbon industries by 1990 such that the increase in electricity consumption per capita from 1990 to 2000 will progress slowly toward its satuaration line as set by the US 1990 value (Figure 7).

Cases B and C

The consumption per capita values are maintained within a 5 year period gap from 1990 - 2000 (case B) or it approaches gradually the US 2000 value (case C). These cases represent the possibility of executing additional development plans, the fifth 5 year plan (case B) and the sixth 5 year plan (case C).

By trial and error, the above preset targets for the scenario-cases are reached as follows:

	Electricity Consumption Per Capita (KWh/y)/cap $(10)^3$			
	Case A	Case B	Case C	USA
1980	7.92	7.92	7.92	14.0
1985	13.77	13.77	13.77	17.0
1990	19.21	19.21	19.21	21.75
1995	21.69	23.60	24.29	25.9
2000	22.14	25.93	28.52	31.0

The percentage increase in the electricity consumption per capita, 1980-2000, and the corresponding total yearly electricity generation, and the necessary expansion in installed capacity are plotted for the three cases of the scenario on Figure 8 (The numerals are given in Table 3).

From this follows:

(1) While the consumption per capita increases, percentage wise it takes a decending order. This is the process of conditioning used in the scenario in order to maintain the per capita values within the preset values. The point to emphasize is that since this decending line is constructed on the basis of the trend which is consistent from 1986 up to 1980, it definitely represents the future line for all reasonable projections. The difference from one projection to another will be dictated by the steepness of the line.

(2) The corresponding installed capacities are:

	Installed Capacity MW(e)		
	Case A	Case B	Case C
1980	3692	3692	3692
1985	7326	7326	7326
1990	11625	11625	11625
1995	14621	15921	16370
2000	16459	19276	21205

This evidences that the scenario is very reasonable in that it accounts for the doubling of the installed capacity within the first 5 years. This high increase in electricity is seen necessary for supporting the third and fourth 5 year plans. The next doubling will take place within 10 years period. Then it doubles no more. In case A, the installed capacity in the year 2000 will be 4.5 fold its capacity 20 years earlier. For the more optimistic case, case C, it will be only 5.7 times. These values are very reasonable to expect.

3.2.5 The Scenario for Electricity District B

Since development intensity in the regions covered by the Electricity District B will be less than the regions covered by the District A, electricity consumption will naturally be less also. The question is then how much less?

To answer this question, the following compares the consumption situations in the regions covered by the two districts in 1975 and 1980:

1975 Comparison[1]

	Consumption/cap (KWh/y)/cap 10^3	Equivalent to USA (year)	Installed capacity in the country MW(e)
District A	2.14	1945-value	907
District B	0.704	1925-value	328

1980 Comparison[2]

	Consumption Per Capita (KWh/y)/cap $(10)^3$	Equivalent to USA (year)	Consumption per capita over 75 value	Installed Capacity in the Country MW(e)	Installed Capacity Over 75-value
District A	7.92	1970-value	3.7 fold	3692	4.07 fold
District B	2.21	1947-value	3.14 fold	1286	3.92 fold

From this follows:

(1) A 22 year gap between the USA value and the consumption per capita value of District B is slightly reduced during 75-80.

(2) The ratio of the consumption per capita for the two districts is as follows:

	1975	1980
$\frac{\text{(Consumption/Capita) District A}}{\text{(Consumption/Capita) District B}}$ =	3.04	3.58

---

(1) Average Yearly Electricity Consumption:
District A = 5.05×10^9 KWh/y
District B = 2.10×10^9 KWh/y

(2) Average Yearly Electricity Consumption:
District A = 21.57×10^9 KWh/y
District B = 7.51×10^9 KWh/y

(3) The ratio of the installed capacity is:

		1975	198o
$\frac{\text{(Installed Capacity) District A}}{\text{(Installed Capacity) District B}}$	=	2.77	2.87

Thus, it is clear that although the consumption per capita and the installed capacity in District B will by 1980 increase nearly 3 and 4 fold, respectively, over the value in 1975, the ratio value of District A to District B will only slightly change from 1975 to 1980.

Therefore, it is found reasonable to construct the scenario for District B maintaining the 1980 ratio value, namely:

Consumption/Capita	1 : 3.58
Installed Capacity	1 : 2.87

The scenario is made out of two cases: case A' and case B'. In case A', the (%) $P_{incr.}$ is maintained similar to that of case A of District A. In case B', it is with respect to case C of District A.

Accordingly, the results are tabulated in Table 4 and depicted in Figures 9 and 10, whereas the above determined ratio limits are achieved to a good approximation.

Development Possibilities One and Two

If the development intensity from 1990 to 2000 remains in the District A side, then the total electricity generation in the two districts will follow the combination of the cases:

case C (District A) + case A' (District B)

This combination is designated in this work as Development Possibility One, representing the total country.

Conversely, if the development intensity shifts to the District B side, the total generation will follow the combination of the cases:

case A (District A) + case B' (District B)

This combination is designated in this work as Development Possibility Two, representing the total country.

Figure 11 compares the total installed capacity requirements for either development possibilities.

3.3 Water Demand Projection Scenarios: 1980-2000

3.3.1 Water Consumption Pattern During: 1970-1975

The pattern of water consumption and electricity consumption are compared for the period 1970-75 in the following presentation which is based on data from the Statistical Year Books:

Year	Water Consumption (W) m^3/y $(10)^7$	Water Consumption (W) m^3/y $(10)^4$	(W) Per Number Of People Served	Electricity Consumption (P) KWh/y $(10)^7$	(P) Per Number Of People Served	Ratio: W/P	% Incr. in Yearly Water Cons. ($W_{incr.}$) (%)	% Incr. in Yearly Electr. Cons. ($P_{incr.}$) (%)
1970	4.83	13.24	0.021	72.43	113.89	0.067		
1971	5.40	14.80	0.023	80.21	123.03	0.067	11.78	10.74
1972	6.10	16.72	0.025	99.98	149.67	0.061	12.97	24.65
1973	6.39	17.52	0.026	116.34	169.91	0.055	4.78	16.41
1974	8.15	22.33	0.032	121.96	173.75	0.067	27.45	4.70

From this follows:

1. The number of people consuming water are slightly less than the number consuming electricity,[1] indicating shortage of water even at areas where electricity is available.

2. The above data does not truly represent the water consumption in the country according to the <u>demand</u>, but rather in accordance to water <u>availability.</u> This is very much pronounced for the two years 1970 and 74, where the percentage increase in water consumption, (%) $W_{incr.}$ exceeded that in electricity consumption, (%)$P_{incr.}$. The reason is that in 1970 a desalting plant with the capacity of 19 thousand m^3/d went into production at Jeddah. In 1974 a larger one (28×10^3 m^3/d) enhanced the water supply system at Al Khobar.

3. The values of (%)$P_{incr.}$ are generally higher than those of (%)$W_{incr.}$ but the ratio of water to electricity consumption, $R_{W/P}$, is almost constant [2].

   Furthermore, this value of $R_{W/P}$ is nearly the same as that when considering the "more comprehensive" data of the Ministry of Central Planning, as follows:

Total Requirement
(1975)

(W)	(P)	$R_{W/P}$
m^3/y $(10)^7$	KWh/y $(10)^9$	
17	2.4	0.071

---

(1) No. of Consumers (in Million)

	(P)	(W)
1970	6.36	6.31
1971	6.52	6.44
1972	6.68	6.69
1973	6.85	6.74
1974	7.02	6.98

(2) It was, however, off-set in 1973, probably due to the long shut down of the dual production plant at Jeddah.

3.3.2 Formation of the Scenarios

To form the scenarios, 3 questions must be answered first.
Which areas are to be served by the water grids?
What are the appropriate values of $R_{W/P}$ for the period 1980-2000?
What are the boundary limiting values?

The answers to these questions are developed below:

(1) Service Areas of the Water Grids

The objective here is to project the water requirement at those areas which are served by the two Electricity District A and B, in order to examine the possibility of applying nuclear power reactors to produce the required electricity and water simultaneously.

The regions which can be served by desalination on the Gulf and the Red Sea will be the same regions covered by the two Electricity Districts excluding two areas from District A, the Al-Hasa and Qasim areas. The former is found to have much abundant ground water supply, and the latter belongs to the area of less potentiality for development beside its far distance from the Gulf, which may cause a high transportation penalty.

(2) $R_{W/P}$ Values for 1980-2000

The exclusion of the above mentioned areas from the service of the water grids necessarily demands the deduction of the $R_{W/P}$ values from the consumption rate at the remaining areas, namely:

	Population $(10)^6$	
	1975	1980
District A:		
Riyadh Province	1.27	1.47
Dammam Province	0.45	0.53
District B:(1)		
Mecca Province	1.75	2.03

Beyond this, based on data supplied by the Ministry of Central Planning, the water consumption per capita, W/cap, and P/cap is compared below for the two years 1975 and 1980:

	(W) (m^3/y)/cap		(P)(2) (KWh/y) cap× $(10)^3$	
	1975	1980	1975	1980
Mecca Province	20.75	63.97	1.15	3.36
Dammam Province	40.56	97.15	8.17	32.89
Riyadh Province	39.75	77.07	0.80	2.15

From this follows:

1. The 1975 values of (W/cap) for the Riyadh and Dammam Provinces are similar (3), while for Mecca Province the value is cut to one half, indicating the great shortage of water supply at this area.

---

(1) Information over the consumption rate at the south-western region is not available.

(2) Yearly average consumption values are used in order to be consistent with electricity projection scenario.

(3) Both population and rate of water consumption at Riyadh Province are 2.8 fold over those at Dammam Province

2. On the other hand, the 1980 projected value of (W/cap) for the Dammam Province overtops that for the Riyadh Province by about 26%, signifying development concentration on the Gulf side of District A.
3. The increase in the 1980 projected values of (W/cap) and (P/cap) over that of the 1975 values are as follows:

	Ratio of Consumption Per Capita: (1980)/(1975)	
	(W)	(P)
Mecca Province	3.1	2.9
Dammam Province	2.4	4.0
Riyadh Province	1.9	2.7

This shows that the expected increase in (W/cap) consumption in 1980 will not be paralleled with that in (P/cap) at both the Dammam and Riyadh Provinces.

Futher, this same shift to more (P/cap) consumption at the two Provinces, has the effect of lowering the $R_{W/P}$ values in 1980 as follows:

	$R_{W/P}$	
	1975	1980
Mecca Province	0.018	0.019
Dammam Province	0.005	0.003
Riyadh Province	0.05	0.036

Conclusion:

Since the value of (W/cap) consumption in 1980 will be already over three times the 1975 value at Mecca Province, 2.4 times at Dammam, and nearly twice at Riyadh Province, one may fix the 1980 value of $R_{W/P}$ as the base value for future projection on the account that this ratio value describes the regional relation considering consumption of water and electricity, as determined by the planners in association with the development potential of each region.

The base values are then: For District A, $R_{W/P}$ = (.0195, or 0.02)[(1)]
For District B, $R_{W/P}$ = (0.019)

(3) Limiting Boundary Values

In order to be consistent with the scenarios developed earlier for electricity consumption, the boundary values for water consumption should be of the same limit. That is, water consumption per capita in USA from 1980 to 2000 should be used as the upper limiting values. Such values are reported in ref. 6 and are given below.

Test of $R_{W/P}$ Value Against the Boundary Value

By fixing the water to electricity ratio for District A as 0.02, it was found that the consumption per capita overtops the USA values as follows:

Water Consumption Per Capita
$(m^3/d)/cap$

	District A	USA[1]	
1980	0.42	0.70	(1960 : 0.5)
85	0.72		
90	1.03		
2000	9.60	0.85	

[1] ref.6

(1) Average value for Dammam and Riyadh Provinces.

Therefore, in order for the consumption per capita be bounded by the limit values, the ratio must be lowered. The suitable ratio found is 0.012. With respect to District B the ratio can remain unchanged, since the electricity for this district is designed in this work as being proportional to that of District A from 1980 to 2000.

Results

Accordingly, the following values are obtained: (see Tables 5,6)

	Water Consumption Per Capita $(m^3/d)/cap$		Water to Electricity Consumption Ratio	
Year	District A	District B	District A	District B
1980	0.260	0.120	0.0088	0.019
1985	0.453	0.201	0.0088	0.019
1990	0.632	0.285	0.0088	0.019
2000	0.713	0.324	0.0088	0.019
2000	0.728 (0.938)*	0.331 (0.466)**	0.0088	0.019

* In accordance to electricity scenario case C.

** In accordance to electricity scenario case B'.

It should be noticed that with respect to District A, the water to electricity ratio now is somewhat lower than the above quoted value, namely 0.012. This is expected since two regions of the district will not be served by the desalted water, and consequently the number of people served by the water grid will be less than by the electrical grid.

Figure 12 depicts the percentage increase in water consumption per capita and the total water production requirement by the electricity District A. A similar plot for District B is given in Figure 13.

The curves on these figures are similar to the respective one for electricity generation, since the relation for the generation of the two products is correlated by the local constants.

The curve depicting the percentage increase in the consumption per capita presented in Figure 13 drops faster than that in Figure 12, due to the fact that a larger number of people will be served by the water grid at District B.

3.4 Summary

It was conceived by the (MCP) that starting from 1980 there will be two national grids in the country. These were named here as Electricity District A (abbreviated as District A) and Electricity District B (abbreviated as District B). The former was conceived to serve the central and eastern part of the country. The latter was conceived to serve the south western and the western part of the country.

The population growth during 1980-2000 at all the regions involved were projected in accordance to the development potentiality of each region individually. Accordingly, the number of people to be served at District A will be 3.5×10^6 in 1990 and 4.3×10^6 in 2000. At District B it will be higher, namely 4.3×10^6 in 1990 and 5.3×10^6 in 2000.

The demands for both electricity and desalted water during 1980-2000 at District A and B were projected by constructing scenarios based on: (1) The past and present pattern of consumption per capita in the country (2) The application of the values for the consumption per capita in USA as bounding limits for consumption and (3) The consideration of the rate of development at the individual regions.

The scenario cases were represented by two different development possibilities, named as Development Possibility One and Two. Development Possibility One was conceived to account for the continuation on expanding the hydrocarbon based industries. Development Possibility Two was conceived to account for the case of reaching saturation in hydrocarbon based industries in 1990 and starting the preparation for the exploitation of the mineral resources in the country.

Accordingly, the following were obtained for electricity generation and desalted water production:

		Electricity Grid Necessary Expansion in Installed Capacity MW(e)	Water Grid Necessary Production of Desalted Water $(10)^6$ m^3/d
Development Possibility One	1985	9877	1.81
	1990	15676	2.87
	1995	21466	3.86
	2000	26941	4.73
Development Possibility Two	1985	9877	1.81
	1990	15676	2.87
	1995	20279	3.78
	2000	24534	4.78

4. Determination of the Nuclear Unit Sizes

4.1 Introduction

The integration of nuclear power reactors to the power systems in Developing Countries takes a slow process, mainly due to the fact that the sizes of the grids in most of these countries are not large enough to absorb an economically competitive nuclear reactor unit. Therefore, one recognizes the first barrier confronting the introduction of nuclear power is the size of the grid.

In Saudi Arabia, in spite of the fact that the execution of two 5 year plans will be concluded by 1980, the forecast to meet the electricity peak demand in 1980 will amount only to a total installed capacity of 4978 MW(e). Thus, in 1980 the inherited feature of "small grid size" will remain unresolved.

However, between 1980-2000 a gradual change in this situation will take place, as one has learned from the previous chapter, such that:

- The total installed capacity of the electrical grids will expand from 4978 MW(e) in 1980 to 26941 MW(e) or 24534 MW(e) in 2000, according to Development Possibility One and Two, respectively.

- The total installed capacity of the desalted water production grids will expand from 0.583 x 10^6 m^3/d in 1980 to 4.776 x 10^6 m^3/d according to Development Possibility Two.

The objective in this part of the work, therefore, is to quantify these expansions in terms of the number and size of units that can be added to the grids during 1980-2000 as nuclear stations.

The grids will be conceived in two ways:

- Either for power only production stations

- Or, a combination of power-only and dual production stations. Thus, aiming at the application of nuclear reactors for fresh water production from the seas.

4.2 The Sizes for Power-Only Stations

The sizes of the stations for power-only production which should be integrated in order to meet the yearly increasing demands on the Electricity Districts A and B are estimated as presented in Table 7.

The calculation is made within the following framework:

1) For the purpose of maintaining high system reliability, the percentage contribution of the largest new unit is kept within 10-11% of the total installed capacity at the time of addition (Table XI in ref. 7 was used as a guideline).

2) Older units are accounted as being replaced after 15 years of operation, which is the average life time of the oil fired stations in the country (see Figure 14).

3) With respect to Electricity District A, all new stations less than 600 MW(e) in size which will be added after 1980 are considered in this calculation as oil fired stations, since this area is rich in oil and so competition of nuclear fuel may not withstand until the size of the unit grows to 600 MW(e). On the other hand, for District B, nuclear competition is accounted for units starting from 400 MW(e) onwards.[1]

---

(1) The limits to nuclear unit size competitiveness are both arbitrary and conservative. It is arbitrary, because the "actual" fuel cost of electricity generation in the country is not clearly defined, because this industry is subsidized by the government but to what percentage the fuel cost is subsidized is not revealed. It is conservative, because smaller units than 600 and 400 MW(e) can be economically feasible as has been determined in ref. 7

From the table the following should be noticed:

1) With respect to District A, nuclear stations producing power only can be introduced as early as 1985. On this grid, even with scenario case A, large units can be integrated, the predominate being 1000 MW(e) in size. With scenario case C, modern units of 1200 MW(e) are plausible.

2) With respect to District B, if nuclear units of 400 MW(e) are considered economically feasible, then it is obvious that only few additions can be nuclear stations with scenario case A', and all additions from 91 onwards with scenario case B'.

Table 8 presents the nuclear unit sizes for power only production.

4.3 Desalination

Why Go for Desalination?

Desalination is already deeply recognized as the most possible means for providing the country with the major part of its demand for fresh water for years to come. This is due to the fact that the country was born without a single river and it has not been possible up to now to construct dependable subterranean water supply systems.(1)

Rainfall and run-off after raining are the main natural sources of water for most parts of the country, except at locations, especially in the eastern part, where underground aquifers are present. Average rainfall, however, is less than 101.6 mm, except for the mountainous regions of the south-western part, where the average was recorded of some 304.8 mm/y /2/.

(1) The only exception is a system which was built several centuries ago named after its builder, Ain Zubaida. It supplies Mecca with some 9500 m^3/d /18/.

Governmental efforts to enhance natural water resources in the country are centered on man-made springs and well drilling. By applying powerful drilling rings and deep well pumps to free flowing aquifers at depths averaging 50 m, over 70,000 wells have now been drilled. Some 160 man-made springs have been constructed in the Al-Hasa region. Some produce up to 143846 cubic meters daily.

But the problem of water shortage grows with growing demand and the seas remain the ultimate solution.

When desalination is coupled with electricity production, two advantages can result for the country. These are discussed in the following two sections.

4.3.1 Thermodynamic Effect of Dual Production

The application of the power plant to dual production of electricity and fresh water has already been recognized as presenting two major advantages to the country:

1) The sharing of the same operating and maintenance labor
2) The sharing of the same site and administrative crew

Relative to nuclear power, the dual production will advantageously tend to counterfeit the high capital cost of the reactor by means of a rather more efficient utilization of the heat source.

This can be seen from Figure 15 which compares the amounts of heat which are discharged to the condenser and ultimately to the cooling media, for three different power production alternatives. The highest discharge is made by the Light Water Reactor (LWR) and the least by the Fossile Fired Plant.(1)

---

(1) Note, fossile fuel plants discharge directly to the atmosphere through the stack 2.5 times greater than what LWRs discharge indirectly at miscellaneous components.

Similarly, a single purpose desalting plant of a large capacity (e.g. 10^6 m^3/d) needs some 3000 MW(th), all of which are ultimately discharged to the condenser as low temperature waste heat /9/.

Now, if a dual purpose plant with LWR is to produce these two products, the total energy requirement will be 4030 MW(th) /9/, and the total exhaust waste heat will be 3000 MW(th). This way a saving in power generation of 2000 MW(th) can be achieved and the exhaust heat load can be reduced from 4930 to 3000 MW(th) (see Figure 16).

However, it should be kept in mind, that this calculation assumes that desalination makes benefit of the exhaust steam which is discharged to the turbine condenser. The question then is how valuable is this assumption relative to the desalination process commonly applied in Saudi Arabia (see section 4.3.4).

4.3.2 Economic Incentives for Nuclear Desalination

In ref. 22 a cost comparison for desalination is roughly estimated. This is carried out by assuming the desalting plant at Jeddah, named Jeddah Phase I, utilizes as heat source: Light Water Cooled Reactors, Gas Cooled Reactors, and Fossile Fueled Boilers (both low and high pressure). The result is here repeated in Table 9.

The following was noticed:

1) The cost of desalted water from oil fired plants is higher than the actual cost of water as produced at the time of the study (1977) from Jeddah Phase I (namely, 15.6 cents per cubic meter).

2) When desalted water is delivered from smaller nuclear units, it is cheaper than that from oil fired plants of the same size.

3) The competitiveness of nuclear energy grows with larger plant sizes.

4.3.3 Methods of Desalination

Generally, natural water resources are classified in accordance to their total content of solids as shown in Table 10. To turn brakish, salt or sea water into drinkable water, salt must be reduced down to a standard content as shown in Table 11.

Desalination processes generally are classified into two categories: Firstly, in which the fresh water is taken away and concentrated brine is left behind. Processes of this category (e.g. evaporation, osmosis) are applicable to sea water desalination. Secondly, in the second category, applicable to brakish water, salt is removed and fresh water is left behind. The processes of the two categories are classified in Table 12.

The salt content of the water is a rather economical decision factor, which can lead to the preference of one process to others. This can be seen from Figure 17, where water production cost is plotted against salinity of raw water /23/, using the following desalination processes:

(1) Multi Stage Flash Distillation (MSF)
(2) Reverse Osmosis (RO)
(3) Electrodialysis (ED)
(4) A combination of: Vapor Compression Distillation (VC) and Vacuum Freeze (VF): (VF-VC)
(5) A combination of: Vertical Tube Evaporation (VTE), MSF and VC: (VC-VTE-MSF)

From this follows:

1) ED, RO and the combined processes (VC-VTE-MSF) are most competitive for the conversion of low salinity water

2) The combination processes (VC-VTE-MSF) compete with the individual process of MSF and the combined processes of VF-VC

3) Both the MSF and the combined VF-VC processes are similar in costs up to 26000 ppm; but for higher salinities (e.g. 43000 ppm at the Red Sea), the MSF process seems less expensive.

4.3.4 Desalination Practice in Saudi Arabia

The first dual production plant is named Jeddah Phase I. Its operation commenced in 1970. The water and electricity production capacities for this plant and for all others as projected up to 1980 are presented in Table 13. Also shown in the table are the starting year of operation, internal electricity consumption and the production ratio.

The production ratio of Jeddah Phase I is 0.38 and so is the case for nearly all other plants, except Jeddah Phase II [1] and Al Khobar I. This is true, because the design of Jeddah Phase I is used as a standard design which is extrapolated for all other cases.

The standard plant is a multi stage flash process type (MSF). In this process, first sea water is heated to 250°F (121°C) under sufficient pressure to prevent boiling in the section called brine heater (Figure 18).

From there the heated brine is forced through an orifice into the first flash stage which is maintained under pressure P_1 lower than that of the brine heater. The reduced pressure causes an immediate transformation of part of the liquid into vapor, which flows to a heat exchanger and becomes condensed by the incoming sea water which in turn becomes heated.

---

(1) Jeddah Phase II also applies the process of flash distillation, but its design is of a long tube type, giving rise to a different production ratio.

When equilibrium is established in this first stage, both the fresh distilled water stream and the more concentrated (but somewhat cooler) salt water are introduced into the second stage, the pressure of which, P_2 is lower than P_1. Again both streams get boiled with a fraction proportional to P_2-P_1 flashing into vapor, which in turn becomes condensed by cooler incoming sea water stream.

This process is repeated in subsequent stages, where the pressure and temperature are gradually lowered approaching the inlet sea water temperature (ave. 33^{o}C). The economically optimum number of stages, determined by balancing between the costs of additional heat transfer surface and the cost of the heat saved, is 42 stages in Jeddah Phase I /12,13/.

In addition to the MSF standard plants, the second process practised in the country is the reverse osmosis process (RO).

In the Riyadh area deep wells produce brakish water with salinity varying from 1200 to 1500 mg/l. The water is first diluted, due to its high calcium content, then treated in three treatment plants: Malez, Shemessy and Manfouhe, having the capacities, resepectively, of 1200, 1800 and 1800 m^3/h. After treatment, consisting of carbonate removal, partial softening followed by double filtration, the water is sent to the RO plant /14/.

One advantage of the RO process is its high energy efficiency in comparison to other processes as shown in Table 14. This advantage should be very attractive to the country, because the energy component of the water cost makes up a substantial part of the water production cost as follows:

The energy component of the water cost E, is given by /22/:

$$E = 2.09\ H/R \quad \text{cents per cubic meter}$$

where H = the cost in cents/GJ (GJ=10^{9}J)
and R = the performance ratio (see section 4.3.6)

For Jeddah Phase I, E is found to be in the range of 6.27 - 7.20 cents/m^3.

This energy component cost makes up almost one half of the water production cost of Jeddah Phase I, which is 15.6 cents/m^3.

Table 14 shows that the energy requirement of the MSF process 1980 technology is higher than that for the RO process by a factor of 0.51, meaning a shift to the RO process would reduce the water cost as due to energy expenditure with the same factor.

However, the high salt content of the Red Sea and the Gulf will result definitely in higher end product costs with RO than with MSF, as pointed out in section 4.3.3, and consequently the advantage presented by RO's higher energy efficiency will be neglectable until improved structure materials emerge.

4.3.5 Desalination Energy Requirement for the Case of Dual Production Multi Stage Flash Distillation Process (1)

Consider Figure 19 in which the heat source is to produce salable power P_s, auxilliary power P for the desalting plant, and heat input H for distillation.

If the heat source is not coupled to the desalting plant, the normal procedure is to discharge the reject heat Q_{er} at the lowest possible temperature, say t_{er}, in order to achieve the highest possible thermodynamic conversion. If T_s is the maximum temperature of the heat source (e.g. engine), then to obtain one unit of work in this case needs to supply $T_s/(T_s - t_{er})$ units of heat at T_s, and reject $t_{er}/(T_s - t_{er})$ units at t_{er}.

But, if coupled to a desalting plant, a portion of heat which is required for distillation must be rejected at a temperature higher

(1) Detailed treatment of the subject is presented in ref. 15.

than t_{er}, let this temperature be t_{er}'. Consequently, the heat source must supply:

$$\frac{T_s}{(T_s-t_{er}')} - \frac{T_s}{(T_s-t_{er})}$$

units of heat more for obtaining one unit of power production[1]

Now consider P' as the amount of power which is obtained by rejecting a portion of the total energy reject heat, Q_{er}, and let this portion be αQ_{er}, then

$$\alpha Q_{er} = \frac{P't_{er}'}{(T_s-t_{er}')}$$

or

$$P' = \alpha Q_{er} \left(\frac{T_s-t_{er}'}{t_{er}'}\right) \quad \text{(A)}$$

To obtain this portion of power, the excess heat required to supply is thermodynamically expressed as:

$$\text{Excess heat required} = P'\left(\frac{T_s}{T_s-t_{er}'} - \frac{T_s}{T_s-t_{er}}\right)$$

$$\text{By substitution for } P' = \frac{\alpha Q_{er}\left(\frac{T_s}{t_{er}'}\right)(t_{er'}-t_{er})}{(T_s-t_{er})}$$

The total heat input to the engine is:

$$(P+P_s-P')\left(\frac{T_s}{T_s-t_{er}}\right) + \frac{P'T_s}{T_s-t_{er}'} = (P+P_s)\left(\frac{T_s}{T_s-t_{er}}\right)+P'\left(\frac{T_s}{T_s-t_{er}'} - \frac{T_s}{T_s-t_{er}}\right) \equiv$$

---

(1) Note, it is this increase of the heat source which enables the rejection of

$$\frac{t_{er}'}{(T_s-t_{er}')}$$

units at temperature which is suitable for distillation plant, namely t_{er}'.

$$= (P+P_s)\left(\frac{T_s}{T_s-t_{er}}\right) + P'T_s \frac{(t_{er}'-t_{er})}{(T_s-t_{er}')(T_s-t_{er})} \qquad \text{(B)}$$

The total heat input to the system Q_T, is obtained by adding the input to the engine and the distillation plant:

$$Q_T' = H + (P+P_s)\frac{T_s}{T_s-t_{er}} - P'\frac{t_{er}}{T_s-t_{er}} \qquad \text{(rejection term)}$$

Substituting for P' from (A),

$$Q_T' = (P+P_s)\left(\frac{T_s}{T_s-t_{er}}\right) + H - \alpha Q_{er}\left(\frac{t_{er}}{t_{er}'}\right)\left(\frac{T_s-t_{er}'}{T_s-t_{er}}\right)$$

Since the heat input required to produce P_s is only,

$$P_s\left(\frac{T_s}{T_s-t_{er}}\right)$$

let be equal to Q_T, then the extra consumption caused by desalination plant must be $Q_T'-Q_T$

$$\text{or} \quad Q_T' - Q_T = (P+P_s)\left(\frac{T_s}{T_s-t_{er}}\right) + H - \alpha Q_{er}\left(\frac{t_{er}}{t_{er}'}\right)\left(\frac{T_s-t_{er}'}{T_s-t_{er}}\right) -$$

$$- P_s\left(\frac{T_s}{T_s-t_{er}}\right) = \frac{PT_s}{T_s-t_{er}} + H - \alpha Q_{er}\left(\frac{t_{er}}{t_{er}'}\right)\left(\frac{T_s-t_{er}'}{T_s-t_{er}}\right)$$

But $\alpha Q_{er} = H$, then

$$Q_T' - Q_T = \frac{P\,T_s}{T_s-t_{er}} + H\left(\frac{1-\frac{t_{er}}{t_{er}'}}{1-\frac{t_{er}}{T_s}}\right) \qquad \text{(C)}$$

Now consider R, the performance ratio, defined as the number of pounds of distillate produced per 1000 BTU of heat input /16,21/.

Hence, R = 1000 Md/heat in put

where, Md = Mass flow rate of distillate

or, (1000 Md)/R = H + P

Substituting and manipulating, one gets

$$Q_T' - Q_T = \left(\frac{1000\ Md}{R}\right)\left(\frac{1 - \frac{t_{er}}{t_{er'}}}{1 - \frac{t_{er}}{T_s}}\right) + \left(\frac{\frac{P\ t_{er}}{t_{er'}}}{1 - \frac{t_{er}}{T_s}}\right)$$

Heat input per pound of distillate is designated as q_T,

$$q_T' = \frac{Q_T'}{Md}$$

Therefore, the excess heat required by a dual production plant per pound of distillate can be calculated from:

$$q_T' - q_T = \left(\frac{1000}{R}\right)\left(\frac{1 - \frac{t_{er}}{t_{er'}}}{1 - \frac{t_{er}}{T_s}}\right) + \left(\frac{\frac{P\ t_{er}}{t_{er}'\ Md}}{1 - \frac{t_{er}}{T_s}}\right) \qquad \text{(D)}$$

4.3.6 Performance Ratio, Flash Range, Water Yield

The performance ratio, which is a measure of effectiveness of a given distillation plant design, is influenced by two major factors. One, the flash range, the temperature difference between the maximum sea water temperature (e.g. as emerging from the brine heater) and the temperature of the reject brine. Two, the number of flashing stages.

The quantitative relation, developed in ref.15, is as follows:

$$R = \frac{1000}{L} \left(\frac{1-e^{-a}}{a} \right) \frac{n}{J}$$

where,

L = latent heat, (energy/weight)
a = $S(T_M - T_{BM})/L$
S = specific heat,
T_M = Maximum temperature = temperature at which sea water emerges from the brine heater.
T_{BM} = Temperature at which the brine is rejected from the n-stage
J = No. of recovery stages, (see Figure 18).

In order to demonstrate the above mentioned influences, Table 15 is prepared from the United Nations publication /17/:

(1) In comparing the two plants of Kuwait, one notices when the number of stages increased from 4 (1950-plant) to 19 for the 1960 plant and the flash range from 25 to 33°C, the performance ratio of the latter plant has nearly doubled and its water yield was more than doubled.

(2) The two Netherland plants, both built in 1968, have opposing design characteristics. The first with 62°C flash range but only 18 stages. The second with 30 stages but only 32° flash range. The result is, the first plant achieves a much higher water yield but lower performance ratio; with the second, the opposite is true.

This indicates to achieve simultaneously both high performance ratio and high water yield. The plant design must incorporate large numbers of flashing stages and operate in the meantime at large flash range.

The incorporation of large number of stages, however, is limited by many factors such as economics, maintenance, and so on. The achievement of high flash range is limited also, not responsible to shortage of high temperature source, but rather due mainly to "scaling" problems associated with desalination.

Scale is a mineral deposit formed by precipitation from the saline solution of substances which have reached their solubility limits. The main contents of such deposits are calcium carbonate ($CaCO_3$), magnesium hydroxide $Mg(OH)_2$, three types of calcium suphate: ($CaSO_4$), hemihydrate ($CaSO_4$ 1/2 H_2O), and gypsium ($CaSO_4$ $2H_2O$). When they deposit on heat exchangers' surfaces serious problems arises /16,18/.

Control of scale is the major process which limits the maximum temperature. Commonly, phosphate additives are used but they are ineffective at about $200^{o}F$ ($93.3^{o}C$). Most recently, p_h-control methods are applied. They are effective but only up to $250^{o}F$ ($121.1^{o}C$), and therefore this is the maximum allowable temperature.

Conclusion

The aforementioned investigation leads to the conclusion that as long as the desalination process used in the country is the conventional MSF process, the steam supply at the brine heater must be at an appreciably high temperature level in order to achieve a high performance ratio. In fact, the economic performance ratio of the standard desalting plant at Jeddah correspond to a maximum temperature of $121.1^{o}C$ for the saline water emerging from the brine heater.

This means in turn, it seems not practical with conventional MSF plants to make use of the steam which is entirely exhausted (e.g. the discharge at the turbine condenser), because its temperature should be only in the vicinity of $86^{o}F$[1].

Therefore, to satisfy the MSF plant's temperature condition, less exhaust steam must be provided with which definetly will be at the expense of some loss in electricity production.

In fact, some 20% efficiency loss can be the result, when the exhaust steam is delivered to the brine heater at $260^{o}F$ ($126.7^{o}C$) [2] /20/. Another set back of coupling the brine heater to the turbine would be the possible leakage of radioactivity to the brine heater, or conversely, saline water to the condenser /9/.

Of course, a shortage in the production of one product (e.g. electricity) cannot be tolerated on the expense of the full production of the second product, because a dual production grid must fully satisfy the demand at both of its ends simultaneously.

4.4 The Sizes for the Dual Production Plant

Now assume that the grids of the Electricity District A and B will be, starting from 1980 to 2000, made of a mixture of single and dual purpose stations. Thus both water and electricity requirements are to be supplied simultaneously.

---

(1) There are researches leading to the use of the waste heat and hence making desalted water completely a by-product as far as energy expenditure is concerned. An example of a new method in distillation is reported in ref.19. The application of such methods in Saudi Arabia depends on its readiness for adoption to large scale production, because water production is a matter of need in the country.

(2) Even then, to get such high temperature exhaust steam, the turbine must be operated at the pressure of 2 atm. It was reported in ref.25 that a survey of the market indicated such turbines are not well developed.

In this case, however, the heat source of the power station determined in section 4.2 must be larger than that for power-only production.

In this work, the excess heat input needed for when coupling the power station with conventional MSF plant is found by calculation to be around 60 KWh/m^3 (or 2.5 KW(th)/m^3/d), including internal consumption.

The calculation is performed by applying the following characteristics of Jeddah Phase I to Formula D (section 4.3.5):

$h(T_s ; P) = 2771.32$ kj/kg	$T_s = 282.22^oC$	P = 65.98 bar
$h(t_{er}' ; P) = 2715.49$ kj/kg	$t_{er} = 126.67^oC$	P = 2.44 bar
$h(t_{er} ; P) = 134.90$ kj/kg	$t_{er} = 32.22^oC$	P = 0.045 bar

Economic Performance Ratio, R = 4.73 kj/kg

<u>The Scheme for Integration a Dual Production Plant</u>

By trial it was found that the introduction of dual production plants on the base of satisfying the demands year by year on the two products will lead to different production ratios from plant to another, which are collectively different from the production ratio of the standard plant. This in turn may call for several engineering modifications for every new plant to be buildt, which can be at some additional costs and efforts.

To avoid this, the scheme followed in this work maintains the production ratio equals to the standard plant, namely 0.38. And since electricity, unlike water, cannot be stored, then its production is kept in accordance to its yearly demand while water production is left subject to the constraint imposed by the ratio value.

Further measurements considered in this scheme are the following:

- Since the total desalination capacities at the eastern and western coasts in 1980 will be less than the demands for desalted water as set out by the respective scenarios, the 1981 plant is accounted here to produce this deficiency in addition to the year's demand.

- Since up to 1980 all desalination will be with oil fired plants, which has the average life time of 15 years in the country, replacement of the heat sources is accounted for after 15 years of operation (see Figure 20).

- To determine the thermal capacity of the dual production unit, the efficiency of the electrical grids are made comparable to the LWR efficiency in the country: 30.87% and 31.58% at District A and District B, respectively (see chapter 6).

Results

The results are presented in Table 16a and b, which show that the disadvantage of fixing the production ratio to 0.38 is that water production cannot be controlled within the frame of its demands.

This set back is well pronounced as follows:

At District A, the 1980 deficiency will be carried out up to the end of 1982. At District B, this will go on up to the start of 1991. Immediately following deficiency begins surplus of water over the years demand, which must be either stored in quantities as shown in the Table, or diverted to some other uses.

In fact, the availability of surplus water can be of major significance to the country, especially for agricultural expansion, since at present more than 60-70% of the needed basic foodstuffs are imported and only 0.2 - 0.4% of the land is cultivated.

The nuclear unit sizes for the mixed grids are presented in Table 16c.

4.5 Conclusion

As for the total country, the numbers and sizes for the nuclear stations that can be integrated following either development possibilities are presented in Table 17a for the case of single grid (e.g. power-only production), and in Table 17b for the case of the mixed grids.

Further, Table 17a can be summarized as follows:

	Development Possibility One	Development Possibility Two
(1) No. of Nuclear Units (1985-2000)	31	27
(2) No. of Small Units (400-600 MW(e))	18 (9 of 600 MW(e))	10 (4 of 600 MW(e))
And (%) of the Total	58%	37%
(3) No. of Intermediate Units (650-900 MW(e)	3	7
And (%) of the Total	10%	26%
(4) No. of 1000 MW(e) Units	6	7
And (%) of the Total	19%	26%
(5) No. of Large Units (1200-1300 MW(e))	4	3
And (%) of the Total	13%	11%

This shows, even if the country will follow the most prosperous strategy, namely that represented by Development Possibility One, over one-half of the installations will have to be in the small range: 400-600 MW(e). In the meantime the installation of 4 large units (1200-1300 MW(e)) can be expected.

When considering desalination, the thermal capacities of the reactors are increased, giving rise to greater numbers and larger sizes than before. This can be seen from the following summary of Table 17b:

	Development Possibility One	Development Possibility Two
(1) No. of Total Nuclear Units (1985-2000)	39	33
(2) No. of Small Units, And (%) of Total:		
Single (400-600 MW(e)	13 (33%)	5 (15%)
Dual (less than 1500 MW(th))	8 (21%)	6 (18%)
(3) No. of Interm. Units, And (%) of Total:		
Single (650-900 MW(e))	1 (3%)	3 (9%)
Dual (1600-2600 MW(th))	5 (13%)	6 (18%)
(4) No. of 1000 MW(e),And(%) of Total		
Single Only	4 (10%)	6 (18%)
(5) No of Large Units, And (%) Total		
Single (1200-1300 MW(e))	3 (7%)	2 (6%)
Dual (2600-3000 MW(th))	1 (3%)	2 (6%)
(6) No. of Very Large Units, And (%) of Total		
Dual Only (3000-5000 MW(th))	4 (10%)	3 (9%)

Thus,

- With respect to Development Possibility One, the number of units which can be integrated when considering desalination will increase by 26% (39 against 31) : 3 new plants at each intermediate and small ranges, and 4 at very large range, all of which are on the account of the drop out of 2 units of 1000 MW(e).

- Similarly, with respect to Development Possibility Two, the total numbers of units now will increase by some 22% (33 against 27). The new units are in the following ranges: One small, two intermediate, one large, and three very large sizes, all of which are on the account of the drop out of only one unit of 1000 MW(e).

Then, this work - and for the first time - made it clear, that the former feature of "small-grid-size" will not remain so in the future, rather the growth of the grid will take place such that starting from 1985 nuclear units can be integrated. The sizes will vary from 600 to 1300 MW(e) ranges.

5. Investigation on Fuel Cycle Alternatives for the Energy Growth Scenarios: 1980 - 2000

5.1 Introduction

Up to now the search for an economical fuel has never been seriously performed, partly due to the fact that there are 5 governmentally owned refinaries in the country which sufficiently provide with the required fuel-oil for electricity and water production, and partly due to the small sizes of the grids.

But during 1980 - 2000 the electricity generation capacity and the desalted water production capacity will increase more than 5 and 8 folds, respectively, over the capacities in 1980. Thus it becomes possible to integrate several large units in the range of 600 - 1300 MW(e).

This means starting from 1980 the question on the fuel type should gain a special concern, particularly in the light of two influential factors.

Firstly on the international markets oil is picking up high sale price and hence one is faced with a self imposing debate: Should oil be saved for sale or burned locally ?

Secondly there is uranium in the country. Its application for thermal power production can result in lower generation cost which can be advantageous to desalination as well.

However, when considering the generation of thermal power with nuclear fuels several interrelated aspects come into concern which are in relation to the type of fuel, its quantity, its chemical and physical forms, its transportation, the elimination of its wastes, availability of its technology, and last not least its cost.

Further, the interactions of these different aspects bring about number of constraints which give birth to several fuel cycle strategies, e.g. fueling with natural uranium, slightly enriched uranium, highly enriched uranium, etc.

The objective in this part are as follows:

- Investigate the several fuel cycle alternatives which are possible with the different reactor systems (e.g. LWR, HWR, HTGR) in terms of the U_3O_8 requirements, reprocessing requirements, and fuel cycle cost

- Then, quantify the results in terms of the oil exporting capacity of the country, in order to measure the competetive stand of each reactor system within the special condition of Saudi Arabia

In the following, the present and future ore utilization practices are reviewed:

5.2 Present Ore Utilization Practices

Patterns of using uranium fuel characterize the reactors into different systems as follows:

(A) Light Water Reactors (LWR): Enrichment in U-235 is imperative.

	PWR	BWR
Average Initial Core Enrichment (Wt.%)	2.38	2.03
Yearly Reload Enrichment (Wt.%)	3.2	2.7

(B) Heavy Water Reactors (HWR): Use natural uranium, but large quantities of the rather expensive heavy water is imperative.

(C) Magnox Reactor: Use natural uranium, cooled with the inexpensive gas coolant, CO_2.

(C) High Temperature Gas Cooled Reactors (HTGR): Use highly enriched uranium, U-235 Wt.% = 93 %, in combination with thorium.

(D) Fast Breeder Reactors (FBR): Make use of depleted uranium, but enriched in plutonium.

Figure 21 depicts the fuel cycle for the proved reactor systems (e.g. LWR, HWR, Magnox). It should be noticed that only LWR system can make benefit of the cycle to its full length. While HWR and Magnox systems shorten the front end of the cycle by not demanding the enrichment (and the subsequent reconversion) step, it is not possible with these two systems to benefit from the option of uranium recycling, because the percentage of left over fissile uranium in spent fuel is much lower than that of the natural uranium, a matter which make it impossible to be reclaimed by the present technology.

The fuel cycles for HTGR and FBR systems are depicted in Figure 22 and Figure 23 respectively.

Comparison and Remarks

FBR System

Within its pattern of uranium usage each reactor system displays advantages in certain areas which are offset by disadvantages in other areas. Only FBR system can contribute much to the economy of uranium on the long range outlook through the exploitation of the rather abundant stock pile of depleted uranium (e.g. tail waste of enrichment plants) and production of plutonium fissiles for further application. But spent fuel element reprocessing is an imperative service. Consequently, the world wide spread of FBR system is mostly dependent on the extent of the availability of reprocessing services, which at present are not well defined with respect to Developing Countries.

Water Reactors

The water reactors stand almost on the same line as far as uranium economy is cocerned. Yet uranium consumption in LWRs is to some degree larger than that in HWRs. This can be seen from measurement taken at two areas:

(A) Waste of uranium at enrichment plants

(B) In-core uranium use

Consider the relation /27/:

$$y = (E - E_t) / (E_{nat} - E_t)$$

where,

E_{nat} = Enrichment of natural uranium (0.711 %)

E_t = Enrichment of the diffusion plant (0.25 %)

y = The No. of tons of natural uranium fed to the diffusion plant to yield one ton of uranium of enrichment E.

Applying to this relation the respective values for fresh fuel enrichment at the yearly loading for PWR and BWR, one gets for every ton uranium enriched for PWR's loading some 6.399 tons of natural uranium must be delivered at the diffusion plant. It is less for BWR, namely 5.315. This loss in uranium which is characteristics of LWR system is not suffered by HWR system.

On the other hand, the HWR system suffers from both low burn up and lower thermal efficiency (Table 18) /28/. The burn up in PWR system for example is around 4 fold over that of Candu-PHWR. The efficiency of the latter is lower by 13.8 %.

Even with these setbacks in HWR system the uranium ore savings by not requiring enrichment is somewhat noticeable, as can be seen from the following relation which relates the aforementioned three factors.

Consider /30/:

$$D = \frac{(Exp)\ (Eff)}{y\ X\ 365} \qquad MW(e)y/t \text{ nat U}$$

where,

D = Dynamic utilization of the reactor system, MW(e)y/t nat U

(Eff) = Reactor net efficiency (%) MW(e)/MW(th)

(Exp) = Burn up discharge value, MWd/t U

y = Amount of uranium fed to enrichment plant, (t) $\frac{\text{nat U}}{\text{U}}$

For PWR, BWR, and HWR the following efficiency values were respectively estimated in this work (see section 6.4) at the Red Sea area: 31.58 %, 31.42 %, and 27.98 %.

Now, applying these efficiency values and the previously calculated values of y for PWR and BWR (with y = 1 for HWR), the dynamic utilization of the three systems are such as:

D = 6.13 MW(e)y/t nat U for HWR
D = 4.37 MW(e)y/t nat U for BWR
D = 4.26 MW(e)y/t nat U for PWR

Additional comparison can be seen from the annual requirement for natural uranium (see Tables 20 and 21) where it has been noticed that the annual natural uranium requirement concerning the "once through" fuel cycle alternative in PWR is 20% higher than for HWR at equal production capacity and rate of production. One reason for this is stated in ref. 27 saying that in the neutron balance equation is a term designated as R_{ex} which signifies that some produced neutrons are not available for conversion but rather get absorbed unbenificially.

That is, to increase the fuel life time in LWR system, additional amount of fuel over and above critical mass is built in. This practice is seen by LWR advocates to have the advantage of saving in terms of reducing fuel fabrication and fissile recovery costs.

But longer fuel life time means, evidently, higher fuel inventory and poorer neutron economy, the latter arising from the facts that neutrons get absorbed by fission products and control mechanism, and that each time the reactor is shut down, for refueling or otherwise, neutrons are lost and such high built in reactivity is required to bring the entire core to criticality and maintain the desired life time.

Now consider HWR system. Because of its lack in enrichment, its built in reactivity is so low such that continuous reactivity feed in is absolutely necessary. This is what termed as on load fueling. It is, however, a daily operation with highly specialized complicated machinery.

A further comparison shows that the amount of spent fuels unloaded yearly from an HWR is a factor of 2 larger than the amount unloaded from an LWR of the same electrical output. Since the uranium content of the spent fuel is the main controlling factor of the reprocessing plant throughput, the reprocessing requirement per unit electrical output is also 2 times larger for HWR than for LWR fuels.

Both LWR and HWR systems use the uranium fuel in the form of uranium oxide. An extensive knowledge and technology have been developed to improve the irradiation behaviour of such fuels.

The factors contributing to fuel failures include /31/:

(1) Densification and ratchetting of fuel

(2) Stress corrosion cracking (SCC) of zircaloy

(3) Influence of fission products

(4) Excessive moisture in fuel and hydriding of cladding

(5) Pellet cladding interactions

(6) Cladding embrittlement at high fluences
and

(7) Water corrosion of zircaloy.

The general performance of UO_2 in HWR and LWR is nearly similar, even with much different burn up rates. For example, stress corrosion cracking of zircaloy results from the impact of stress and strain and the presence of certain fission products such as iodine. And since the concentration of fission products increases with time, one may conclude that (SCC) is a problem most particular to LWR system for having a higher burn up rate, but it was found it to take place even at low burn ups, as low as 2000 MWd/t /32/.

Gas Cooled Reactors

Gas coolants are distinguished with their ability to attain high temperatures without high pressurization. High gas temperature leads to increased cycle efficiency.

The operating temperature of the old gas reactors, the Magnox generation, is however limited on a purly metallurgical basis as imposed by the structural materials, fuel and cladding /33, 34/.

The desire for confining to the use of natural uranium confronted with the requirement of using materials with extremely low neutron absorption cross section for the purpose of neutron conservation. Màgnesium among others, satisfies this basic requirement. In addition, it is adoptable to conventional fabrication techniques.

Magnesium melts at about 648.88 ^{o}C. Its working temperature is around 454 ^{o}C, and consequently the maximum cladding temperature is limited to 399 ^{o}C.

Because the Magnox system use metalic uranium (in order to take advantage of relatively simple fabrication technology, high fissile and atom density, and high thermal conductivity /28/) the maximum fuel temperature at the center of the fuel rod is limited by the phase change phenomenon from alpha to beta, taking place at temperature of 662 ^{o}C. On changing the phase the material grows causes the fuel element to buckle, the effect of which can be the obstruction of the coolant flow with subsequent fuel element burn out /35/.

Consequently, the maximum fuel temperature of the Magnox system is 413 ^{o}C (in the most advanced Magnox reactor, Wylfa Head, it is 570 ^{o}C) and fuel burn up is only 3,000 MWd/t. The Magnox reactor has low specific power (KW/kg).

The steam condition in the Magnox system is only slightly better than that of LWR, but the plant net efficiency is less due to pumping losses.

The modern gas cooled reactors, HTGR, use graphite not only for moderation as in Magnox system, but additionally for fuel particle coating and fuel structural material. This all ceramic fuel element results in low parasitic neutron capture in the core and therefore high conversion ratio /36/.

There are two basic HTGR designs, the pebble bed and the prismetic fueled HTRs. The former uses spherical fuel element. The fuel element of the latter is a graphical block with integral coolant and fuel channels. The fuel inventories for the two designs are about the same /37/.

In both design, the fissile and fertile particles are coated with a combination of pyrolytic carbon and silicon carbide. Failure of the fuel particle results from failure of the coating layers, the mechanism of which includes /31/:

(1) Transportation of fission products through intact coating

(2) Mechanical failure of coating

(3) Fuel transport through the coatings and

(4) Fission products attack on the coatings

With proper attention and quality control of manufacturing, the performance of HTGR fuel elements appears so far satisfactory. Fertile-particle exposure in excess of 10% burn up and fissile particle exposure of 80 % burn up is technically attainable, permitting average fuel exposure around 100,000 MWd/t.

5.3 Possible Future Practices

The ore utilization practice so far has been following the so called "once through" procedure in which the bred fissile and the left over fissile nuclides are not reclaimed. This practice naturally results in the maximum fuel requirement.

A procedure to lower this maximum will be achieved by recycling the bred and, if possible, the left over fissile nuclides.

Another possible alternative for a "more effective" ore utilization would be to exploit the second nuclear fuel, namely thorium, which is said to be abundant in nature, suitable for thermal converters, and capable of breeding the fissionable fissile U-233 /38/.

Thermal neutron absorption in U-233 produces more neutrons per absorbed (e.g. η) than does the corresponding absorption in either Pu-239 or U-235. The neutron production for U-233 is relatively insensitive to change in temperature while for U-235 and Pu-239 (η) decreases as the temperature increases. From the nuclear standpoint, the use of U-233 in a reactor makes it possible to achieve higher fuel conversion ratios and longer fuel burn ups than is practical with either U-235 or Pu-239.

Figure 24 displays the isotopic build up chains for the thorium and uranium fuels /39/.

5.4 Total U_3O_8 Requirements for the Energy Growth Scenarios (1980 - 2000) : A Comparison between Alternatives

Now assume that nuclear fuels will be applied exclusively to generate the energy demand during 1980 - 2000. With this assumption, the aim here is to compare the total U_3O_8 need to secure as required by the different reactor systems.

The different alternatives considered in this work are as follows:

1. LWR System

Uranium Fuel Cycle

a. Once through alternative (OTA)

b. Uranium + Plutonium recycling (U&Pu-Recy.)

Thorium Fuel Cycle

c. Thorium-uranium oxide, all uranium recycling (ThO_2-UO_2, U-Recy.) (Highly enriched U-235 is applied as external feed). (1)

The (OTA) is excluded from this study on the following account: A study carried out by General Atomics (ref.41), summarized in Table 19, shows that more uranium ore is required by the thorium fuel cycle than the uranium fuel cycle in LWR system.

d. Thorium-uranium metal, all uranium recycling (Th-U, Met., U-Recy.)

2. HWR System

Uranium Fuel Cycle

a. Once through alternative (OTA)
b. Slightly enriched in U-235 (SE-1.2 %) (no recycling)
c. Plutonium recycling (Pu-Recy.)

---

(1) The possibility of relying exclusively on U-233, which will lead to a significant improvement in conversion ratio, is excluded since without a source of U-233, e.g. thermal Breeder Reactor, there is little opportunity to take advantage of such improvement.

Thorium Fuel Cycle

d. Thorium-uranium oxide, all uranium recycling:
   (ThO_2-UO_2, U-Recy.) high burn up (H.B)
   (ThO_2-UO_2, U-Recy.) intermediate burn up (I.M)
   (ThO_2-UO_2, U-Recy.) self sufficient (S.S)

3. HTGR System

Uranium Fuel Cycle

a. Low enriched uranium (LEU-HTGR), no recycling

b. Low enriched uranium (LEU-HTGR), all uranium and plutonium recycling

Thorium Fuel Cycle

c. Thorium fueled HTGR, (THTGR), no recycling (highly enriched in U-235)

d. Thorium fueled HTGR, (THTGR), with recycling (highly enriched in U-235).

The calculation in this work is based on reactor characteristics data which were presented at the International Conference on Nuclear Power and its Fuel Cycle in Salzburg (1977). Tables 20, 21 present characteristics of PWR and Candu-PHWR systems, respectively. (1) They are extracted from ref. 40 which supplys the following comments on the tables:

> "In the "standard" burn up cases the fuel is substituted in a "standard" design and has the same average in-reactor dwell time as the "standard" fuel. Differences in burnup and specific power arise from differences in heavy-element densities.
>
> The "equivalent natural uranium" is the uranium which must be mined to satisfy the needs of the particular reactor.

---

(1) BWR is excluded for: a) Having lower power density than PWR, requires more uranium ore, b) In comparing thorium fuel cycles (oxide and metal), similar trends to PWR has been identified /42/.

"Inventory has a very specific meaning as used here. It is defined as the difference between actual requirements over a fairly long period of time and the requirements determined from the equilibrium net feed rates applied from the in-service date. This concept permits an approximate characterization of the fuel cycle uranium requirements by only two parameters, the equilibrium net feed rate and the "inventory". The bulk of the "inventory" requirements occur very early in the cycles, within the first few years of the in service date. For the once through cycle an allowance is made for fabrication and hold up amounting to half of the annual equilibrium feed rate.

The three thorium cycles (for Candu-PHWR) cover the range of interest from the "high burnup" case, which requires relatively large additions of external fissile material, to recycled fuel, to the "self sufficient" case in which, at equilibrium, no external fissile material is added to the recycled fuel."

Table 22 presents the life time uranium requirements for the 30-years operation of 1 GW(e) power station with PWR and Candu-PHWR systems, and Table 23 presents those relavent to HTGR alternatives.

These data are applied for determining uranium ore requirements for the energy growth scenarios during 1980 - 2000 as stipulated by the different alternatives of the three reactor systems.

The data, however, were first normalized in relation to the estimated values of the thermal efficiency of each reactor system at the respective locations in the country.

Results and Discussion

The cumulative U_3O_8 requirements for 30 years operation life time are compared for the selected different alternatives of each reactor system. Figures 25 through 27 depict these requirements for PWR, Candu-PHWR, and HTGR systems respectively, for the growth scenarios for the total country as postulated by the two development possibility cases.

From this follows:

1. The uranium requirement curves are similar in shape to the energy growth scenario curves (compare for example, Figure 11 with Figure 26). This means at any future change of the scenarios, the U_3O_8 requirements can be easily detected by finding the respective correlation factor.

2. For the three reactor systems the once through alternative (OTA) presents, naturally, the maximum requirement.

   In percentage wise, the requirement of the other alternatives can be stated as follows:

   (A) <u>For PWR System</u>

(U&Pu-Recy.)	= 66 % of (OTA)
(ThO_2-UO_2, U-Recy.)	= 55 % of (OTA)
(Th-U, Met., U-Recy.)	= 47 % of (OTA)

   (B) <u>For Candu-PHWR System</u>

(SE-1.2 %)	= 73 % of (OTA)
(Pu-Recy.)	= 45 % of (OTA)
(ThO_2-UO_2, U-Recy., I.B)	= 25 % of (OTA)

   (C) <u>For HTGR System</u>

(LEU-HTGR), with Recy.	= 80 % of (LEU-HTGR, no Recy.)
(THTGR, with Recy.)	= 59 % of (THTGR, no Recy.)

3. From (2) one notices that with PWR system when U and Pu fissiles are recycled the requirement is 45 % less than that of the (OTA), compared to 55 % less with Candu-PHWR, Pu-Recy. system. This is due to the nearly twice as much production of plutonium fissile in Candu-PHWR than PWR (Tables 20, 21) [1]

   Also one notices, a great difference between PWR and Candu-PHWR when fuelled with thorium-uranium oxide. The much less reduction in U_3O_8 requirement with HWR system is definetly due to the better neutron moderator resulting from the application of the more expensive D_2O as moderator and coolant.

4. Thus both recycling and applying the second nuclear fuel (Th) present undoubtedly "savings" in uranium. Such savings, however, is not very conspicuous at early years of the scenarios (as the curve appears closely gathered).

   By the end year of the scenarios (e.g. 2000) the total possible savings in U_3O_8 are as follows:

---

(1) Final Plutonium Isotopic Composition (%), (ref. 44)

	PWR (1000 MW(e))	HWR (500 MW(e))
Pu-238	1.46	0.1
Pu-239	55.74	68.4
Pu-240	24.53	25.5
Pu-241	13.39	4.6
Pu-242	4.88	1.4

	Development Possibility One	Development Possibility Two	% Saving Relative to (OTA)
	$(10)^3$ t	$(10)^3$ t	
(A) For PWR System			
($U\&Pu$-Recy.)	46.84	42.33	34
(ThO_2-UO_2, U-Recy.)	62.40	56.40	45
(Th-U,Met., U-Recy.)	73.46	66.39	53
(B) For Candu-PHWR System			
(SE-1.2 %)	29.63	26.79	27
(Pu-Recy.)	59.69	53.96	55
(ThO_2-UO_2, U-Recy.,I.B.)	82.31	74.41	75
(C) For HTGR System			
(LEU-HTGR, with Recy.)	28.61	25.93	20
(THTGR, with Recy.)	44.95	40.75	41

5. The total 30 years operation requirement of U_3O_8 for the once through alternative with PWR system and LEU-HTGR no recycling are nearly the same, 137.56 x 10^3 and 140 x 10^3 t respectively for the Development Possibility One. This is however surprising, because of the great difference in the average reload enrichment between the two systems.

6. The total 30 years operation requirement of U_3O_8 for the once through alternative with Candu-PHWR is around 80 % of that with PWR system, 109 x 10^3 and 137.56 x 10^3 t, respectively for Development Possibility One. This results in a difference of 28.29 x 10^3 t. This amount, actually, is sufficient to produce the required energy with PWR system up to 1986 on District A side or up to late 1984 for the total country representation.

That is if one chooses the once through alternative of Candu-PHWR system, the first 4 years energy demand can be generated freely (as far as U_3O_8 requirement is concerned only) relative to the once through alternative of the PWR system.

5.5 Comparison of the Annual U_3O_8 Requirement for the Period 1980 - 2000 only with World Uranium Supply and Demand

Beside petroleum the country is endowded with almost all types of mineral resources, including uranium. The organized search for minerals in the country are already in progress for over 20 years. Only in the last three years, however, uranium has been identified in large quantities in the northern part of the country.

The search for minerals in the country undergoes chains of activities, starting with air born geophysical surveys and ending with economical feasibility studies for each resource individually. Therefore, the studies concerning newly identified resources, such as uranium, has not yet reached the final stages.

The general mining policy in the country is to allow the exploitation of a resource in accordance to its need for local consumption or its supply and demand marketing situation in the international markets. Hence, the schedule for exploiting a given mineral resource will depend on its position on the priority list.

In any case, however, the large scale exploitation of a resource is unlikely to take place before the start of the depletion of the oil revenues (not before the year 2000 in any way), since the minerals generally constitute the second source of wealth for the country.

Now relative to the prospect of uranium mining in the country, the following question is posed:

If the country decides to use nuclear fuels to generate the energy need during 1980 - 2000 does that necessarily call for the mining of the local uranium ?

Figures 28 and 29 present a comparison of the cumulative annual U_3O_8 requirement for the operation period 1980 - 2000 only for the selected fuel cycle alternatives with PWR and Candu-PHWR systems respectively.

With PWR, the annual cumulative U_3O_8 requirement for the OTA will reach by the year 2000 some 4.6×10^3 metric ton (t), averaging over 20 years period to some 230 t per year looking at Development Possibility One. With Candu-PHWR, it is 182 t per year. (1)
This is to be compared by the world known uranium ore resources as presented in Figure 30 /56/. The western world annual requirement for U_3O_8 will reach by 1990 some 1.5×10^5 t the cumulative of which will be 11.40×10^5 t by 1990 /57/.

This indicates as far as the availability of uranium ore in the international market is concerned, there can be in principle no constraint. Therefore, the mining of the local uranium during 1980 - 2000 does not seem imperative.

This means, in turn, the country has enough lead time for planning and implementing local uranium mining in accordance to the international market situation or according to a predetermined nuclear fuel cycle strategy in the country.

---

(1) Applicable to both systems; When considering the requirements for alternatives other than OTA, the percentage reductions are similar to that obtained in the previous section (see discussion point 4).

5.6 Reprocessing Requirements

The previous sections clearly pointed out the advantage of recycling, as far as ore utilization is concerned, over the once through alternative in each reactor system. Obtaining reprocessing system from abroad, however, cannot be foreseen at this time.

Nevertheless, one may take an optimistic view by assuming that when the capacities of the reprocessing plants in the OECD countries (namely the European region) [(1)] will exceed the demand in these countries, say in the vicinity of 1990 if followed the high schedule forecasts as shown in Figure 31, this extra capacity will be made available for developing countries.

Even then, transportation of spent fuel from the country to Europe by roads or railways as practiced now and the return of the waste back to the country [(2)] is foreseen very problematic since multinational boundaries will be involved.

Further, the separation plant of the spent fuel deliveres acqueous solutions of uranium and plutonium. Transportation of plutonium solution beyond the reprocessing site is unacceptable. This means as long as reprocessing is performed out side the country, MOX fuel element fabrication must take place out side the country also which may deprive the locals from gaining experiences on such technology.

[(1)] The American capacity is not considered, because the prospect for commercial reprocessing availability in USA is now uncertain /46/.

[(2)] Waste return cannot be prevented, on the account that it cannot be burried in Europe for lack of space suitable for the purpose.

The most reasonable alternative to reprocessing in Europe, of course, is "local reprocessing" which advantageously eliminates transportation cost, estimated at 30-40 $ per kg of shipping spent fuel /44/.

Now assuming positevely with respect to technology transfer, the highest constraint that tends to block "local reprocessing" will stem from reprocessing plant capacity as shown below.

Figure 32 clearly displays the economical disadvantages of small unit sizes (e.g. 500 - 1000 t/a). Figure 33 displays a comparison of the cumulative heavy element reprocessing requirement for the selected fuel cycle alternatives of PWR and Candu-PHWR systems. These requirements covers only the operation period of 1980-2000. [(1)]

Numerically, the requirement for the reprocessing plant capacity per year for the years 1991 and 2000 are as follows:

[(1)] The following should be noticed:

a. Generally, Candu-PHWR demands the highest reprocessing requirement. In this system, the requirements for (Pu-Recy.) and (ThO_2-UO_2, U-Recy., I.B.) alternatives are nearly similar, as seen from the overlapping of curves 1 and 2.

b. With PWR the (Th-U, Met., U-Recy.) alternative demands the highest, and like the Candu-PHWR system, the (U&Pu-Recy.) and (ThO_2-UO_2, U-Recy.) alternatives demand nearly equal reprocessing requirements.

	Development Possibility One:		Development Possibility Two:	
	Plant Capac. by: 1991	Plant Capac. by: 2000	Plant Capac. by: 1991	Plant Capac. by: 2000
	(t)	(t)	(t)	(t)
(A) PWR System				
(U&Pu-Recy.)	387	724	383	654
(ThO_2-UO_2, U-Recy.)	365	683	362	617
(Th-U, Met., U-Recy.)	505	945	501	854
(B) Candu-PHWR System				
(Pu-Recy.)	795	1482	787	731
(ThO_2-UO_2, U-Recy.,I.B.)	738	1376	1340	1244

This indicates that if the plant is to operate by 1991, giving a 10 years lead time for construction, with PWR system the largest unit size will be 1000 t/y. This unit with (U&Pu-Recy.) and (ThO_2-UO_2, U-Recy.) fuel cycle alternatives will start running at one third of its full capacity, reaching to two thirds by 2000. With (Th-U, Met., U-Recy.) alternative, the plant will start operation at 1/2 full capacity but gradually will reach its full operation capacity by the year 2000.

With Candu-PHWR system, however, a large unit size is possible, e.g. 1500 t/y (looking at the Development Possibility One). This unit will start operation, again, at 1/2 full capacity reaching the full use by the year 2000.

5.7 Possible Economical Benefit when Replacing Oil with Nuclear Fuels

Since the country has uranium ores in large quantities, the argument is why burn oil locally and not provide it for the international markets whereas it constitutes the base material for many industries and use, instead, locally mined uranium which if brought to the international market, its selling returns will be much less compared to oil's especially as the world demand for the latter grows with time.

Or saying it briefly, this argument states that if the country remains on its traditional energy resource, what it will be doing is burning the more expensive commodity, namely oil, and selling the less one, uranium.

Uranium, however, is not a cheap material now as it was in the past but rather its price, like oil's, is increasing unpredictably (see Figure 34 /47/).

In order to examine the extent of the afore mentioned argument and being in the mean time aware of the increasing uranium price, a calculation will be carried out to detect the economical benefit, or expressing it precisely as the "monetary gain", if any, in replacing oil with nuclear fuels.

Uranium price alone, however, cannot be compared to oil's expenditure, but rather the total cost of the nuclear fuel cycle must be considered. Accordingly, the following will be performed:

(1) The nuclear fuel cycle (NFC) cost for 1000 MW(e) unit size for the selected fuel cycle alternatives with PWR and Candu-PHWR systems will be determined (e.g. mills/KWh).

(2) Then for each alternative, the total NFC expenditure which should be spent in meeting the energy growth during 1980-2000, and in the mean time for the reactor life time of 30 years, will be determined.

(3) The total oil expenditures for the same energy growth and supply periods will be determined.

5.7.1 Nuclear Fuel Cycle Cost for 1000 MW(e) Unit Size

The NFC cost calculation is made of the following components:

1. Inventory (Capital):

   total fissil inventory,
   fabrication of the first core,
   thorium inventory (for Th cycle),
   heavy water (for HWR)

2. Shipping

3. Makeup:

   fissile,
   fertile

4. Reprocessing (for recycling cases)

5. Fabrication & Refabrication

6. Spent Fuel Storage (for non-recycling cases)

7. Heavy Water Makeup (for HWR)

The cost is determined in two parts:

(1) The cost for the installation of the first core, an investment the value of which is averaged over the reactor life time.

(2) The cost for an equilibrium core, a steady state consumption which is supposed to be reached by the end of the third cycle.

In this work, the "Simplified Method for Fuel Cycle Calculation" is applied /48, 49, 50/. Accordingly, the levelized batch (region) fuel cycle cost is given by:

Energy generation cost (mills/KWh) =
$(\text{Sum } C_x \,/\, \text{Sum } E_x) \times 10^3$

where,

$$\text{Sum } C_x = C_u + C_c + C_e + C_m + C_r - C_{ur} - C_p \quad \text{(dollars)}$$

$$\text{Sum } E_x = E_1 + E_2 + E_3 \quad \text{(KWh)}$$

where,

$$C_u = (m_u)\ (u)\ (f_c)\ (V_u)\ (V_m)\ (P_u)\ (1+i)^{t_u}$$

= Cost of uranium concentrate

$$C_c = (m_u)\ (u)\ (V_m)\ (P_c)\ (1+i)^{t_c}$$

= Cost of conversion of U_3O_8 to UF_6

$$C_e = (m_u)\ (t)\ (V_m)\ (P_e)\ (1+i)^{t_e}$$

= Cost of separative work unit (swu)

$$C_m = (m_u)\ (P_m)\ (1+i)^{t_m}$$

= Cost of fuel element fabrication

$$C_r = (m_u)\ (P_r)\ (1+i)^{-t_r}$$

= Cost of reprocessing (including fuel element refabrication)

$$C_{ur} = (m_u)\ (r)\ (V_r)\ (V_{rc})\ (u_r\, f_c\, V_u\, P_u + U_r\, P_c + s_r\, P_e) \times (1+i)^{-t_{ur}}$$

= Uranium credit

$$C_p = (m_u)\ (fp)\ (V_r)\ (P_p)\ (1+i)^{-t_p}$$

= Fissile plutonium credit

and,

$$E_1 = 24\ (Th.E)\ (m_u)\ B_1\ (1+i)^{-t_1}$$

= Energy produced during the first cycle

$$E_2 = 24\ (Th.E)\ (m_u)\ B_2\ (1+i)^{-t_2}$$

= Energy produced during the second cycle

$$E_3 = 24\ (Th.E)\ (m_u)\ B_3\ (1+i)^{-t_3}$$

The explanation of all symbols and their values as used in this calculation are presented in Table 24. In order to be consistent, all values are extracted from one source, namely ref. 38.

However, since future uranium price cannot be predicted now, it is the intention here to detect the sensitivity of the NFC cost in relation to the rising uranium price. That is U_3O_8 price is not maintained constant but rather progressively scaled up at the intervals of 44 $/kg from 132-441 $/kg (corresponding to 20 $/1b from 60-200 $/1b).

The prices for D_2O, enrichment, and thorium, are maintained constant in other works /38, 40, 44/. This is however cannot be the case in the future. Therefore, in this work the prices for these three items are also progressively scaled up, such that the initial ratio of U_3O_8 price to the price of each item individually is maintained constant throughout the price spectrum.

The range of the prices are as follows:

Thorium	=	30 - 100 $/kg
Enrichment	=	150 - 500 $/kg swu
D_2O	=	120 - 400 $/kg.

Further, the application of the energy generation formulas presented above are dependent on burnup data for the first three cycles. Such data for all the NFC alternatives concerned in this work are not available. So as a means of normalizing, the total yearly energy generation from 1000 MW(e) unit size is determined at 80 % load factor, 10 % interest charge, and 2.75 lag time for revenues of the third cycle. This is equal to 5.392×10^9 KWh, and used for all NFC alternatives.

Results

The energy generation costs (mills/KWh) with respect to FC expenditure only for a unit of 1000 MW(e) for the selected NFC alternatives with PWR and Candu-PHWR systems are tabulated in Table 25 and depicted in Figure 35.

From this follows:

(1) The table shows that the first core investments for Candu-PHWR system cost more than that for PWR system, for the following two alternatives:

a. The once through alternative (e.g. with PWR, the cost is only 60 % of Candu-PHWRs)

b. The Pu recycling alternative (e.g. with PWR (U+Pu Recy.), the cost is from 70-69 % of Candu-PHWRs)

This, of course, is the effect of requiring the large quantity of D_2O at the rate of 1 t/MW(e) for the case of Candu-PHWR system. But when shifting to the thorium fueled reactors, the situation is reversed such that the investment on the first core with Th fueled PWR costs at the start of the price scale up spectrum some 40 % in excess of that for Th fueled Candu-PHWR. Then it rapidly drops approaching that of the other system by the end of the spectrum.

This must be due to the fact that the required quantities of Th and U_3O_8 for Th fueled PWR are 40 % and 50 %, respectively, over that for Th fueled Candu-PHWR. Also the D_2O requirement in this case is 20 % less than that for the OTA.

But what makes the two investment costs approach each other toward the end of the price spectrum is definetly due to the scaling up of D_2O and Th prices, on one hand. On the other hand although more thorium is required for PWR, this seems not much influential, because the price magnitude of thorium is much less than that of D_2O (see price range presented above).

(2) The prices for the items U_3O_8, Th, swu, and D_2O, were assigned in this work to scale up uniformly at the rate of 33.33 % of the starting value (e.g. 132 \$/kg-U_3O_8 x 0.3333 = 44 \$/kg; 120 \$/kg-D_2O x 0.3333 = 40 \$/kg etc.).

The corresponding costs of energy generation, however, does not increase similary but rather at lesser percentages. For PWR system the energy generation cost with OTA increases throughout the price spectrum at the rate of nearly 29.24 % of the generation cost at 132 \$/kg-U_3O_8.

It is 21.64 % with U+Pu recycling alternative and 21.54 % with (ThO_2-UO_2, U-Recy.) alternative.

For Candu-PHWR system the energy generation cost with OTA increases at 24.69 % of the generation cost at 132 \$/kg-U_3O_8.

It is 12.2 % with Pu-Recy. alternative, 24.66 % with SE-1.2% alternative, and 27.52 % with (ThO_2-UO_2 I.B., U-Recy.) alternative.

(3) Inspite the high costs assigned to reprocessing and refabrication (which includes shipping cost), the once through alternative remains the most expensive in the two reactor systems.

The cost with OTA-PWR is always in excess of that for OTA-Candu-PHWR, ranging from 45 % at 132 \$/kg-U_3O_8 to 62 % at

441 \$/kg-U_3O_8. To explain, the 45 % excess cost is due to the fact that with PWR the natural uranium to be purchased yearly exceeds that required by the Candu-PHWR by some 29.32% (171.99 x 10^3 kg for PWR against 133 x 10^3 kg for Candu-PHWR).

The 62 % excess cost at the end of the price spectrum must be considered an exaggeration, because it is mainly due to the effect of scaling up the enrichment price. On the other hand, although D_2O price was also scaled up such that the ratio of enrichment price to D_2O price is always maintained constant (e.g. 1.25), yet the effect of it is not much pronounced because the total yearly expenditure for replacing lost D_2O (e.g. 20 % of the original) is much less compared to the expenditure for enrichment. For example, the D_2O cost at 441 \$/kg-U_3O_8 (e.g. end of price spectrum) with OTA-Candu PHWR totals for the equilibrium core to \$ 8 x 10^6 while the equilibrium enrichment cost with OTA-PWR totals to \$ 72.15 x 10^6 or nearly 9 fold.

(4) Looking at the different alternatives, one gets the following conclusions:

(a) With PWR system the (U+Pu Recy.) alternative provides a cheaper energy generation cost than the (ThO_2-UO_2, U-Recy.) alternative. Therefore, the thorium fueled PWR can be excluded on such pure economical basis.

(b) With Candu-PHWR system the (ThO_2-UO_2, I.B., U-Recy.) alternative provides the cheapest energy generation cost. The Pu recycling alternative, unlike the case with PWR, starts more expensive than both the OTA and the SE-1.2 % alternative. Then it drops as prices are scaled up, breaken even at 177 \$/kg-U_3O_8 and 243 \$/kg-U_3O_8 with OTA and the SE-1.2 % alternative, respectively, and nearly approaching that of the (ThO_2-UO_2, I.B., U-Recy.) alternative by the end of the price spectrum.

This means, in turn, at higher prices, starting at 353 \$/kg-U_3O_8, the thorium fueled Candu-PHWR becomes less economically attractive with respect to the Pu recycling alternative.

Going the SE-1.2 % alternative does not present high economical advantages relative to the OTA, since the energy generation costs of the two alternatives are nearly similar.

(c) By the end of the price spectrum, there appears a wide price gap between the OTA and the recycling alternatives with both PWR and Candu-PHWR systems. For example, the energy generation cost at 132 \$/kg-U_3O_8 with OTA-PWR is some 28.78 % in excess of the price for U+Pu recycling. By the end of the price spectrum this percentage is magnified to 56.32 %. This, however, is not only due to the higher uranium and enrichment prices reached by the end of the price spectrum, but additionally due to the fact that reprocessing and refabrication prices were maintained constant throughout the spectrum.

5.7.2 The Total Nuclear Fuel Cycle Expenditure for the Energy Growth Period 1980 - 2000 and Reactor Lifetime of 30 Years

The question now is how much will be the total nuclear fuel cycle expenditures in \$ which must be paid by the country in order to meet the total energy demand during 1980 - 2000, if this demand is to be supplied by one of the reactor systems having a 30 years operation lifetime.

Now, in order to come out with such a figure, first a price for uranium must be selected at which the energy generation cost (with respect to NFC expenditure) is reasonable. But the aforementioned discussion pointed out that at higher uranium prices a price discrepancy between the OTA and the recycling alternatives can happen, due mainly to failure to predict future prices for reprocessing, fabrication, storage, etc.

Yet, any selected price must be in conformity with the forecast presented in Figure 34, from which one may reason out that future uranium prices will be at minimum 132 \$/kg (60 \$/1b) and 221 \$/kg (100 \$/1b) at maximum.

Using the corresponding fuel cycle costs for 1000 MW(e) at the two prices (Table 25) and performing the necessary manipulations, the total fuel cycle expenditures in meeting the energy demand for the total country during 1980 - 2000 with reactor supply time of 30 years for the different alternatives are as follows:

	Development Possibility One		Development Possibility Two	
	\$ $(10)^9$		\$ $(10)^9$	
	Minimum	Maximum	Minimum	Maximum
PWR:				
OTA	63.9643	101.3753	57.8201	91.6376
(U+Pu, Recy.)	49.6664	71.1132	44.8956	64.2823
(ThO_2-UO_2, U-Recy.)	51.6551	73.96201	46.6933	66.8575
Candu-PHWR:				
OTA	43.2172	64.5617	39.0669	58.3617
(1.2% Enrich.)	39.2019	58.5916	35.4373	52.9649
(Pu-Recy.)	47.9194	59.4896	43.3176	53.7767
(ThO_2-UO_2, U-Recy.)	27.2616	42.2662	24.6434	38.2073

Note: Total energy generation is assumed at 80 % L.F. Thermal efficiencies for PWR at District A and B are respectively, 30.87 %, 31.58 %: For Candu-PHWR are respectively, 27.30 %, 27.98 %, as estimated in chapter six.

5.7.3 The Total Oil Expenditure for the Energy Growth Period 1980 - 2000 and Supply Lifetime of 30 Years

Oil price, after its sudden increase in 1973 (Figure 36) /51/, its upward movement has been somewhat systematic within 5-10 % of the last price, making the price of a barrel by end of 1979 equals to nearly $ 18. There is no way at this time to predict the future oil exporting price, because of the many factors involved in marketing this commodity including politics in the first place.

For the purpose of this calculation, the crude oil selling prices used are 20 $/b at minimum and 25 $/b at maximum. There are no basis for selecting these values in particular, except speculation in reference to the world wide future oil demand and supply forecast which predict that while oil resources run toward depletion, the golable oil demand grows even much beyond the future production capacities in oil countries /52/. When the demand exceeds the supply, the result is always dictation of higher prices.

Also, it should be kept in mind that this calculation involves over a quarter of century in terms of the time table, because as mentioned earlier the total energy growth for 1980 - 2000, if it were to be produced by nuclear reactors, the supply will remain for 30 years. So to be consistent, the comparison with the expenditures for oil fired stations must consider 30 years supply time as well.

This means that since the life time of a conventional power station in the country is 15 years, to supply energy for 30 years the stations then must be reinstalled one more time. That is, while the total capital investment with nuclear power stations is only once, it is twice with oil fired station in this case.

This situation, however, does make the total capital investments of the two energy sources - nuclear and oil - nearly equal, because, there seems to be an agreement stating that the specific capital cost of an oil fired station is about 50 % of that for a nuclear station /7, 53, 54, 55/.

Further, it should be noticed that crude oil price is somewhat higher than fuel oil price, the difference, however, seldom exceeds 10 % /7/. But since this calculation is considered with determining the "monetary gain" if oil was exported instead of burning it locally, the fuel oil prices are considered here identical with crude oil exporting prices.

Using the minimum and miximum prices, respectively, of 20 $/b and 25 $/b, the total oil expenditures are determined on the basis that 1 ton of heavy fuel oil produces 42.52 x 10^6 kj with assumed heat rate of 3.6 x 10^3 kj/KWh /7/. The calculation assumes 40 % thermal efficiency and 80 % load factor.

The values obtained are as follows:

Development Possibility Cases :	Total Numbers of Barrels:	Total Oil Expenditure for 30 Years Production:	
	$(10)^9$	$ $(10)^9$	
		Minimum	Maximum
Possibility One	8.2233	164.4651	205.5814
Possibility Two	7.4862	149.7231	187.1539

A remark should be stated: The total cumulative oil production of the country up to the end of 1975 was recorded to reach 23 x 10^9 barrels /52/. This Figure will lift up to 36.14 x 10^9 barrels by the end of 1979 (at average production rate of 9 x 10^6 barrels per day). The total remaining proven reserves as of end of 1975 was 152 x 10^9 barrels /52/. This figure will be by the end of 1979 138.86 x 10^9 barrels. This means, if the country remains generating its energy from oil, it would consume about 6 % and 5.4 % of the remaining proven reserves as of end of 1979, not including new discoveries since 1975, for the two development possibility cases one and two respectively. Or looking at it differently, what the country would be saving for the international market will be at maximum 6 % of its remaining reserves.

5.7.4 The Magnitude of the "Monetary Gain"

The difference between the total expenditure for oil and that for nuclear fuel cycle is the possible "monetary gain". Such difference can be obtained by 4 cases of price matching, as follows:

Case 1: Maximum Fuel Oil Price with Maximum U_3O_8 Price
Case 2: Minimum Fuel Oil Price with Minimum U_3O_8 Price
Case 3: Maximum Fuel Oil Price with Minimum U_3O_8 Price
Case 4: Minimum Fuel Oil Price with Maximum U_3O_8 Price

Numerically, the "monetary gains" are as follows:

	Development Possibility One :	Development Possibility Two :
	\$ $(10)^9$	\$ $(10)^9$
Case 1:		
PWR System		
OTA	104.20601	95.51631
U+Pu, Recy.	134.46812	122.87155
ThO_2-UO_2, U-Recy.	131.61934	120.29641

	Development Possibility One : $ (10)^9	Development Possibility Two : $ (10)^9
Case 1 (Continue):		
Candu-PHWR System		
OTA	141.01966	128.79221
SE 1.2 %	146.98972	134.18895
Pu-Recy.	146.09172	133.37719
ThO_2-UO_2, U-Recy.	163.33151	148.94659
Case 2:		
PWR-System		
OTA	100.50076	91.90298
U+Pu, Recy.	114.79873	104.82754
ThO_2-UO_2, U-Recy.	112.80997	103.02981
Candu-PHWR System		
OTA	121.24791	110.65618
SE 1.2 %	125.26312	114.28581
Pu-Recy.	116.54571	106.40555
ThO_2-UO_2, U-Recy.	137.20345	125.07947
Case 3:		
PWR System		
OTA	141.61703	129.33376
U+Pu, Recy.	155.91500	142.25832
ThO_2-UO_2, U-Recy.	153.92624	140.46059
Candu-PHWR System		
OTA	162.36418	148.08696
SE 1.2 %	166.37939	151.71659
Pu-Recy.	157.66198	143.83633
ThO_2-UO_2, U-Recy.	178.31972	162.51025

	Development Possibility One : $ (10)^9	Development Possibility Two : $ (10)^9
Case 4:		
PWR System		
OTA	63.08974	58.08553
U+Pu, Recy.	93.35185	85.44077
ThO_2-UO_2, U-Recy.	90.50307	82.86563
Candu-PHWR System		
OTA	99.90339	91.36143
SE 1.2 %	105.87342	96.75817
Pu-Recycling	104.97545	95.94641
ThO_2-UO_2. U-Recy.	122.19886	111.51581

Now, one can interpret these results qualitatively in the form of a "Priority List" showing an arrangement of the different fuel cycle alternatives in descending order of priority with respect to the concept of "monetary gain". This list is given in Table 26.

But, quantitatively these results must be viewed in relation to the national income of the country.

That is, one should pose a question in the following manner. How much the "monetary gain" of each fuel cycle alternative is actually worth to Saudi Arabia, a country of a rather high income rate ?

The answer is, that one needs only to determine how many years of oil income is the "monetary gain" of each nuclear fuel cycle alternative equivalent to ?

This is carried out below for the two selected oil prices, minimum 20 $/b and maximum 25 $/b for an average rate of production of 3.285×10^9 barrels per year.

Development Possibility One

	Maximum Oil Price		Minimum Oil Price	
	Equivalent Numbers of Barrels in $(10)^9$	Equiv. National Income in (Years)	Equiv. Numb. of Barrels $(10)^9$	Equiv. National Income in (Years)
Case 1:				
(ThO_2-UO_2, U-Recy.)-Candu-PHWR	6.53	1.99	8.17	2.49
(SE 1.2 %)-Candu	5.88	1.79	7.35	2.24
(Pu-Recy.)-Candu	5.84	1.78	7.31	2.22
(OTA)-Candu	5.64	1.72	7.05	2.15
(U+Pu Recy.)-PWR	5.38	1.64	6.72	2.05
(ThO_2-UO_2, U-Recy.)-PWR	5.27	1.60	6.58	2.00
(OTA)-PWR	4.17	1.27	5.21	1.59
Case 2:				
(ThO_2-UO_2, U-Recy.)-Candu-PHWR	5.49	1.67	6.86	2.09
(SE 1.2 %)-Candu	5.01	1.53	6.26	1.91
(OTA)-Candu	4.85	1.48	6.06	1.85
(Pu-Recy.)-Candu	4.66	1.42	5.82	1.77

	Maximum Oil Price		Minimum Oil Price	
	Equivalent Numbers of Barrels in $(10)^9$	Equiv. National Income in (Years)	Equiv. Numb. of Barrels $(10)^9$	Equiv. National Income in (Years)
Case 2 (Continue):				
(U+Pu Recy.)-PWR	4.59	1.40	5.74	1.75
(ThO_2-UO_2, U-Recy.)-PWR	4.51	1.37	5.64	1.72
(OTA)-PWR	4.02	1.22	5.03	1.53
Case 3:				
(ThO_2-UO_2, U-Recy.)-Candu-PHWR	7.13	2.17	8.92	2.71
(SE 1.2 %)-Candu	6.66	2.03	8.32	2.53
(OTA)-Candu	6.50	1.98	8.12	2.47
(Pu-Recy.)-Candu	6.31	1.92	7.88	2.40
(U+Pu Recy.)-PWR	6.24	1.90	7.80	2.37
(ThO_2-UO_2, U-Recy.)-PWR	6.16	1.87	7.70	2.34
(OTA)-PWR	5.66	1.72	7.08	2.16
Case 4:				
(ThO_2-UO_2, U-Recy.)-Candu-PHWR	4.89	1.49	6.11	1.87
(SE 1.2 %)-Candu	4.24	1.29	5.29	1.61
(Pu-Recy.)-Candu	4.20	1.28	5.25	1.60
(OTA)-Candu	4.00	1.22	5.00	1.52

	Maximum Oil Price		Minimum Oil Price	
	Equivalent Numbers of Barrels in $(10)^9$	Equiv. National Income in (Years)	Equiv. Numb. of Barrels $(10)^9$	Equiv. National Income in (Years)
Case 4 (Continue):				
(U+Pu Recy.)-PWR	3.73	1.14	4.67	1.42
(ThO_2-UO_2, U-Recy.)-PWR	3.62	1.10	4.53	1.38
(OTA)-PWR	2.52	0.77	3.15	0.96

Development Possibility Two

	Maximum Oil Price		Minimum Oil Price	
	Equivalent Numbers of Barrels in $(10)^9$	Equiv. National Income in (Years)	Equiv. Numb. of Barrels $(10)^9$	Equiv. National Income in (Years)
Case 1:				
(ThO_2-UO_2, U-Recy.)-Candu-PHWR	5.96	1.81	7.45	2.27
(SE 1.2 %)-Candu	5.37	1.63	6.71	2.04
(Pu-Recy.)-Candu	5.34	1.62	6.67	2.03
(OTA)-Candu	5.15	1.57	6.44	1.96
(U+Pu Recy.)-PWR	4.91	1.50	6.14	1.87
(ThO_2-UO_2, U-Recy.)-PWR	4.81	1.46	6.02	1.83
(OTA)-PWR	3.82	1.16	4.78	1.45

	Maximum Oil Price		Minimum Oil Price	
	Equivalent Numbers of Barrels in $(10)^9$	Equiv. National Income in (Years)	Equiv. Numb. of Barrels $(10)^9$	Equiv. National Income in (Years)
Case 2:				
(ThO_2-UO_2, U-Recy.)-Candu	5.00	1.52	6.25	1.90
(SE 1.2 %)-Candu	4.57	1.39	5.71	1.74
(OTA)-Candu-PHWR	4.43	1.35	5.53	1.68
(Pu-Recy.)-Candu	4.26	1.30	5.32	1.62
(U+Pu Recy.)-PWR	4.19	1.28	5.24	1.60
(ThO_2-UO_2, U-Recy.)-PWR	4.12	1.25	5.15	1.57
(OTA)-PWR	3.68	1.12	4.60	1.40
Case 3:				
(ThO_2-UO_2, U-Recy.)-Candu	6.50	1.98	8.13	2.47
(SE 1.2 %)-Candu	6.07	1.85	7.59	2.31
(OTA)-Candu	5.92	1.80	7.40	2.25
(Pu-Recy.)-Candu	5.75	1.75	7.19	2.19
(U+Pu Recy.)-PWR	5.69	1.73	7.11	2.17
(ThO_2-UO_2, U-Recy.)-PWR	5.62	1.71	7.02	2.14
(OTA)-PWR	5.17	1.58	6.47	1.97

	Maximum Oil Price		Minimum Oil Price	
	Equivalent Numbers of Barrels in $(10)^9$	Equiv. National Income in (Years)	Equiv. Numb. of Barrels $(10)^9$	Equiv. National Income in (Years)
Case 4:				
(ThO_2-UO_2, U-Recy.)-Candu	4.46	1.36	5.58	1.70
(SE 1.2 %)-Candu	3.87	1.18	4.84	1.47
(Pu Recy.)-Candu	3.84	1.17	4.80	1.46
(OTA)-Candu	3.65	1.11	4.57	1.39
(U+Pu Recy.)-PWR	3.42	1.04	4.27	1.30
(ThO_2-UO_2, U-Recy.)-PWR	3.32	1.01	4.14	1.26
(OTA)-PWR	2.32	0.71	2.90	0.88

In the final analysis, the following statement can be made:

Since the once through alternative is in reality the only readily available technology with proved record of safety, a decision on a reactor system type must be viewed from this alternative in the first place.

Looking at the OTAs of the two systems, one finds there is no such an intensive economical advantage to Saudi Arabia in deciding in favor of one reactor system over the other, because though the OTA of the Candu-PHWR system appears higher on the priority list, yet the actual size of the "monetary gain" which the country would be benefiting from choosing the Candu-PHWR system over the PWR system can be equivalent to revenues collected from selling oil in a time of 1/4-1/2 year (only) depending on the case of price matching, as shown below:

Excess of Equivalent National Income in Years, when Choosing OTA-Candu-PHWR over OTA-PWR

	Development Possibility One		Development Possibility Two	
	At Max. Price	At Mini. Price	At Max. Price	At Mini. Price
Case 1:	0.45	0.56	0.41	0.53
Case 2:	0.26	0.32	0.23	0.28
Case 3:	0.26	0.22	0.22	0.28
Case 4:	0.45	0.40	0.40	0.51

5.8 Conclusion

- As regards for the total 30 years operation requirements of U_3O_8, the following conclusions are reached:

1. In all cases the OTA demands the maximum requirement. This is a well recognized case. It means, without recycling the efficiency in ore utilization is the lowest.

2. With OTA-Candu-PHWR, however, the demand is around 80 % of that required by the PWR system.

   Thus from the ore utilization point of view, the Candu-PHWR system is advantageous.

3. In spite of the fact that the LEU-HTGR (no recycling) requires an average reload enrichment of 11 %, the total ore requirement is nearly similar to that required by the

PWR system (equilibrium enrichment, 3.2 %).

Thus, the LEU-HTGR system, can be considered as an alternative to PWR, but with the target of achieving higher coolant out let temperature.

4. Recycling and application of thorium will result in less total ore requirements. But the effects accompanying such reductions will surface at times beyond 1995.

   Thus, at the start the considerations of recycling and use of (Th) are not of any decisive nature.

- As regards for the ore requirements for the operation period 1980 - 2000, there can be no constraint on the availability of uranium in the international market.

  And thus, mining of local uranium during this period is seen not imperative.

- As regards for the electricity generation cost (e.g. mills/KWh) with respect to the fuel cycle expenditure (only), for a unit of 1000 MW(e) with PWR and Candu-PHWR systems, the following can be stated:

1. In spite of the high costs assigned to reprocessing and refabrication, the generation cost with the OTA remains the most expensive. With PWR, it is always in excess of that with Candu-PHWR.

2. With PWR system:

   - Recycling of plutonium and uranium provides the cheapest generation cost.

   - Thorium fueled PWR is not economical.

3. With Candu-PHWR system:

   - Both plutonium recycling and application of thorium are especially sensative to the price of uranium.

   - Thorium fueled Candu-PHWR provides the cheapest generation cost at lower uranium price ranges only.

   - Plutonium recycling will not be competetive with the OTA unless uranium price goes up to and beyond 177 $/kg U_3O_8.

- Local reprocessing during 1980 - 2000 is not seen economically competitive.

- Generating electricity and producing fresh water with oil-fired stations during 1980 - 2000 will result in the total burning of oil (but for 30 years supply life time) amounting to 6 % (at Max.) of the country's assured oil reserve.

- Although the OTA-Candu-PHWR system displays both lower total ore requirement and lower generation cost (with respect to FC expenditures), these advantages are not found of noticeable significance in relation to the specific financial condition of the country, because if the country chooses the Candu-PHWR the total benefit will be equivalent to revenues collected from selling oil in a time of 1/4 to 1/2 year only

6. Investigations on Siting Requirements of a Nuclear Power Station

6.1 Introduction

Unlike hydro stations, nuclear stations can be erected at the desired location, provided that, the location in concern fulfills several special requirements.

Most of these requirements, however, are physical in nature. Therefore, for each location separate evaluations must be fully carried out on, for example, topography and meteorology of the site, its geology, seismology, flooding, etc.

Some of the site defects can be tackled by incorporating additional design features in the reactor design, though with a given impact on the plant's capital cost. Only by detailed investigation, however, can the defects at each site be identified.

Recognizing this, the goal in this part of the work is to cast light on general requirements especially concerning the following three areas:

- Transportation of heavy loads, which at first glance seems somewhat problematic due to the topographical conditions in the country.

- Cooling water requirements, which can be of highest constraint to the country, due to the absence of rivers and water ways.

- Plant thermal efficiency fluctuations with different cooling options. The meteorological conditions of the country are much different from most of the locations around the world. Hence, it is of special concern to learn about the efficiency of nuclear reactors in the country.

6.2 General Siting Considerations

6.2.1 Availability of Land, Land Size, Accessibility for Heavy Loads

The land requirements for housing one nuclear unit, depending on its power output, is between 3 to 6 hectar [(1)] of ground. Added to this is 2 to 4 hectars for wet cooling towers, and even 20% more if dry cooling is required.

Usually future site extension to accomodate at least one more unit is considered. This calls then for a total area of 8 to 17 hectars or 12 to 25 hectars, including areas for cooling towers. Also an area of 2 to 5 hectars must be made available for preparatory installations /58/.

However, it should be kept in mind that the land requirement for siting a nuclear power station runs to a total of over 150 hectars, e.g. siting of Iran 1,2 covers about 200 hectars, reserved exclusively for the two units /59/.

Analysis with Respect to the Conditions in the Country

The total area of Saudi Arabia is 2,149,690 km^2. The population is 7.2 million (as of 1975 census). Thus, there are only 3.3 person per km^2. For expediting industrialization the government allocates all necessary lands to both public and private investors charging only nominal prices. Consequently land acquisition for nuclear power plants is seen, in principle, to be mainly subject to technical approvals.

The locations of the two electricity districts conceived in this work are on shores. Thus as far as availability of land is concerned, a major constraint cannot be expected for the

---

(1) 1 hectar = 10,000 m^2 or 100 hectar = 1 km^2

population of reactors considered in this work.

Looking at the Electricity District B one finds that though the Saudi side of the Red Sea covers nearly 1770 km, siting of nuclear power plants is yet limited to the central part of the shore in order to be in proximity to the load center. Also it should be considered, on one hand the lack of political stability at both the southern and northern boundaries, and on the other hand the following topographical condition:

Along the Red Sea lies only a narrow plain. Its width varies as follows: 64 km wide in the south, then gradually narrows to 48 km from Jizan to Al-Laith; to 16 km where it reaches Al-Wajh, and stays so up to the Gulf of Agaba.

This coastal plain is characterized by extensive marshlands called, "Tihamats", east of which runs a "range" of high mountains broken by great valleys. The highest mountains of the range are in Asir with peaks over 2745 m, declining to 2440 m to the west of Mecca; to 1220 m to the west of Mahd-Ad Dahab, and to 915 m at Medina. The range remains at this elevation to the north.

Availability of land with respect to the Electricity District A can be somewhat more constrained for the following major reasons:

a) Scattering of oil fields nearby the Gulf

b) Having multi boundaries with other Arab countries, Kuwait, Qatar, etc.

c) Being the pass way for pipe lines, and consequently having many restricted areas

d) Growth of petrochemical industrial concentration, e.g. Jabail Complex

e) Reservation of land for further petroleum discoveries

In this case as more power plants will be erected, especially after the year 2000, inland siting will have to be considered. The most reasonable direction will be toward the Riyadh area, since the service of the grid includes this area as well.

6.2.2 Heavy Loads Transport to the Central Region

Inland transportation to the central region named as the "Najd" region seems at the first glance to become problematic, because the Najd region in general resembles a plateau which is slightly inclined towards the east. I has an altitude of 800 m above sea level in the west. Toward the east this is reduced to 500 m.

A north-south escarpment, situated in the extreme east on the edge of the valley As-Sulayy, raises the level of the plateau again up to nearly 700 meters above sea level. The plateau is cut by numerous valleys having the form of the canyons type /60/.

But since the capital of the country is situated in this region which is deprived from direct access to shores, transportation difficulties due to the areas' heights and elevations have been in the course of the last 10 years minimized by the construction of reliable roads.

In fact, there are now about 9000 km of main and secondary roads which are in satisfactory condition. By early 1980, according to the second development plan, additional 13 000 km will be available. These were designed in order to provide adequate services up to the year 2000.

There are several good road connections between Riyadh and other cities. With respect to rail road there is only one connection, Dammam-Riyadh. It has now been in service for 25 years, covering a length of 563 km (Figure 37). Table 27 summarizes the rail roads capacity, problems, and plans of expansion.

6.2.3 Heavy Components of a Nuclear Power Station

Table 28 compiles, as an example, the heavy load components for the largest nuclear power unit size, e.g. PWR 1300 MW(e).

The heaviest of these, valid for other reactor systems as well, are: the transformer, steam generator, turbines, feedwater storage tanks, and the pressure vessel.

In considering the transportation of these heavy components to the Riyadh area, the following two points must be kept in mind:

1.) Not only the first delivery but also the possible shipment in future of a part of a component, e.g. HP turbine back to the manufacturer, in case of serious malfunctioning

2.) The annual shipment of fuel elements in casks weighing 125 t and containing one third of the core load.

In principle, the transportation of the transformer, steam generator, turbines, and storage tanks can be designed such that the delivery can be in parts, and hence major difficulties cannot be expected, especially viewing from the rail road condition.

On the other hand, a pressure vessel, characteristic of reactor type, should be recognized as the most cumbersome single piece of equipment to be delivered, not only from its weight point of view, but most important, since the maintenance of its "full integrity" through transportation is also one of the basic measurement in safety assurances /63/.

Table 29 compares the type, dimension, and weight for the pressure vessel of different types of reactors.

From this follows:

1.) The PCRV type (e.g. applied with THTR and HTGR system) offers to the inland site relatively transportation free advantage, since this type is usually constructed on site.

2.) The dimension of the steel pool for LMFBRs is relatively larger which necessarily calls for on-site construction.

3.) The weight of the steel calandria in Candu-PHWR is 390 t for only a 600 MW(e) unit size. For larger plant units, this heavy load my constitue a serious set back, especially if partwise transportation is not allowed.

4.) The dimension and weight of the steel vessel for PHWR-vessel type with an output of only 340 MW(e) is almost similar to that of a PWR of 1300 MW(e), giving rise to a well pronounced economical set back at larger unit sizes.

5.) With respect to LWRs, characteristically pressure vessels for BWRs are higher, wider, heavier, and the walls are thinner than those for PWRs of comparable sizes, for the following reasons:

   a. In BWR, the steam is allowed to be generated within the vessel. Steam separating and drying equipment is mounted on top of the core, making the vessel higher.

b. Due to higher void fraction in BWR, the critical heat flux is restricted to be lower than that for PWR, consequently the average power density is lower in BWR (56 KW/l vs 93 KW/l for PWR). Therefore, to yield the same output, the BWR's core necessarily becomes larger. This and inclusion of pumps within the vessel result in wider vessel.

c. Because water is allowed to boil within the vessel in BWR, its system pressure is lower than that for PWR (70 bar vs 150 bar for PWR), a direct consequence of which is thinner vessel walls.

In conclusion, the following can be stated:

Though water ways are completely absent, yet heavy load transportation to the central region, in general, cannot be a major problem due to the existence of a rail road line which is expected to evolve in the near future. Much care, however, must be exercised when considering the transportation of a pressure vessel as an integral part, because the local phenomenon of "sand storms" can cause sudden transport obstruction which may also subject the vessel's walls to defects, depriving it from its manufactured qualities.

An alternative to "one piece" transportation, of course, is "on-site" assembly, a matter which calls for a considerable investement for erecting at sites workshops for welding, testing, etc. The justification for such investement will depend on the extent of the services to other industries.

While this is the case with steel pressure vessels, there is no doubt that from the transportation point of view the PCRV is most suitable for all inland locations.

6.3 Condenser Cooling Requirements and Estimation of Reactor Efficiency at Locations along the Red Sea and the Gulf

6.3.1 Cooling System Alternatives

Condenser cooling falls into two general catagories /64/:

1. Open cycle system:
   a. Once through (direct cooling from river, sea, lakes, ponds, etc.)

   b. Once through in series with a wet cooling tower, as a means of reducing the impact from heat load.

2. Closed cooling system:
   a. Wet cooling tower, naturally draught or forced draft

   b. Dry cooling tower

   c. Cooling ponds, spray ponds, etc.

Absence of rivers in the country made it necessary to mobilize all major industrial development to locations nearby the seas. The requirement for condenser cooling necessitates the location of the power stations close to the seas also (see Figure 3). Direct sea water cooling is now the practice for all systems that need cooling (e.g. refinaries, fertilizer industries, power stations, etc.), and it is seen to continue so for the period 1980 - 2000 as well. Application of cooling towers at locations nearby the seas may eventually be necessary, provided that the "thermal impact" on the seas will exceed preset tolerable levels.

The climatic and geological formation of the seas in the country make them somewhat abnormal relative to temperature and salt conditions. Consequently condenser cooling requirement in the country should be expected to differ from other locations in the world.

6.3.2 Meteorological Conditions in the Country

Figures 38-a, 38-b and 39 depict for the Red Sea and the Gulf regions, respectively, surface temperature and salinity conditions.

Figures 40 and 41 depict for the city areas at Jeddah, Dahran, and Riyadh, the average monthly values of recorded temperatures and relative humidity, respectively /65, 66, 67, 68/.

6.4 Application of the Direct Cooling Option

In order to investigate the condenser cooling requirement and estimate the value for the reactor efficiency in the country, which was necessary for calculations in chapter 5, a simplified thermal flow chart for the secondary cycle is constructed for PWR, BWR, Candu-PHWR, HTGR and FBR. These are presented, respectively, in Figures 42 through 46 [(1)].

---

(1) The approximation is carried out with consultance with ref. /69/. The simplification for LWRs is deduced from the full flow chart given in ref. /70/ and for Candu-PHWR, HTGR, and FBR, from refs. /71, 72, 73/ respectively.

Consider the relation

/74, 75, 76, 77/,

$$(Eff) = (q_{in} - q_{out}) / (q_{in}) \qquad (1)$$

where,

(Eff) = The thermal efficiency of the cycle, (%)

q_{in} = In put heat, (kj/kg)

q_{out} = Discharged heat, (kj/kg), given by:

$$q_{out} = \int_{T_1}^{T_2} T \, ds \; \underset{=}{\Delta} \; T\Delta s \qquad (2)$$

where,

Δs = Change in entropy, (kj/kg ^oK)

T = Condenser temperature, expressed in absolute Kelvin

From the approximation, values for Δs and q_{in} are determined as follows:

	Δs (kj/kg ^oK)	q_{in} (kj/kg)
PWR, 1000 MW(e) (net)	6.965	3.1479×10^3
BWR, 1000 MW(e) (net)	6.848	3.0976×10^3
Candu-PHWR, 645 MW(e) (gross)	6.890	3.0474×10^3
HTGR, 1160 MW(e) (net)	7.4225	3.6926×10^3
FBR-PHENIX, 250 MW(e) (net)	7.1257	3.6518×10^3

The efficiency in relation to the condenser temperature T is then expressed as follows:

$$(Eff)_{PWR} = 1 - 0.0022125\ T$$

$$(Eff)_{BWR} = 1 - 0.0022178\ T$$

$$(Eff)_{Candu-PHWR} = 1 - 0.002261\ T$$

$$(Eff)_{HTGR} = 1 - 0.002010\ T$$

$$(Eff)_{Phenix} = 1 - 0.0019512\ T$$

Thus, with increasing condenser temperature the efficiency decreases. Accordingly the discharge heat increases (and so the steam mass flow for the same thermal watts produced). The rate of the discharging heat is given by the relation:

$$Q_{out} = (\dot{m}_{st})\ (T)\ (\Delta s),\ kj/h \qquad (3)$$

where,

$\dot{m}_{st}$ = steam mass flow in kg/h, given by:

$$\dot{m}_{st} = (P_t)/(Eff)\ (q_{in}),\ kg/h \qquad (4)$$

where,

P_t = Plant output in kj/h .

Now, the requirement of steam mass flow rate in relation to the drops in efficiency (as condenser temperature increases) is determined by the following relation:

$$(\dot{m}_{st})_{PWR} = (1.144 \times 10^6)/(Eff)$$

$$(\dot{m}_{st})_{BWR} = (1.166 \times 10^6)/(Eff)$$

$$(\dot{m}_{st})_{Candu-PHWR} = (0.7620 \times 10^6)/(Eff)$$

$$(\dot{m}_{st})_{HTGR} = (1.131 \times 10^6)/(Eff)$$

$$(\dot{m}_{st})_{Phenix} = (0.24645 \times 10^6)/(Eff)$$

Substituting $\dot{m}_{st}$ value in (3) leads to the calculation of Q_{out} from the following relation:

$$(Q_{out})_{PWR} = (7.968 \times 10^6)(T)/(Eff)$$

$$(Q_{out})_{BWR} = (7.985 \times 10^6)(T)/(Eff)$$

$$(Q_{out})_{Candu-PHWR} = (5.2502 \times 10^6)(T)/(Eff)$$

$$(Q_{out})_{HTGR} = (8.395 \times 10^6)(T)/(Eff)$$

$$(Q_{out})_{Phenix} = (1.756 \times 10^6)(T)/(Eff)$$

Applying the above relations, the impact of the increase in the condenser temperature on the plant thermal efficiency and the corresponding increasing rate of the discharged heat are depicted in Figures 47 through 51, respectively, for PWR, BWR, Candu-PHWR, HTGR and FBR (Phenix).

With respect to the Candu-PHWR, two points must be mentioned.

Firstly, the heat balance data given for the Candu-PHWR in ref. (71) does not account for the station electrical consumption, and consequently it represents the gross production rather than the net production, as is the case with other reactor systems. Hence, the thermal efficiency curve depicted in Figure 49 cannot be truly representitative, but rather some 7 % less of the values on the curve should be considered as the actual obtainable efficiency.

Secondly, while the net electrical output of the Candu-PHWR is 60 % of that of LWR (e.g. 600 and 1000 MW(e) respectively) the condenser's heat discharge does not follow with the same percentage. The Candu-PHWR condenser's heat discharge is 69 % and 74 % of that of LWR at condenser temperatures 33 °C and 100 °C respectively.

To determine the cooling water flow requirement, consider the relation:

$$\dot{m}_w = (Q_{out}) / (C) (V_{Upp} - V_{Low}), \text{ (kg/h)} \qquad (5)$$

where,

$\dot{m}_w$ = Cooling water mass flow rate, (kg/h)

C = Specific heat constant of water (kj/kg °C)

V_{Low} = Inlet cooling water temperature, °C

V_{Upp} = Outlet cooling water temperature, °C.

The required water mass flow rate is determined on the following two conditions:

1. Setting V_{Upp} = the condenser temperature (an ideal case, however)
   e.g. V_{Upp} = T = 33, 35, 40, 45, etc. °C.

2. Two inlet temperatures are selected, the lowest during the winter time and the highest during the summer season. These are for the Red Sea 21, 31 °C and the Gulf 17 and 32 °C.

Under these conditions, the flow requirements are depicted in Figures 52 through 56, respectively, for PWR, BWR, Candu-PHWR, HTGR, and FBR-Phenix.

It should be mentioned that the flow rate drops as the condenser temperature increases. This, however, is true only because the efficiency drops accordingly, as depicted in the figures also. That means, if one maintains the efficiency constant, water mass flow will necessarily increase with increasing condenser temperature.

Now, how would the cooling water flow requirement be, if one wants to keep a constant efficiency at all locations along the Red Sea and the Gulf, and at all times of the year ?

To determine this, firstly the outlet temperature is set equally to the designed condenser temperature for each reactor, namely 33.3 °C for water reactors, 40.55 °C for HTGR, and 28 °C for FBR-Phenix (by this Q_{out} is fixed, and hence plant efficiency is fixed, while the cooling water flow requirement will depend on the inlet temperature). Secondly the inlet cooling water temperature variations are set equally to the surface temperature at various locations along the two seas.

Under these conditions, the flow requirements are depicted in Figure 57 for water reactors and Figure 58 for advanced reactors. The figures, in general, show that the desired efficiency can be achieved regardless of the condition of the inlet temperature, but at the cost of higher cooling mass flow rate.

Figure 57 shows that the impact of the increase in inlet water temperatures on the flow requirement is not too drastic up to 27 °C. Beyond this, a difference of one degree from a location to another, say from a location at 31 °C to another at 32 °C, can result in doubling the requirement of the cooling water flow rate.

Figure 58 shows that with HTGR the flow requirement increases comparatively slowly with increasing inlet temperature, but it should be kept in mind that this is off-set by having a much hotter outlet water temperature (around 41 °C). This hot water will have to be discharged directly to the sea or alternatively after cooling in a pond.

Now the question is:
How would the efficiency fluctuate at the various locations along the Red Sea and the Gulf for, say, a minimum cooling water flow requirement ?

To determine this, again the outlet temperature is set equally to the designed condenser temperature. The water flow requirement is selected as that demanded by the location having the lowest possible surface inlet temperature, namely 21 °C at the Red Sea (Agaba area), and 17 °C on the Gulf (Dahran area).

Next, by rearranging equation (5) for Q_{out} and equating it with equation (3), and carrying out the necessary manipulations, the relation for the efficiency of the different reactors at locations along the two seas are then as follows:

Red Sea

$$(Eff)_{PWR} = 1 - 0.0022125 \left(\frac{67.541+6.321\ V_{Low}}{6.07374} + 273.16 \right)$$

$$(Eff)_{BWR} = 1 - 0.0022178 \left(\frac{67.903+6.363\ V_{Low}}{6.11414} + 273.16 \right)$$

$$(Eff)_{Candu-PHWR} = 1 - 0.0022609 \left(\frac{46.487+4.353\ V_{Low}}{4.18326} + 273.16 \right)$$

$$(Eff)_{HTGR} = 1 - 0.0020101 \left(\frac{62.144+3.558\ V_{Low}}{3.3306} + 273.16 \right)$$

$$(Eff)_{Phenix} = 1 - 0.0019512 \left(\frac{11.640+1.829\ V_{Low}}{1.78667} + 273.16 \right)$$

Gulf

$$(Eff)_{PWR} = 1 - 0.002215 \left(\frac{67.541+4.730\ V_{Low}}{4.48292} + 273.16 \right)$$

$$(Eff)_{BWR} = 1 - 0.0022178 \left(\frac{67.903+4.722\ V_{Low}}{4.11414} + 273.16 \right)$$

$$(\mathrm{Eff})_{\text{Candu-PHWR}} = 1 - 0.0022609 \left(\frac{46.487+3.265\ V_{Low}}{3.0949} + 273.16 \right)$$

$$(\mathrm{Eff})_{\text{HTGR}} = 1 - 0.0020101 \left(\frac{62.144+2.972\ V_{Low}}{2.74456} + 273.16 \right)$$

$$(\mathrm{Eff})_{\text{Phenix}} = 1 - 0.0019512 \left(\frac{11.640+1.160\ V_{Low}}{1.11691} + 273.16 \right)$$

Figure 59 depits the efficiency fluctuation under the conditions stated above.

The Average Efficiency Values

For the purpose of fuel cycle calculations carried out in this work, it was necessary to pick up an average value of efficiency for each reactor system. This was done on thinking that inlet water should not be drawn from the surface, since it is already hot, but rather the water uptake should be at reasonable depth where the water temperature is somewhat cooler than at the surface.

In fact, the deep water temperature of the Red Sea is cooler from the surface such that it is reduced by 4 degrees at the depth of 100 m. It is then constant up to the depth of 1960 m. Beyond that, it rises to 50°C.

Going in deep at Dahran area, the water temperature lowers by 2 degrees within 50 meters.
Now consider drawing the inlet water from a depth of 50 m. Accordingly the inlet temperature at the Red Sea (Jeddah area) will be 21°C during the winter time and 27°C during the summer. At the Gulf, it will be 16 and 30°C during the winter and summer respectively.

With these inlet temperatures and the preset outlet temperatures, as defined earlier, the efficiency values for the winter and summer times were estimated, the averages of which are stated below:

	Estimated Average Efficiency (%)	
	Red Sea	Gulf
PWR	31.58	30.87
BWR	31.42	29.84
Candu-PHWR	27.98	27.30
HTGR	36.19	35.54
Phenix	40.64	40.01

6.5 Cooling Towers

6.5.1 Thermodynamics, Meteorological Effects

Figure 60 presents two schemes of the natural draught wet tower, the counter flow (air-water) and the cross flow. In both cases the water moves downward through the packing providing a larger exchange surface. The inflowing air moves upwards, as the result of the chminey effect created by the difference in density between the warm moist air inside the tower and the colder and denser outside it /78,79/.

In fact, the performance demand for a particular cooling condition is given by the following relation /80,81/:

$$\frac{KaV}{L} = c_{p_W} \int_{t_2}^{t_1} \frac{dt}{h'-h}$$

$$\frac{KaV}{G} = \int_{h_1}^{h_2} \frac{dh}{h'-h}$$

where,

K = heat transfer coefficient, between the water and the air $(kg/m^2\text{-sec})$

a = area of the transfer surface per unit tower packed volume (m^2/m^3)

V = effective packed volume per unit aera of the packing (m^3/m^2)

L = water flow rate $(kg/m^2\text{-sec})$

C_{p_w} = the specific heat of water at a constant pressure $(cal/kg\text{-}^oc)$

G = air flow rate $(kg/m^2\text{-sec})$

h' = water enthalpy (cal/kg)

Concerning wet cooling towers, h' represents the enthalpy of the saturated interfacial air film surrounding the water drop-lets as they pass through the tower. The temperature of this film varies from the hot water temperature t_1 at the top of the tower to the cold water temperature t_2 at the bottom.

Further, h is the enthalpy of the cooling air passing through the tower. It is greatly influenced by the wet bulb temperature as the air enters the tower.

Figure 61a, depicts the temperature-enthalpy diagram for a wet cooling tower. The hot water emerging from the condenser is admitted to the tower at temperature t_1. It is then cooled along the curve h` till reaching t_2.

The cold air enters the tower at the wbt, t_{wb}. It is discharged to the environment at t_1. The larger the area between the two curves, h` and h, the larger the driving force, i.e. the heat transfer efficiency.

The process of heat transfer between the water and the air is described by

$$\Delta h = c_p \frac{L}{G} (t_2 - t_1).$$

This is the straight line h in the figure. It is known as the operating line.

The area between the saturation line h' and the operating line h represents the driving force which is created by the density difference between the warm moist air and the colder one. Thus, this driving force must be sufficiently high in order to overcome the resistance to air flow.

The thermodynamic properties of the surrounding atmosphere play the major role in the natural draft effect[+)]. Figure 61b depicts the effect of wet bulb temperature (WBT), applicable to wet towers only, on the density difference driving force /82/. It should be noticed that as the wet bulb temperature increases the density difference driving force drops rapidly. The density difference at a wet bulb temperature of 5°C is more than twice that at 20°C.

Figure 61c shows the effect of relative humidity on the density difference driving force. As the relative humidity increases from 20 to 100 percent, the density difference increases by a factor of 1.80.

[+)] The surrounding atmosphere plays somewhat a lesser role in the mechanical draft tower, due to the fact that this type of tower is designated with a fan at the top to draw air upwards.

The combined effects of wet bulb temperature and relative humidity on the driving force is shown in Figure 62a. It shows that for a given wet bulb temperature, the density driving force increases with increasing relative humidity. From these figures it is evident that favorable conditions for natural draft wet cooling occurs when the wet bulb temperature is low, and the relative humidity is high.

The climatic variations through the year at Jeddah area (Figures 40 and 41)+) actually satisfy these two conditions for natural draft wet cooling tower application. On the other hand, looking at the Riyadh and Dahran areas, one finds that favorable conditions for wet cooling tower application do not occur simultaneously with high power demand season. That is, during the summer season the high ambient air temperature at these two areas results in a large demand for electricity for air conditioning. But it is this high amient air temperature coupled with low relative humidity make the climatic conditions unfavorable for the application of natural draft wet cooling towers.

Figure 62b displays for a LWR of 1000 MW(e) /83/ the effect of wet bulb temperature and relative humidity on the rate of cooling water loss from the wet tower in the form of evaporation. It shows that during the summer seasons, at locations of less humidity but high temperature (e.g. Riyadh, Dahran areas) the replacement for losses, or 'make-up' water requirement, can reach up to nearly 1 m^3 per second.

Figure 62c compares the influence of the cooling temperature on the condenser pressure, and hence on energy generation, between the two applications of wet tower and dry tower to a 1000 MW(e) LWR. In fact, the lowest cooling water temperature which can be

---

+) Average year conditions are given on page 125 achieved, known as 'limiting cooling temperature', is determined by the air temperature in the case of dry cooling towers, and not by the wet bulb temperature as for the case of wet towers.

Thus, since the air temperature varies during the course of a year (or even a day) more than the temperature determined by the wet bulb thermometer, the climatic effect is much higher with dry cooling than with wet cooling. The figure shows that with dry cooling the loss effect on energy generation increases sharply with increasing air temperature, while with wet cooling the loss in energy generation increases much less sharply with increasing wet bulb temperature.

This means that even with the application of dry cooling towers to Riyadh and Dahran areas the two cross effects will remain during the summer time, namely loss in energy generation and large demand for electricity for air conditioning. The two effects are due to the high ambient air temperature.

There are actually two dry cooling systems, the direct and the indirect cycles. The design of the direct concept is based on forced cooling and its application for power plants greater than 600 MW(e) is not economical at present /84/.

The indirect system utilizes jet condenser. The high quality circulation water is sprayed into the jet condenser where the exhausted steam loses heat as it condensates.

By means of large circulating water pumps most of the heated condensate is recycled to the tower while the remaining condensate is returned to the feed water cycle.

Dry cooling operates essentially without losses of water from evaporation and drift, since the water which holds the heat removed from the condenser is circulated through a close system of tubes exposed to air, and consequently there is no need for fresh water make up /78,85/.

However, with respect to BWRs the use of spray condensers is almost impractical, since the steam emerging from the pressure vessel carries with it some radioactivity which can leak to the atmosphere when a defect takes place in cooling tubes of the tower.

The designer of the dry cooling tower is faced with various optional possibilities concerning the structural materials for the tower enclosure and the hydraulic system (e.g. the arrangement of the cooling elements and the configuration of the cooling tubes).

The structural component can be a reinforced concrete enclosure, a steel lattice, or a rope network construction. With reinforced concrete shell, the tower height can be up to 200 m for height/diameter ratio down to 1.03. With larger dimensions, the shell becomes instable and unable to withstand side winds or explosion pressure.

The arrangement of the cooling elements in the dry tower is made with particular consideration of the sensitivity to the wind flow. Vertical arrangement of the elements is avoided in order to prevent the development of positive and negative pressure areas around the circumference of the tower which can effectively reduce the air throughput. When the elements are arranged with an inclination toward the center, however, equal air flow velocities will prevail in all areas of the heat exchange surface.

Looking from the cost point of view, the energy generating cost of a water reactor (e.g. PWR, Candu-PHWR) cooled with wet tower is more advantageous to that cooled with dry tower. The reasons are the capital investment for a dry tower is much higher than that for the wet tower and water reactors suffer from low thermal efficiencies. Based on such economical reasons, in the first place, the application of dry towers in the nuclear field is now practiced only with HTGR.

From the environmental point of view, however, the impact of the waste heat discharged to the environment by means of a dry tower is expected to be somewhat less than that deliverd by a wet tower. That is while water precipitation is not associated with the operation of a dry tower, cumulus clouds formation is possible.

6.5.2 Determination of the Characteristics for Wet Cooling Towers and Dry Cooling Towers with PWR and HTGR at Three Locations Near Jeddah, Dahran, Riyadh

As mentioned previously, the highest constraint in the country and especially at all inland siting is availability of sufficient water for condenser cooling. The previous sections pointed out that application of wet cooling towers requires less water than the direct cooling option. Application of dry cooling towers satisfies the water scarcity condition. Dry towers, however, impose high investment penalities.

In order to provide with different climatic and elevation conditions, and cover in the mean time coastal and inland siting, three locations near Jeddah, Dahran, and Riyadh are selected.

The Jeddah site is about 16 km north east of Jeddah. The location is in the vicinity of a valley named 'Daghbaj'. A site was selected at the height of 35 m above sea level.

The Dahran site is within 10 km south of Dahran city and at the height of 2 meters above sea level. The Riyadh site is on the Najd plateau at the height of 740 m above sea level.

Earlier preliminary investigations have identified these three locations in particular as suitable from the geological points of view for a nuclear facility /86/.

6.5.2.1 The Case of PWR System

The objective in this part is to compare with a PWR reactor type the wet cooling and dry cooling tower in so far as:
(1) Over all plant efficiency
(2) Cooling tower's dimension
(3) Cooling tower's cost

The computation is carried out by inserting the climatic conditions at the three sites (as given in section 6.3.2) to a computer program which is designed for a unit size of 1300 MW(e) of the type (BBR)-Nuclear Steam Supply System(1). The results are then linearily extrapolated to unit sizes, 1200, 1000, 900, and 600 MW(e). These are the units of interest to the country.

This computer program is designed to economically optimize the cold end of the steam cycle. It aims at determining, within the established frame boundaries of technology, the sizes of all the components involved within the blocks designated as 'variable parameters' at either a minimum investment expenditure or that corresponding to the maximum value of a fixed capital interest.

The program designates the following blocks as variable parameters:(2)

- All components belonging to the cooling tower
- All components belonging to the cooling water flow (e.g. facilities related to inlet and outlet piping, pumping, cleaning, and all electrical machinaries)
- Condenser components (e.g. condensing surface area)
- Low pressure parts of the turbine block

---

(1) It should be emphasized that there are no reasons of preference in selecting this particular design of PWR. The choice was subject to source availability of computerized programs for the two reactor systems, PWR and HTGR /87/.

(2) Detail structure of the program is published in ref./88/.

For a predetermined optimum value of 15°C and 16°C as the difference between the inlet and outlet cooling water temperatures concerning, respectively, wet tower and dry tower the optimization program determined under the conditions prevailing at the three selected sites the following values for inlet temperature and condenser temperature and pressure:

	Jeddah Site		Dahran Site		Riyadh Site	
	Wet Tower	Dry Tower	Wet Tower	Dry Tower	Wet Tower	Dry Tower
Inlet Temp. °C	34.3	48.0	32.1	46.5	26.8	44.4
Outlet Temp. °C	49.3	64.0	47.1	62.5	41.8	60.4
Condenser:						
Temperature, °C	53.8	68.5	51.6	67.0	46.3	64.9
Pressure, bar	0.149	0.292	0.134	0.274	0.102	0.24

It is interesting to notice that the optimum values of the condenser presser obtained for both wet and dry towers at the Riyadh site is somewhat less than those for the other two sites. The direct consequence of which is that at Riyadh site more electrical energy from the same thermal input, namely 3760 MW(th), can be generated and hence higher efficiency can be obtained as demonstrated below:

	Jeddah Site	Dahran Site	Riyadh Site
Generated Power (gross), MW(e)			
- Wet Tower	1280.0	1289.9	1309.2
- Dry Tower	1172.5	1180.7	1192.2
Cooling Water Pumping Consumption, MW(e)			
- Wet Tower	11.3	11.3	11.2
- Dry Tower	9.1	9.1	9.1
Station Total Consumption, MW(e)			
- Wet Tower	86.5	86.5	86.4
- Dry Tower	84.3	84.3	84.3

	Jeddah Site	Dahran Site	Riyadh Site
Generated Power (net), MW(e)			
- Wet Tower	1193.5	1203.4	1222.8
- Dry Tower	1088.2	1096.4	1107.9
Plant Thermal Efficiency, %			
- Wet Tower	31.74	32.00	32.52
- Dry Tower	28.94	29.16	29.46
Heat Discharge at the[a] Condenser, MW(th):			
- Wet Tower	2473.0	2463.0	2444.0
- Dry Tower	2582.0	2574.0	2562.0
Cooling Water Flow Rate, kg/s			
- Wet Tower	39420	39260	38950
- Dry Tower	38620	38495	38320

(a) Not including the discharge heat from component cooling

From this follows:

(1) With dry cooling towers, the plant efficiency at the three sites is lower by about 10% of that achieved by the wet cooling towers.

(2) As a consequence of loss in efficiency, with dry cooling towers more waste heat must be discharged to the atmosphere.

(3) With dry cooling, the cooling water flow requirement is nearly equal to that with wet cooling. The difference is the dry cooling demands high purified water which, in principle, needs not to be replaced or make up supplies.

(4) The lowest thermal efficiency with both dry and wet cooling is at Jeddah site. To explain, it should be kept in mind that the meteorological conditions supplied to the computation program are those determined as the 'year average' values, namely:

	Jeddah Site	Dahran Site	Riyadh Site
Year Average			
Air Temperature, ^{o}C	28.0	26.5	24.4
Relative Humidity (%)	61.1	55.3	33.9
Wet Bulb Temperature, ^{o}C	22.3	20.1	14.8

But looking at Figures 40 and 41 one finds that at Dahran and Riyadh sites the difference in the recorded meteorological condition between winter and summer times is much conspicuous. Thus the year average temperature and relative humidity must be necessarily lower than that of the summer time. On the other hand, at Jeddah site the meteorological conditions do not greatly change from season to season.

This means that at Dahran and Riyadh sites the efficiency values during the summer time should be expected to be lower than those presented above, while at Jeddah site the values can be said to be truely representative of the year throughout.

Next determined are the size of the towers, rate of evaporation, and make up cooling water requirement.
To determine the number of towers for the unit of 1300 MW(e), the computation procedure presents an upper limit to the height of the tower to the value of 200 m at maximum. With such a limit, the optimum tower dimensions are determined in relation to the investment cost for a natural draft concret shelled tower.

Accordingly the values are compared as follows:

	Jeddah Site		Dahran Site		Riyadh Site	
	Wet Tower	Dry Tower	Wet Tower	Dry Tower	Wet Tower	Dry Tower
Number of Towers	1	2	1	2	1	2
Tower Diameter, m	119	190	127	189	155	194
Tower Height, m	152	200	162	200	194	200
Rate of Evaporation kg/s	884	---	882	---	885	---
Make up Water Requirement, kg/s	1327	---	1323	---	1327	---

From this follows:

1. There should be 2 dry towers against 1 wet tower. The dimension of each dry tower is even larger than the wet tower.
2. At Riyadh site the size of the wet tower is larger than at the other two sites, even though the quantity of heat to be discharged is less (2444 MW(th) at Riyadh, Vs 2473 and 2463 MW(th) at Jeddah and Dahran, respectively). This requirement of larger tower size is due to the fact that because the inner part of the country is dry and less humid, a penality is imposed on the operating characteristics of the wet tower which depends on the wet bulb temperature. The same can be said, but conversely, for requiring at Jeddah site a smaller tower.
3. Applicability of wet tower to the Riyadh area cannot come in consideration, due to the large make up water requirement. The daily make up water requirement for only one station of 1300 MW(e) is 144.65×10^3 m^3/d. The projected water requirement for the Riyadh city by 1980 is 163×10^3 m^3/d. Thus the station would need about 70% of the water which must be pumped up from a depth of 1200 - 1400 meters below ground level.

The determination of the capital costs follows a relative calculation. For the purpose of this work the cost of the dry tower at Dahran, being the smallest of all dry towers, was selected to be the base. Relative to it the costs of other towers are determined as follows:

	Jeddah Site		Dahran Site		Riyadh Site	
	Wet Tower	Dry Tower	Wet Tower	Dry Tower	Wet Tower	Dry Tower
Relative Tower Investment Cost (%)	12.1	101.1	13.5	100	18.5	106

From this follows:

1. Individually dry towers at all sites are nearly equal in investment requirements, so are the wet towers at Jeddah and Dahran.
2. Since 2 dry towers are necessary, the cost of wet cooling is only 6% of dry cooling at Jeddah and Dahran sites. It is 9% at Riyadh site (overlooking make up water supply investment).
3. Therefore it can be concluded that for all inland siting the water constraint can be relieved when relying on dry cooling towers but an economical penality must be expected due to two effects, loss of efficiency and high investment cost of tower.

The above results were then extrapolated to unit sizes of 1200, 1000, 900 and 600 MW(e) with both dry and wet towers. The results are tabulated in Table 30.

6.5.2.2. The Case of HTGR System

The meteorological conditions at the three sites were introduced to an optimized design for an advanced concept of HTR, namely the one loop system known as HHT (High Temperature Reactor with helium turbine).

In this design, the only cooling system considered is dry cooling. Even then, the reactor efficiency reaches 40% (3000 MW(th) out put results in 1200 MW(e)).

An attractive design feature of HHT is the fact that the heat to be discharged to the atmosphere, by means of water air heat exchange in the tower, is at a considerable level of temperature. Under the central European conditions, the warm water to be carried to the tower has the uptimum temperature of 67.2^{o}C.

This means that with this type of reactors there is a source of 'free' heat which may be put to use to certain processes without penalizing the production of electricity.

Having this feature in mind, the objective in this part is to determine for the different climatic conditions at the three sites the uptimum temperature at which the cooling water would be carried to the tower.

The size of the tower is assumed to be only a little larger than that already incorporated in the opimization program, namely 231, 135, 155 m for the tower lower diameter, upper diameter, and the tower height respectively.

For the year average values of air temperatures and relative humidity, the computation resulted in the following uptimum values:

	Jeddah Site	Dahran Site	Riyadh Site
Cooling Water			
Inlet Temperature, ^{o}C	32.0	30.5	28.4
Outlet Temperature, ^{o}C	85.3	83.8	81.7
Power Production			
(gross), MW(e)	1172.0	1179.0	1189.0
(net), MW(e)	1157.0	1164.0	1174.0
Plant Efficiency, (%)	38.56	38.79	39.14

It should be noticed that the efficiency values are now lower than that can be achieved in Europe by only one degree in all cases. The outlet temperature, however, has increased from 15 to 18^{o}C.

Thus, at both Jeddah and Dahran sites with this type of reactors a great advantage can be detected in so far as using the 'free' heat for desalination. Even then, the warm water temperature is not sufficiently high enough for the MSF desalination process at its optimum design in the country (chapter 4).

6.6 Conclusion

(1) Near Term Considerations (e.g. 1980-2000)

Since all major developments for the period 1980-2000 are planned to grow at locations nearby the Red Sea and the Arabian-Persian Gulf, due to lack of rivers and most of the basic requirements for industrial and agricultural growths in the inner parts of the country, the power plants will be located along the two seas as well. Hence, the following are concluded for the near term applications of reactors:

- There can be no major constraints as regards for both land availability and heavy load transportations.

- The application of wet cooling towers for locations along the seas can be justified only after having proved that the thermal discharges to the seas can result in a negative impact on sea life. To prove an impact positively or negatively, however, will take sometimes. Thus direct sea cooling can be envisaged at least for the foreseeable future.
- By direct sea cooling any predetermined efficiency value (less or equals to the maximum efficiency obtainable by the reactor system) for a given location at the Red Sea and the Gulf can be achieved, regardless of the inlet temperature conditions at the location in concern. This, however, will be at the cost of higher cooling mass flow rate.

(2) Far Term Considerations (e.g. beyond 2000)

In future, however, the consideration of inland siting will become very possible especially for those areas covered by the Electricity District A and also in connection with coupling of reactors to mining industries which will be located mostly within the Arabian Peninsula. Hence, in this respect the following are concluded:

- The application of wet cooling tower for inland siting is not practical on the account that the daily make up water requirement for a large station (e.g. 1300 MW(e)) under the desert conditions will be some 115 × 10^3 cubic meters per day, or 70% of the total water demand expected for the capital city Riyadh in 1980.
- Thus dry cooling towers remain the only alternative, since water replacement is not required in principle.
- But, with PWR system there should be two dry towers against one wet tower for units greater than 600 MW(e), each having larger dimensions than the wet tower and hence imposing a large penality in terms of capital investment.
- Another penality of dry tower with PWR system appears in terms of the plant efficiency which becomes lower by 10% of that achievable by wet tower which in turn leads to the discharge of more heat to the atmosphere.

- On the other hand, dry tower with HHT-system will operate in the country at all locations, inland or otherwise, with plant efficiency nearly as achievable in Europe.
  Thus, for all inland sites an advanced type of reactor, e.g. HTGR,HHT,FBR, etc., must be considered in order to avoid the consequent penalities arsing from the application of dry towers.

7. Conclusion and Recommendation

7.1 Why Consider Nuclear Power?

Firstly, it is deduced in this work that if the power required for meeting demands on electricity and desalination during 1980-2000 is to be exclusively supplied by oil fired stations for 30 years supply life time, the local consumption of oil will amount to 6% (at maximum) of the country's oil reserve (see section 5.5.3).

Because of such a relation between local consumption and oil reserve, and because the country possesses a large oil reserve (148×10^9 Barrels of Proven Reserve as of end 1979), the circulating opinion is that this country will never need to consider an alternative for its energy system.

This opinion, however, is only partly true, because it overlooks the fact that the oil reserve in Saudi Arabia makes up the main oil reserve for the free world. Hence, its depletion is directly proportional in the first place to the consumption rate in the free world, estimated to reach over 40 million barrels per day by 1980.

Secondly, while oil must be sold for mutual interest of the country and the free world, non-salable energy sources, e.g. truly "indigenous" sources as hydro and solar alternatives, are very much limited.

There are only a couple of small dams located in the south-eastern part with only few kilowatts production capacities. On the other hand, both high solar intensity and availability of large areas in the country make solar energy a gigantic potential, but the very high capital investment required with the present technique precludes its consideration for the foreseable future.

Thirdly, like solar energy, uranium exists in abundance in the country. It has been identified in the northern part of the country. The exact amount of it, however, is not yet known, because it is considered so far as one of the several mineral resources of the country, the exploitation of which are deferred to the periods beyond 2000 and according to the world market situation.

Knowing the exact amount of uranium present in a Developing Country can influence the choice of the reactor type such that having large uranium resources promotes natural uranium reactors on the priority list of choice.

This internationally agreed opinion, must be carefully interpreted, because an additional and non-separable requirement for choosing a natural uranium reactor, and hence becoming independent of enrichment., is the ability to devote a considerable size of man power for the fuel fabrication committments. Actually, this was the base for countries like India and Pakistan for deciding to follow the path of natural uranium reactors (e.g. the Candu-PHWR system).

Thus, for countries like Saudi Arabia, where a shortage of man power is almost unsolvable [(1)], choosing natural uranium reactors on the basis of having large quantities of uranium does not lead to the desired independency from outside influences. What it will do in effect is to limit the choice of the supplier to Canada and India, instead of having a larger choice of suppliers as in the case of enriched uranium reactors.

Nevertheless, and regadless of the reactor type, the fact that the country has uranium in abundance leads to the consideration

---

(1) Experience shows, while skilled and non-skilled workers from other Arab and Moslem countries relieve man power constraint, new problems arise, such as high wage rates, high crime rates, and very specially the phenomenon now termed in the country as "pseudo unemployment" - meaning the service of the large number of workers is made intentionally scrace.

of nuclear fuels as an indigenous energy source for which matured technology is available in the free world.

Last not least, the potential industries of the country are of the energy intensive type, e.g. refinaries, steel making, aluminum, fertilizer industries, etc. These industries require both electricity and process steam. Nuclear reactors can supply these industries with both steam and electricity simultaneously, knowingly that an advanced type of reactor such as HTGR and FBR can provide, for example, a refinary with heat and steam at the required temperature levels ranging from 360 to 800°C.(1) The supply with steam needs further coupling development, but electricity can be directly diverted from reactors to industries.

Thus, nuclear reactors which are fueled in most cases once annually can be in the position of providing industries with permanent and reliable energy supply source.

Further, technology transfer to the country through a nuclear power program should not be underestimated. It can have a chain effect, once it is initiated. It is true, for the first couple of plants the country will have to import all the plant's equipment, due to lack of domestic industrial capabilities. But in the meantime, during the planning, implementation, and erection of the first plants, the impact of technology transfer will be born. It will start with trained staff at all levels, management, engineering, welding, fitting, operation, maintenance, etc., an experience which can be extended to other areas, followed by gradual participation of local industries, knowingly nuclear power industry covers a wide spectrum of both light and heavy industries.

---

(1) Temperature levels for basic processes in a refinary: (°C)

Atmospheric Distillation	= 360
Vaccum Distillation	= 400
Gas-Oil Desulfurisation	= 330
Catalytic Reforming	= 540
Steam Reforming	= 800-900

Moreover, the participation of local industries will definitely improve their capabilities in meeting the strict specification, and hence creating a new skilled labor force. Followed by further improvement of capabilities, leading to finally the undertaking of projects requiring high levels of performance.

Thus, there is no doubt that the technical and management levels of the country can be brought up through a nuclear power program. The degree of such upgrading, however, will be totally dependent on the predetermined strategies for the transfer of technology, a point not to be treated in this work.

7.2 The Choice of the Reactor Type: A Comparison of Alternatives

There are many ways to classify nuclear power reactors e.g. according to neutron energy, fuel reproduction characteristics, conversion etc., but the most known classifications are according to the coolant and the fuel type.

Practically, three materials are known as proper coolants: water, gas, and liquid metals.

Both light and heavy water (D_2O), separately, are used as coolant, moderator, and reflector, because they display several advantages, e.g. collectively having both high specific heat (so that small circulation rate is necessary for a given heat output) and high negative temperature coefficient (contributing greatly to the safe and stable operation of the plant) and individually, as being cheap and readily available (only applicable to H_2O) and not demanding enrichment of uranium (valid for D_2O application only). On the other hand, water reactors of the two cycle system, primary and secondary cycles, suffer from the requirement of high primary cycle pressure, and low temperature, resulting in poor thermodynamic efficiency.

That is, in this type of reactor, known as the Pressurized Water Reactor (PWR) no bulk boiling is permitted during plant operation, and hence the pressure of the primary cycle must be kept above the saturation pressure for the highest temperature achievable. For the heat to be transferred the secondary cycle must be at lower temperature and pressure, leading to low thermodynamic efficiency.

Further, the temperature of water within the water reactors ranges from 288-343^{o}C. At these temperatures the corrosion rate of carbon steel is too high, such that direct contact between the coolant and vessels and pipes cannot be allowed, and hence the vessels and pipes must be made out of the much more expensive 300 series stainless steel.

For the gas coolant, two gases are applied. These are CO_2 and He. Advantageously, these two gases are safe, relatively easy to handle, have low macroscopic neutron cross sections, readily available and cheap (not valid for He).

CO_2 is inert at low and moderate temperatures, non-toxic, and inexpensive, thus the gas leakage does not become a cost factor. CO_2, however, is limited by temperature conditions. At higher temperature CO_2 is reduced by reaction with the moderator, namely graphite, to CO. Also at temperatures above 360^{o}C the oxidation of carbon steel by CO_2 takes place. Helium is recognized as the best gaseous coolant. It has good thermal conductivity and virtually zero neutron cross section. It is inert and non-hazardous. Its main set back is due to the fact that its supply is relatively expensive. Helium use is usually considered for reactors with a high outlet temperature displaying high thermal efficiency, such as the High Temperature Gas Cooled Reactor and the Helium Cooled Fast Breeder Reactor.

In general two major disadvantages are associated with gas coolants. Firstly the low heat transfer and transport characteristics which imposes the requirement of large coolant surfaces and flow passages within the reactor and heat exchangers, and hence gas cooled reactors are inheritedly large in size. Secondly, the requirement of high pumping power, which could consume up to 20% of the plant's gross production.

In fact, the growth of nuclear power in the world's electric utility industry relies so far primarily on reactors cooled by water and gas. Such reactors are termed as "Proven Reactors" which by definition have been in operation at commercial maturity level for sufficient time, providing with pertinent operational data by means of which they have demonstrated their reliability as a 'safe' source of electric power.

Within these contents three systems of reactors are recognized as Proven Reactors. These are:

(A) Light Water Reactors, (LWR), with two versions:
- Boiling Water Reactors (BWR),
- Pressurized Water Reactor (PWR)

(B) Heavy Water Reactors, (HWR), with two versions:
- Candu Pressurized Heavy Water Reactors (Candu-PHWR),
- Pressurized Heavy Water Reactor-Vessel Type (PHWR-Vessel Type)

(C) Gas Cooled Reactors (GCR)

In the meantime, two additional reactor systems have strongly emerged, but not yet reached the stage of proveness. These are the High Temperature Gas Cooled Reactors (HTGR) and Fast Breeder Reactors (FBR). The emergence of each was highly motivated in a way of compensating for the weakness of the above mentioned Proven Reactors.

For example water reactors suffer from the limitation as far as the thermodynamic efficiency is concerned. Thus, a goal of interest centers around lifting up the thermal efficiency. This calls for high coolant outlet temperature, and hence necessating high fuel operating temperature.

The steps to high temperatures made it necessary to change the reactor materials. Such was the application of graphite exclusively for the coating of the ceramic fuel particles (UO_2,UC_2), for moderator, for fuel structural material, and for coolant channels. Helium was applied for coolant. This is then the new system HTGR.

As for fuel, this system can use both low enriched uranium and highly enriched uranium (in combination with thorium). As for design layout, it can be of the two cycles system (as has been demonstrated so far) or of the one cycle system whereas the helium turbine must be first developed (e.g. High Temperature Helium Turbine Reactor HHT).

The HTR system in operation so far achieved a considerable improvement on reactor characteristics (see Tab. 18), such that the accomplishment of high coolant outlet temperature (has been demonstrated up to 1000^{o}C) supports the argument of the possible application of the system in areas other than electricity production, e.g. coal gasification, water splitting into its constituents and hence providing a hydrogen source, and coupling to refinaries, petrochemicals and desalination plants.

Next, the concept of Breeder Reactors was born out of the fact that both the above mentioned Proven Reactors and the High Temperature Reactors are actually "burners" in the sense that they consume the fissionable fuels with low conversion ratio(1). Hence, for reasons of conserving uranium reserves and (if possible) keeping the fuel cycle cost down as uranium price goes up, a reactor system with much higher conversion ratio was sought.

---

(1) By Definition, Conversion Ratio, C=(Product.Fissile/Loss of Fissile)
(Fissile=U-235,Pu-239,U-233). Breeding aims at C greater than 1.

Under the title of Breeder Reactors two systems can exist. Firstly, the Thermal Breeder Reactor where the bred fissile is U-233, resulting from neutron capture by thorium-232. The pursuance of this system, however, is not foreseen at present. Secondly, the Fast Breeder Reactor where the bred material is the fissile plutonium (e.g. Pu-239), resulting from the capture of the neutron by uranium-238. The emergence of this system in the foreseable future is widely recognized.

Two coolants are found most suitable for Breeder Reactors, liquid sodium and helium:
Liquid soldium is an excellent coolant in that its boiling point is sufficiently high, 880^{o}C, and thus the pressure of the primary cycle can be kept below 10 atm. In addition, it has the lowest specific pumping power.

Sodium, on the other hand, becomes radioactive (e.g. isotope Na-24), and reacts violently with water, and therefore, an intermediate inactive sodium cycle between the primary and the secondary cycles must be included. Further disadvantages of sodium are in the case of a loss-of-coolant an increase in reactivity of the reactor can happen, and the breeding gain is only near to 1.

In contrast, helium can provide the Breeder system with a higher conversion ratio. It does not become radioactive, hence there is no need for the intermediate cycle. And most important, a loss-of-coolant results in a minimum increase of reactivity.

Although cooling with helium can lead by far to the best conversion ratio, Gas Cooled Fast Breeder Reactors (GCFBR) remain so far in the early development stages.

On the other hand, a demonstration Breeder Reactor representing a version of the well known Liquid Sodium Fast Breeder Reactor, abbreviated as (LMFBR), is already in operation in France (e.g. Phenix, pool version) and similarly another version is scheduled to be on line in West Germany (SNR 300, piped loop version) and USSR. In U.K. PFR, (pool for primary system and piped intermediate loop) is in operation since 1975.

While the system of Breeder Reactor is credited as the only system which is able to contribute largely to the continuation of the nuclear fuel supply through the consumption of the rather abundant stock pile of U-238 in the form of plutonium, it must be admitted that the plausibility of introducing a Breeder Reactor to a power system must be seen in terms of the power production costs as well.[1]

Actually, recent comparison between the capital costs of a LMFBR and a LWR shows that there is an "excess" capital cost associated with the Breeder Station, which can be related to its rather complicated technology. On the other hand, the absence of expenditure for enrichment and natural uranium (since depleted uranium is used) allows the breeder station to compensate, to some percentages, for the "excess" capital cost by having lower fuel cycle cost. This compensation is seen at present to balance out about 26% of the "excess" capital cost. Thus, looking from the utility point of view much improvement is still necessary on power production costs by Advanced Reactor Systems (both LMFBR, and HTGRs).

7.3 What Alternatives are Available to Saudi Arabia?

Since the country has not yet committed itself to a nuclear power program of any reactor type at all, the choice of the alternatives is highly dependent on when the decision to "go nuclear" will take place. In reference to Table 17-a,17-b, one sees that the first nuclear power station can be integrated as early as 1985 for the case of power-only production, or even earlier for the case of

(1) The same applies to the High Temperature Reactors

dual production.

However, it is well recognized that the integration of the first nuclear plant consumes longer time than the consecutive ones. The International Atomic Energy Agency (IAEA) states in its publication (ref./89/) that it takes for the first nuclear power project (e.g. 600 MW(e)) in a country outside the major nuclear powers at least six years from the signing of the contract with the reactor vendor to its commercial operation. Prior to construction time, a preparation period of some 5 years is necessary for the first plant. Thus, in all 11 years must be allocated.

This means, if the country embarks the decision to "go nuclear" in 1980, for example, the plant to be considered will be the ones to be added to the grid in 1991, namely 1000 MW(e) or 600 MW(e) (or even the 1200 MW(e) according to the Development Possibility One).
Further, for the 1991 plant(s), the choise of the reactor type will, however, be confined to those reactors now called Proven Reactors, since at times of decision, e.g. 1980, the technical and economical viabilities of the Advanced Reactor Systems will still be under heavy investigations in USA and Europe.

On the other hand, if the country should suffer a delay period of 5 years such that it cannot embark on the decision to "go nuclear" before 1985, the schedule for the introduction of the first plant will shift then to around mid 1990s. Thus a delicate situation is at hand:
That is, at decision time, 1985, one will have a true choice between selecting the 1996 plant(s) either of the Proven Reactor Systems or the Advanced Reactor Systems[(1)].

---

(1) Valid with the assumption that no drastic change on the development of the Advanced Reactor Systems will take place between now and then.

The Proven Reactor Systems will be providing a large record of experience and reliability, including in Developing Countries as well (e.g. Egypt, South Korea, Brazil, etc.). But their inherited disadavantages will become more conspicuous in the light of the better achievement of the Advanced Reactor Systems.

In fact, if the reactors will exist in the country from the mid 90s on, the consideration of industrial applications of nuclear reactors, and hence the selection of an advanced type, HTGR, LMFBR, or GCFBR, becomes very plausible for the following reasons:
Firstly, in USA and Europe approximately 40% of the energy consumption is for industrial uses. Thus, this and the ever growing energy constraints in these countries, present a high incentive for continuing the researches now in progress on coupling reactors with industries. It is just possible that studies on Energy Transport from an advanced reactor to a given industry (e.g. refinary) for the different processes will come to positive conclusions by early 90s.

Secondly, the planning for the industrial infrastructures in the country are in a way of clustering several industries together, termed as "industrial complexes", e.g. Jubail industrial complex on the Gulf, Yenbu industrial complex on the Red Sea. Such gathering of industries, advantageously put them in the situation of sharing simultaneously the power, steam, and heat supplied by an economical size nuclear sation.

Thirdly, one of the problems of 'local industrialization' is the high cost of production, which can be attributed partly to the cost of imported technology, and partly to the high rate of payment acquired by imported labor. Hence, any measure which can result in lower production cost, in the country will be looked forward to.
It is shown in this work that the use of helium turbine can result in obtaining "free" heat energy as a byproduct, and thus

availability of similar possibilities at times of decision taking in the future will considerably raise the interest on selecting an Advanced Reactor System.

However, the discussion so far was focused on thinking about choosing either a Proven Reactor System (e.g. decision taking time, 1980-85) or an Advanced Reactor System (e.g. decision time, beyond 1985).

It, however, must not be so necessarily, because one can think of a combination of systems in that the first few plants will belong to a selected Proven Reactor System followed by an Advanced Reactor System selected on the base of the prevailing conditions then.

Such actually is the most practical path to follow, because stepwise procedure will result locally in an intimate experience with nuclear power upon which the future of nuclear power in the country can be decided.

7.4 What Proven Reactor System Should be Selected?

As mentioned earlier, there are only three Proven Reactor Systems to choose from: LWR, HWR, and GCR (e.g. Magnox). A vital requirement of the LWR system is the availability of enrichment service. More discussion on it will be followed later. Both versions of the HWR system and the Magnox reactor do not require enrichment.

The HWR system, however, requires the highly expensive coolant and moderator material, namely D_2O, consumed at the rate of nearly 1 metric ton per megawatt electricity installed (e.g. 1 t/MW(e) for the first core) beside the annual requirement for replacing losses amounting up to 20% of the original quantity.

The price of D_2O is continuously increasing. It cannot be obtained now at less than 120 × 10^3 US dollars per ton. This high price of D_2O, actually, imposes the need for recollection of the losses as much as possible (followed by upgrading), a daily procedure that results in the exposure of the personnels in charge to the highly toxic radioactive isotope tritium (H-3, $t_{1/2}$ = 12.3 y).

The Magnox system, on the other hand, is free of both enrichment service and D_2O cost and the above mentioned health effects, since it uses natural uranium, but is moderated by the rather inexpensive graphite, and is cooled by the most inexpensive and readily available coolant CO_2.

The Magnox reactors operating in Britain display a great achievement in terms of availability of the reactor for power production, and reliability of the system. Its major disadvantage focuses on the extraordinary core dimensions required, and the high specific costs ($/KWh). A consequence of material limitations in the Magnox type (see section 5.1.2) is the low burn up, e.g. 3000 MWd/t, thus leading to low specific power, and consequently, low core power density. The plant efficiency is lower than that in LWR, due to pumping losses.

Actually, the Magnox type belongs to the first generation of the Gas Cooled Reactors. It has truely succeeded in demonstrating the desired independency in fuel cycle matters, and operation safety attributed to the application of gas as coolant.

Since the Magnox type reactors do not require neither enrichment nor heavy water, it can be said that from the point of view of achieving independency in fuel cycle material requirements, the Magnox system must be seen as the first alternative to the LWR system.

In the meantime, it must be reminded that the power reactors discussed here are those to be operated after more than a decade from now, and thus the question on the availability of the Magnox system becomes rather important. As is known so far, the supporter of the Magnox system, mainly Britain (and to some extent, France), has already decided to abandon the further construction of this version of Gas Cooled Reactor on the account of the high capital cost.

Thus, it will be left for the future to reveal whether the cause(s) forced to take the decision to terminate the Magnox system will remain valid or will be reversed, and whether a Developing Country will be able to buy it.
This means, when writing this, of the Proven Reactor Systems, acutally only the water reactors are available for selection: Of these, the BWR version should not be separately emphasized, on the account of similarities of its overall characteristics with the PWR version on one hand, and the non-suitability of BWR from the psychological point of view for desalination on the other hand.

Also, the HWR pressure vessel type version cannot come into consideration, because a well known set back of this version is that as the reactor size increases, the dimensions of the pressure vessel become much larger, such that a unit of 470 MW(e) must have a pressure vessel with dimensions nearly comparable to that of a PWR of 1300 MW(e).

In addition, experience of this version is limited to the MZFR 100 MW(e) power research reactor at Karlsruhe and its further developed version, the commercial power station in Argentina named as Atucha (319 MW(e)[1].

---

(1) Recently, the consideration of this version became activated as a new order has been placed.

Thus, the choice must be further confined namely to PWR and Candu-PHWR

The discussion below is, therefore, focused on PWR and Candu-PHWR systems:

A more often argument used for pointing out the plausibility of the Candu-PHWR system for Developing Countries is the prospect of producing power in independency of enrichment policy.

Actually, to stay independent on all levels is a common desire which is shared by all countries, because the production of a basic commodity like electricity, being required around the clock at houses, hospitals, streets, schools, and industries, cannot be allowed to be oscillated by outside influences.

Since the start and until now, the dominating supplier in the enrichment field is USA. Most of its enrichment plants were constructed for military purposes, and hence there was always ample capacity to satisfy needs.

But enrichment service was placed under a stringent policy such that the enrichment contract must cover at the minimum a period of 15 to 20 years.

Further, the customer must define the total quantity of separative work unit (swu) that he will purchase during a period of 10 years. Such a definition must be made at least 8 years in advance of the first delivery, and the total amount during the 10 years period has to be at least three times the requirements for the first core.

Moreover, payment must be made in advance such that for a 1000 MW(e) unit an amount of 3.3 million US dollars must be paid, starting from the date of signing the contract. While, on the other hand, the supplier, that is USA, reserves the right to change prices on 60 days notice and hence the customer may be faced with completely unanticipated new financial obligations.

Now USA is not the only supplier. USSR has recently emerged as a second supplier for the Western World, but its enrichment policy is much similar to that of USA. Only URENCO(International Project located in the Netherlands which includes UK, Germany and the Netherlands) is said to show some flexibility. The fourth major supplier is EURODIF (International Project, located in France) has refused to sign enrichment contracts, on the account that most of its future production is already sold out to its sharehloders (France, Italy, Spain, Belgium).

Such are the actual fears on which most of the Developing Countries base their reluctance to the PWR system and thus find a somewhat rather stronger affinity to the Candu-PHWR system.

<u>The question to be posed now is: Should Saudi Arabia Fear Such a Stringent Enrichment Policy as Well?</u>

One can say that Saudi Arabia is in a position of dealing with such policies by two different means. Either refering to a "two dimensional" type of contracts, in which one of the dimensions is represented by the out flow of oil to, say, USA or Europe, and the other dimension, by the in flow of enriched uranium. Or, Saudi Arabia, having a large monetary deposits all over the world, can participate in joint investment in new enrichment plants, and thus secure enrichment services on equal bases with other stockholders.

What this indicates actually is that though Saudi Arabia is a Developing Country, its large world capacities on both financial and oil exporting levels put her in a distinguished situation such that it can get enrichment services if it chooses so, the details will be a governmental policy.

Another question to pose: What Degree of "Independency" Would Saudi Arabia Gain, If It Chooses the Candu-PHWR System?

It must be clear that independency means here the ability to produce locally the most vital items, namely the fuel element and D_2O. To accomplish this, the technology must be first established by three parallel actions. Firstly, finding a "back supporter" who is willing to transfer his own experience according to needs. Presently, only Canada has the entire experience on the Candu-PHWR system. Followed by India, who claims to be capable of producing all components of the reactor. The willingness of these two suppliers to take the role of the "back supporter" of a Candu-PHWR program in a Developing Country, however, cannot be assured at this time, especially knowing that the coorporation between Canada and Pakistan is nearly frozen, and that India has not shown yet any concern for cooporating with Developing Countries. Secondly, establishment, from the zero start, of all the necessary facilities for production, with procurement of D_2O occupying the top on the priority list. Thirdly, engagement in extensive training of personnels locally and abroads.

Thus, it is clear that to follow this path closely, a concrete decision must be preceded, which in turn must be based on a well defined long term strategy such that the exploitation of the Candu-PHWR system will progress gradually from the Once Through Alternative (OTA) at the beginning and ending finally with Breeder Reactors.

This discussion then boils down to the fact that if the country chooses the Candu-PHWR system, the choice must be made on a long term strategy. In the absence of such strategy, the choice of Candu-PHWR system will truly present independency from enrichment. But this will be only a "partial" independency as long as all the reactor components, including D_2O, will not be produced in the country.

Thus, whether selecting PWR (with enrichment requirement) or the Candu-PHWR system (but unable to produce locally the fuel element and D_2O), the risk of the outside influence remain unchanged. The difference being, however, with PWR system, one has the option of selecting one of the major suppliers from USA, W.Germany, and France, and hence the factor of "competition" among the suppliers remains an advantage in favor of the PWR system.

Further knowledges about the two systems are gained through this work as follows:

(1) The PWR system will operate in the country with a higher thermal efficiency. It was estimated to reach around 32% along the Red Sea and 31% along the Gulf.
The corresponding figures for the Candu-PHWR system are 28% and 27%, respectively.

(2) It was assumed that the demand according to the energy growth scenarios during 1980-2000 will be met by a nuclear fuel. Based on this assumption, the total uranium requirement for 30 years operation life time has been determined for the different fueling options in the two systems in section 5.2.
The conclusions in this case is in favor of the Candu-PHWR system. For the OTA fueling option, for example, with Candu-PHWR system the total requirement is around 80% of that with PWR system, resulting in a difference of 28.29×10^3 t.

Further, if reprocessing will be available, recycling is again in favor of the Candu-PHWR system. With PWR system, when both uranium and plutonium are regained and recycled, the total uranium requirement then will be 45% less than

that required by OTA.
As is known, the left over uranium in the spent fuel element of the Candu-PHWR system cannot be regained. Thus only plutonium can be recycled. Yet the total uranium requirement then will be 55% less than that required by OTA. This is actually due to the nearly twice as much production of plutonium fissile in Candu-PHWR than PWR system.
Then, this indicates that the availability of reprocessing services with Candu-PHWR system is highly desirable. Otherwise a large quantity of the valuable fissile plutonium will have to be stored away.

(3) Policies concerning the extension of reprocessing services has not yet been formulated. If the technology will be made available, its service can be acquired from abroad or, alternatively, by local reprocessing.

Reprocessing abroad, however, poses transportation problems (valid for the two reactor systems) of spent fuel element to the reprocessing site and the resulting wastes and the MOX fuel element to the reactor site, a fourth and back procedure which involves crossing of multinational borders.

The prospect of local reprocessing is much tied up with the size of the plant; small units are not economical.
For the reprocessing requirement during the operational period of 1980-2000, the largest possible unit size, for the PWR system will be of a 1000 t/y capacity, for the Candu-PHWR system of 1500 t/y. In both cases, the plant will start operation (e.g. 1991) at 1/2 of full capacity, reaching the full use only by the year 2000.
Thus, to conclude, it is clear that local reprocessing does not seem economical to be considered during 1980-2000, and hence it must be delayed until the time will come for operating large economical units.

(4) The electricity generating cost (e.g. mills/KWh) with respect to the fuel cycle expenditures only for a unit

of 1000 MW(e) with PWR and Candu-PHWR systems[1] fueled with uranium or thorium has been determined as prices scaled up.

The conclusions are:

- The thorium fueled PWR system is not economical. On the other hand, the thorium fueled Candu-PHWR system provides the cheapest generating cost (with respect to FC-expenditure) at lower range of prices, but looses its attractiveness at higher prices of thorium.
- The generating cost with OTA-PWR is always in excess of that for OTA-Candu-PHWR (see explanation, section 5.7.1).
- With PWR system the recycling of plutonium and uranium is worthwhile, because it provides the cheapest generating cost in this system. On the other hand, with Candu-PHWR system, although the quantity of plutonium gained is twice as much as that in PWR, plutonium recycling will not be competitive with the OTA unless uranium price goes up to and beyond 177 \$/kg-U_3O_8.

  This means, though reprocessing is highly desirable with the Candu-PHWR system (as concluded in (2)), the use of the plutonium, however, will be much dependent on uranium prices.

(5) Thus, in principle, there seems an economical advantage associated with the OTA-Candu-PHWR system over the OTA-PWR system, e.g. the saving of 28.29×10^3 t of uranium, and lower generating cost with respect of FC-expenditure. This advantage was in section 5.7 quantified in relation to the specific financial situation of Saudi Arabia. It was found that if Saudi Arabia selects the Candu-PHWR system on a pure financial bases, the "monetary gain" that the country would be benefiting in the total period of 30 years operation time can be equivalent to revenues collected from selling oil in a time of 1/4 - 1/2 year only. This is not of a significant

(1) The largest unit of the Candu-PHWR system in operation is only 745 MW(e) (e.g. Bruce A, in Canada), and thus, the 1000 MW(e) unit concerned here is a pure assumption.

financial advantage to Saudi Arabia.

<u>In summary, the arguments supporting the 'drop out' of the Candu-PHWR system from the selection are:</u>

- The country lacks the mean requirements for achieving complete independency, especially concerning the securement of D_2O.
- The Candu-PHWR system will operate in the country with lower efficiency.
- The recycling of plutonium, even if the technology is made available, does not provide economical advantages unless the uranium price will increase much beyond predictions.
- The overall monetary gain, resulting from the fuel cycle expenditure of the OTA, does not balance out the constraint imposed in terms of the limitation in the number of suppliers.

<u>In the final analysis, the future selection policy can be summarized as follows:</u>

The decision to introduce a reactor system to the country will be much dependent on the outcome of the market survey performed at the time of selection. If then one of the Advanced Reactors (e.g. HTGR,FBR) is made available, it should be the natural choice, since the country can highly benefit from its advantages as pointed out earlier. Further, the application of dry cooling tower for all inland sitting will be imperative. Dry cooling with an Advanced Reactor will result in the best operational characteristics.

On the other hand, if only those reactors termed now as Proven Reactors (e.g. PWR, Candu-PHWR, Magnox) will be available at time of selection, the choice of a system will be highly dependent on finding the suitable solution for the imperative requirements of the system in concern, e.g. enrichment services for PWR, security of D_2O for Candu-PHWR, availability of the system coupled with economical competitiveness for Magnox.

Further, if enrichment, D_2O, and the Magnox reactors are available simultaneously , the first choice should be the PWR, next the Magnox, and finally the Candu-PHWR.

7.5 Recommendations About Procedures

The previous discussion brought into light the following three points:

- To introduce nuclear power to the country, first the decision must be taken by the government. Before such decision can be reached, however, a period of time will be elasped. It can be from 5 to 10 years or more.

- Aside from the time required for the construction of the first plant, a period of 5 years must be allocated as for preparation.
- The advantages associated with the Advanced Reactors (e.g. HTGR, HHT, LMFBR, GCFBR) are highly attractive to the country, but it will take some 5-10 years or more for these reactors to be available for Developing Countries.

In fact, a common component to all the 3 points stated above is the element of time, showing that a period not less than 5-10 years will have to go on without introducing nuclear power. Hence, there is a delay time which if planned carefully can be put into the best advantage of the country.

What Can be Achieved?

Before going into details, it should be reminded that all recommendations must be viewed within the constraint of man power in the country, coupled with the need of the available and growing man power for executing the development programs, which are planned for the particular goals of diversification of national income.

This means, the engagement in fundamental researches in the field of nuclear power, such as development of a given reactor concept, must not be considered. On the other hand, researches all together must not be ruled out. Thus, a balance must be worked out.

Actually, there are minimum requirements which should be achieved gradually on the local level as the introduction of nuclear power on the commercial level approaches its starting time.

These requirements are in connection with establishing qualified groups, partially in organizational and legal matters, and partially in acquiring practical experiences in nuclear fields.

For example, a regularory body must be established. The main responsibility of it is to review and assess the safety of the plant, and later, during operation, inspect it for compliance with regulatory rules. Only if such a group exists, site proporsals can be reviewed and a prelimenary approvals can be issued.

Equally necessary before the introduction of the first commercial nuclear plant is the formation of a project organization staff. The goal here is to have a permenant local staff which by participating on leadership basis in all organizational activities of the first plant, from its early conception to the commercial operation, can creat an unprecedented experience which will become the core for all planning and implementations of the consecutive plants.

A staff of at least 30 is recognized by IAEA(ref./89/) to be sufficient for a project organization group. It should not necessarily consist of nuclear specialists but rather of experienced conventional power engineers. Yet, fundamental training in nuclear power will be necessary, along with training in nuclear fuel management, economics of nuclear system, bid evaluation, contract preparation, methods of quality assurance, site selection and preparation, construction scheduling, etc. Further, the establishment of technical staff concerning reactor operation and maintenance must be considered as well. Due to the unique safety and liability requirements, and the economical consequences if a nuclear plant is not highly available for power production, make it very essential that qualified staff must be in charge of operation and maintenance.

Training of the operation group could, however, be delayed up to the preconstruction step, but for highly qualified staff in maintenance, training must necessarily start some years ahead of the reactor operation.

How Can the Goals be Achieved?

The regulatory body or its "nucleus" will have first to enact the regulatory provisions for the control of nuclear power and its fuel cycle in the country, as well as all radioisotope applications (e.g. in agriculture, medicine, industries, etc.).

Regulatory provisions are already formulated in many countries and International Bodies, and are made available to Developing Countries. Hence, the local adoption will be more or less a job of 'fitting' according to the legistlative channels in the country.

The technical staff preparation can be accomplished by:

- Either, staff-training at a selected research center such as the Kernforschungszentrum at Karlsruhe (West Germany), Saclay (France), Argonne National Laboratory (USA), etc.
- Or, planning to operate a small nuclear power reactor (e.g. 300 MW(e)) in the country.
- Or both.

The advantages of training abroad are:

- Simplicity as far as organizational matters are concerned. For example, with the consultance of a selected advisory group, the regulatory body or it "nucleus" can determine the areas and the schedules for training, followed by selection of qualified college graduates to be sent to the site of training.
- Opportunities to be trained in many fields (e.g. familiarization with existing nuclear power station equipment, construction procedures, methods of quality assurance, waste managements, etc.).
- Opportunity to be trained with different types of reactors by having mutual agreements with different countries, e.g. W.Germany, Canada.
- Opportunity to be trained with different design procedures for the same type of reactor, e.g. LWR: German design, French design, etc. And hence, getting exposure to different philosopies of safety.

The major disadvantage of training abroad, however, is that nuclear power will remain 'strange' to the country. Also, the more the introduction of nuclear power gets postponed, the higher becomes the risk of trainees' transference to other fields of work. In contrast to training abroad, when a small power reactor is planned to be operated in the country, the introduction of nuclear power to the country becomes a reality with the first step of implementation, and as the reactor starts operation, nuclear power will have an existence in the country.

The main advantage, of course, is now experience is not only gained but also in reaction with the local conditions of the country. Hence, a true technical and economical evaluation of the prospect of commercial nuclear power in the country can be performed and updated as data changes.

However, there are two constraints in following this path:

- From the organizational point of view, it looks forward to a qualified body which should be able to concentrate efforts on extracting experience from reactor operation, maintenance, and fuel cycle management.

  The setting up of such a qualified body will depend, actually to the extent of cooperations that can be granted by Europe and USA.

- The operation of a certain reactor type imported from a selected country will result in a set of experiences on one hand. On the other hand, these experience will be confined to both the type of reactor selected and the design philosophy of the selected exporting country.
  Thus, for example, if the small reactor was selected of the LWR type, the experience will be confined on this type. Hence, the possibility of considering, in later time, the HWR type will pose new difficulties, and conversely.

However, concerning the last point there is a solution which serves the purpose of experiencing with the two possibilities (LWR and HWR) side by side. For example, the small power reactor can be selected of the PHW-pressure vessel type (e.g. Atucha type). With this reactor type in operation for experience, the following can be gained:

- As a power reactor, its introduction will expose the country to all the organizational and managerial activities related to bid evaluations, site selection, construction, commissioning etc.

- As a power reactor, its operation will result in an overall experience of integrating nuclear power reactor to the power system, fuel cycle management, routine release of radioactivity to the environment, waste management, etc.

- Since it resembles in its design lay out to the PWR, experiences gained from its operation and maintenance can be easily extrapolated to LWRs, if the selection of the commercial reactors, in future, should be so.
- Since it is a natural uranium reactor, there are enough rooms to gain experiences in relation to D_2O procurements, on-load fueling, and the possibility of learning to manufacture the fuel elements locally.

However, the point to be made clear is that the recommendation to operate a small power reactor in the country aims in the first place to expose the country to the general practices concerning electricity generation (and possibly desalination) with nuclear fuels, and hence becoming in the position of close evaluation of the prospect of nuclear power for the country. Therefore, a small reactor of any type (e.g. LWR, HWR, or GCR) will help to serve the purpose.

Explanation of Abbreviations

BBR	Babcock-Brown Boveri Reactor
BWR	Boiling Water Reactor
Candu	Canda Deuterium Uranium
Candu-PHWR	Candu-Pressurized Heavy Water Reactor
d	day
FBR	Fast Breeder Reactor
FC	Fuel Cycle
GCFBR	Gas Cooled Fast Breeder Reactor
GNP	Gross National Product
GR	Growth Ratio
h	hour
H.B.	High Burn up
HHT	High Temperature Helium Turbine Reactor
H.M.	Heavy Metal
HP	High Pressure Turbine
HTGR	High Temperature Gas Cooled Reactor
HWR	Heavy Water Reactor
I.M.	Intermediate Burn Up
kj	kilojoule
km	kilometer
kWh	kilowatt-hour
l	liter
LEU	Low Enriched in U-235
L.F.	Load factor
LMFBR	Liquid Metal Fast Breeder Reactor
LP	Law Pressure Turbine
LWR	Light Water Reactor
m	meter
Magnox	Magnesium non-oxidizing
MCP	Ministry of Central Planning
mg	milligram
mm	millimeter
MOX	Mixed Oxide Fuel (e.g. UO_2 + PuO_2)

MP&MR	Ministry of Petroleum and Mineral Resources
MSF	Multi Stage Flash Distillation
MWd	Magawatt-day
$MW(e)=MW_e$	Megawatt electric
MW(th)	Megawatt thermal
NFC	Nuclear Fuel Cycle
OECD	Organization for Economic Co-operation and Development
OTA	Once Through Alternative
P	Yeraly Electricity Consumption
PCRV	Prestressed Concrete Pressure Vessel
ppm	parts per million
Pu	Plutonium
PWR	Pressurized Water Reactor
$R_{W/P}$	Ratio of Water to Electricity Consumption
R&D	Research and Development
ref.	reference
RO	Reverse Osmosis
SE-1.2%	Slightly Enriched in U-235 (1.2 wt%)
SCC	Stress Corrosion Cracking
S.S.	Self sufficient
swu	separative work unit
t	ton (metric)
Th	Thorium
THTGR	Thorium High Temperature Gas Cooled Reactor
U	Uranium
W	Water Consumption (daily or yearly)
WBT	Wet Bulb Temperature
WDO	Water Desalination Organization
y	year
$	US dollar

References

/1/ General Directorate of Mineral Resources
Jeddah, Saudi Arabia (1977), Unpublished Results

/2/ Statistical Year Books: 1967 - 1975,
Yearly Publication of the Central Department of Statistics
Riyadh, Saudi Arabia

/3/ The Second Development Plan: 1975 - 1980,
A Publication of the Ministry of Central Planning
Riyadh, Saudi Arabia (1976)

/4/ F. Felix
World Markets of Tomorrow,
Harper & Row. Pub., London and N.Y. (1972)

/5/ H. Blume
Saudi Arabien,
Horst Erdmann Verlag, Tübingen und Basel (1976)

/6/ H. E. Drefne
North American Water Resources,
Presented in "Water Production Using Nuclear Energy",
Edited by G. Post and R.L. Seale
University of Arizona, USA (1966)

/7/ Market Survey for Nuclear Power in Developing Countries,
IAEA, STI/PUB/395, Vienna (1974)

/8/ T. D. Anderson, H. I. Bowers et al.
An Assessment of Industrial Energy Options Based on Coal
and Nuclear Energy,
ORNL-4995 (July 1975)

/9/ J. D. Jones et al.
Coupling Technology for Dual Purpose Nuclear Desalting Plants,
ORNL/TM-4471 (Nov. 1976)

/10/ E. J. Mossllam
Preliminary Design and Feasibility Study of a Nuclear Powered Agro Industrial Complex in Iran,
Ph. D Thesis, Iowa State University, USA (1969)

/11/ Ministry of Central Planning
Riyadh, Saudi Arabia (1976), Unpublished Results

/12/ Water Desalination Organization
Jeddah, Saudi Arabia (1976), Unpublished Results

/13/ Clawson/Landsberg
Desalting Sea Water Achievements and Prospects,
Gordon and Research Science Pub. N.Y. (1972)

/14/ J.J. Allard et al.
Potable Water Supply of Riyadh by Reverse Osmosis Desalting Plants,
Desalination, 20, 227-237 (1977)

/15/ K. S. Spiegler
Principles of Desalination,
Presented in "Distillation"
Edited by R.S. Silver, Academic Press, N.Y. (1966)

/16/ M. D´orival
Water Desalting and Nuclear Energy
Thiemig Taschenbücher, Band 16 (1967)

/17/ First United Nations Desalination Plant Operation Survey,
UN, ST/ECA/112, N.Y. (1969)

/18/ R. E. Gaunt
Operating Experience with MSF Plant,
Presented in "Water Production Using Nuclear Energy"
The University of Arizona Press, Tucson (1977)

/19/ R. Saari
Desalination by Very Low Temperature Nuclear Heat,
ANS Topical Meeting on "Low Temperature Nuclear Heat Application"
Helsinki (Aug. 21-24., 1977)

/20/ J.K. Franzreb et al.
Flexibility in Production of Power and Water from Nuclear Desalting Plants,
ORNL-TM-1564 (1977)

/21/ Desalination of Water Using Conventional and Nuclear Energy,
IAEA Technical Report Series No. 24, Vienna (1964)

/22/ A. F. Abdul Fattah et al.
Nuclear Desalination for Saudi Arabia: An Appraisal,
Desalination, 25, 163-185 (1978)

/23/ A. F. Abdul Fattah
Some Aspects of Nuclear Desalination,
MS Thesis, University of California, Berkeley (1974)

/24/ Answering Mecca´s Swerage Prayers,
World Water, 42-45 (May 1978)

/25/ J. Adar et al.
Near Term Feasibility of Nuclear Reactors for Sea Water Desalting,
Presented at the International Conference on "Nuclear Power and Its Fuel Cycle", Salzburg, Austria
(May 2-13, 1977)

/26/ U. Lantzke
World Energy Supply and Demand and the Future of Nuclear Power,
Presented at the International Conference on "Nuclear Power and Its Fuel Cycle", Salzburg, Austria
(May 2-13, 1977)

/27/ J. R. Dietrich
Efficient Utilization of Nuclear Fuels,
Power Technology 6 No. 4, 1-16 (1963)

/28/ K. Wirtz
Lectures on Fast Reactors,
Institut für Neutronenphysik und Reaktortechnik
Kernforschungszentrum Karlsruhe, Federal Republic of Germany (1973)

/29/ V. Heinzel
Survey and Classification of Nuclear Power Plants,
Presented at the IAEA Interregional Training Course on "Nuclear Power Project Planning and Implementation"
Karlsruhe, (Sep. 6 - Nov. 30, 1976)

/30/ A. Sesonske
Nuclear Power Plant Design Analysis,
Technical Information Center
Office of Information Service, USAEC, TID-26241 (1973)

/31/ P. R. Kasten et al.
Evaluation of Plutonium, Uranium, and Thorium Use in Power Reactor Fuel Cycles,
Presented at the International Conference on "Nuclear Power and Its Fuel Cycle", Salzburg, Austria
(May 2-13, 1977)

/32/ A. S. Bain et al.
The Performance and Evolutionary Development of Candu Fuel,
Trans. Am. Nucl. Soc. 20, 259 (1975)

/33/ A. Bayer
Gas Cooled Reactors,
Presented at the IAEA Interregional Training Course on "Nuclear Power Project Planning and Implementation"
Karlsruhe, (Sep. 6 - Nov. 30, 1976)

/34/ M. M. El Wakil
Nuclear Energy Conversion,
INTEXT Educational Publishers, San Francisco and London (1971)

/35/ C. D. Gregg King
Nuclear Power Systems,
The Macmillan Company, N.Y. (1964)

/36/ H. Vollmar
High Temperature Gas Cooled Reactor Systems,
Presented at the IAEA Interregional Training Course on "Nuclear Power Project Planning and Implementation",
Karlsruhe, (Sep. 8 - Dec. 19, 1975)

/37/ A. L. Lotts
HTGR Fuel and Cycle Technology,
Presented at the International Conference on "Nuclear Power and Its Fuel Cycle", Salzburg, Austria
(May 2-13, 1977)

/38/ P. R. Kasten et al.
Assessment of the Thorium Fuel Cycle in Power Reactors,
ORNL/TM-5565 (Dec. 1976)

/39/ The Use of Thorium in Nuclear Power Reactors,
Prepared by the Division of Reactor Development and Technology, USAEC, WASH 1097 (June 1969)

/40/ E. Critoph
The Thorium Fuel Cycle in Water Moderated Reactor System,
Presented at the International Conference on "Nuclear Power and Its Fuel Cycle", Salzburg, Austria
(May 2-13, 1977)

/41/ Private Communication from R. K. Lane (GAC) to J. F. Homan (ORNL)
Date: June 11, 1976 /38/

/42/ C. Lin et al.
Thorium: An Alternative Fuel for LWRs,
Elect. Power Research Inst. (EPRI)
Research Prog. Report NP-2 (Feb. 1975)

/43/ W. D. Franklin et al.
Total Energy Analysis of Nuclear and Fossil Fueled Plants,
ORNL-MIT-138 (Nov. 1971)

/44/ Regional Fuel Cycle Centers Vo. I, II
1977-Report of the IAEA Project Study Group, Vienna (1977)

/45/ Reprocessing of Spent Nuclear Fuels in the OECD Countries,
A Report of Expert Group of the OECD Nuclear Energy Agency
(6677011), ISBN 92-64-11651-X (June 1977)

/46/ Statement of the President on Nuclear Policy,
Office of the White House Secretary, Washington D.C.
(Oct. 1976)

/47/ S. Tamiya et al.
A Review on Future Trends of LWR Fuel Cycle Cost,
Presented at the International Conference on "Nuclear Power and Its Fuel Cycle", Salzburg, Austria
(May 2-13, 1977)

/48/ P. Schmiedel, W. Schricker
Nuclear Fuel Cycle Cost and Cost Calculation,
Presented at the IAEA Interregional Training Course on "Nuclear Power Project Planning and Implementation"
Karlsruhe, (Sep. 8 - Dec. 19, 1975)

/49/ H. A. Abd El Maksoud
Economical Assessment of Nuclear and Conventional Power Stations,
MS Thesis, Al Azhar University, Egypt (1976)

/50/ Nuclear Fuel Economics,
Westinghouse Electric Corp. Pub. (1974)

/51/ Oil Price Explosion,
African Development Magazine, African Buyer and Trader
London, 5-8 (Feb. 1974)

/52/ Carroll L. Willson et al.
Energy: Global Prospects (1985 - 2000),
Report of the Workshop on Alternative Strategies
McGraw-Hill Book Comp., N.Y. (1977)

/53/ Cost and Competition Situation for Nuclear Power Stations
in the Federal Republic of Germany,
Lahmeyer International GMBH (1971)

/54/ J. A. Lane
The Role of Nuclear Power in the Future Energy Supply of
the World,
9 th World Energy Conference, IAEA, Vienna (1974)

/55/ A. M. Khan
Small and Medium Power Reactors: Present Status and
Prospects
IAEA, Vienna (1969)

/56/ World Energy Resources: 1985 - 2000,
Executive Summaries of Reports on Resources, Conservation,
and Demand to the Conservation Commission of the World
Energy Conference
IPC Science and Technology Press, UK and USA (1978)

/57/ G. Lurf
The World Market Situation for Uranium and Its Enrichment,
Presented at the IAEA Interregional Training Course on
"Construction and Operation Management of a Nuclear Power
Plant"
Karlsruhe, (Sep. 5 - Nov. 25, 1977)

/58/ H. Facius
Bau- und Montage-Erfahrungen bei LWR Kernkraftwerken,
Atomwirtschaft, 199-203 (April 1973)

/59/ W. Altvater
The Nuclear Power Plant Iran I and Iran II on the Persian Gulf,
Sonderdruck KWU-393-101 z, Erlangen (March 1977)

/60/ A. Abdo
The Evolution of Modern Roads in Saudi Arabia,
Bull. de la Societé de Géographique d'Egypte
Le Caire, 41/42, 61-64 (1968)

/61/ National Transport Survey Vol. II: Rail Roads, Pipe Lines,
Ministry of Central Planning, Riyadh, Saudi Arabia (1974)

/62/ K. F. Haas
Special Site Transport and Handling Problems,
Presented at the IAEA Interregional Training Course on "Construction and Operation Management of a Nuclear Power Plant"
Karlsruhe, (Sep. 5 - Nov. 25, 1977)

/63/ W. E. Cooper et al.
The Safety of Reactor Pressure Vessel,
Nuclear Safety, 17, No. 1, 55-61 (Jan. - Feb., 1976)

/64/ G. Linder
Site Characteristics and Site Preparation,
Presented at the IAEA Interregional Training Course on "Construction and Operation Management of a Nuclear Power Plant"
Karlsruhe, (Sept. 5 - Nov. 25, 1977)

/65/ Instruction Nautiques (Mer Rouge et Golfe d'Aden),
Service Hydrographique et Océanographique de la marine
Paris-Série L, Vol. 7, Paris, 16-20 (1965)

/66/ Instructions Nautiques (Golfe d'Oman et abords Est, Golfe Arabique)
Service Hydrographique et Océanographique de la marine Paris-Série L, Vol. IV, Paris, 28-50 (1965)

/67/ Climatological Data (1960-1975)
Monthly Report of the Department of Civil Aviation Ministry of Defense, Riyadh, Saudi Arabia

/68/ Temperature and Relative Humidity: Monthly and Daily Mean and Extreme (1960-1976)
Ministry of Agriculture and Water, Riyadh, Saudi Arabia

/69/ Private Communication and Consultance with Prof.Dr. Sigmar Wittig, Head of Institut für Thermische Strömungsmaschinen Universität Karlsruhe, Date: March 1978

/70/ Boiling Water Reactor Plant: 1000 MW(e) Central Station Power Plant Investment Cost Study,
Prepared by the Division of Reactor Development and Technology USAEC, WASH-1230 Vol. II (June 1972)

/71/ Candu-Nuclear Power Station: An Introduction and Technical Description of Candu Nuclear Design, Engineering Services, and Auxiliary Programs,
Atomic Energy of Canada Ltd., Canada (1977)

/72/ M.W. Rosenthal, R.E. Adams et al.
A Comparative Evaluation of Advanced Converters,
ORNL-3686 (Jan. 1965)

/73/ Directory of Nuclear Reactors Vol. II,
IAEA, STI/PUB/74, Vienna (1963)

/74/ K. Wark
Thermodynamics,
McGraw-Hill Book Comp. N.Y. (1977)

/75/ K. Wirtz
Grundlagen der Reaktortechnik, Teil I, II
Universität Karlsruhe, Karlsruhe, (1966)

/76/ D. Smidt
Reaktortechnik, Band 2: Anwendungen,
G. Braun, Karlsruhe, (1971)

/77/ H. Zwahr
Nukleare Dampfturbinen,
Kerntechnik 17, Nov. 3, (1975)

/78/ Thermal Discharge at Nuclear Power Stations,
IAEA Technical Report Series, No. 155, Vienna (1974)

/79/ R. D. Woodson
Cooling Towers,
Scientific American, 70-78 (May 1971)

/80/ J. C. Ovard
Salt Water Cooling,
Ecodyne Cooling Products Co. Research Report No. 11,
N.Y. (1971)

/81/ A. Roffmann et al.
The State of the Art of Saltwater Cooling Towers for Steam
Electrical Generating Plants,
WASH-1244 (Feb. 1973)

/82/ W. J. Jones
A New Look at Cooling Towers for the Power Generation
Industry,
Presented at Cooling Tower Institute Winter Meeting
Houston, Texas, USA (Jan. 20-22, 1969)

/83/ H. Krolewski
Technische und wirtschaftliche Probleme zur Frage der
Abwärme von thermischen Kraftwerken,
Wasserwirtschaft, 63, 11/12, 363-371 (1973)

/84/ S. Kliemann
Dry Cooling Towers,
VDI-Berichte No. 236, 229-238 (1975)

/85/ B. M. Johnson et al.
On the Minimum Size for Forced Draft Dry Cooling Towers for Power Generating Plants,
Presented at the Annual Meeting of the American Society of Mech. Eng., Detroit, Michigan, USA (1973)

/86/ Ministry of Petroleum and Mineral Resources
Riyadh, Saudi Arabia (1977), Unpublished Results

/87/ Private Communication and Consultance with Dr. J. Bogen
Project Manager, BBC Mannheim, Federal Republic of Germany,
Date: December 1978

/88/ K. H. Schüller
Das Optimale "Kalte Ende" von Kondensations Blockeinheiten,
Elektrizitätswirtschaft, Heft 3, 53-60 (Feb. 1971)

/89/ Steps to Nuclear Power: A Guidebook,
IAEA Technical Report Series No. 164, Vienna, 27-28 (1975)

1) Water:

Extensive programs of hydrological data collection and analysis

1 000 wells were dug for supply of 6 major cities

Numerous water distribution systems were constructed

Over 20 small dams were constructed or approved

5 dual purpose desalination plants on the Red Sea coast and 2 on the Gulf area were constructed, producing collectively: 50×10^3 m^3/d water and 60 MW(e) electricity
Plants under planning or construction are to produce: 330×10^3 m^3/d and 905 MW(e)

2) Agriculture:

Slow agriculture production, due to numerous problems

Subsidies introduced to supplement research and extensive programs in stimulating agricultural production

Significant expansion in agricultural credits

3) Petroleum:

Production increased to an average of 8.5 mb/d in 74; the prices increased from US dollars 1.8 per barrel at the beginning of the plan to US dollars 10.46 in 1974

Extensive programs to expand output were implemented

4) Minerals:

4 licenses for exploration and development of minerals were issued to private companies

Commercially assured minerals are found to constitute: Copper, Lead, Zinc, Nickel, Gold, and Silver

Extensive program to inventory non-metallic mineral resources is in progress

Table 1: Some Highlights of the First 5 Year Plan (1970-1975)

5) Electricity:

Establishment of the Electrical Service Department

Standardizing voltage (127/220) and frequency (60 hz)

Total generating capacity amounted to:
1 256 Mw(e), serving: 2.2 million persons

Electricity tariffs were reduced to 19.7 mills/KWh for residential and to 14.1 mills/KWh for industrial applications

6) Manufacturing:

Expansion of non-hydrocarbon industries exceeded the target set in the plan

Petroleum refining and hydrocarbon-based industries fell short of target

Establishing of a refinery in Riyadh

Cement production doubled

Saudi Arabian Industrial Policy was issued and Industrial Development Fund was established

7) Man Power:

The labor force grew to about 20%, achieving a level of 1.6 million persons in 1975

800 000 full time students enrolled in public schools, and 12 000 attending colleges and universities

With other forms of mass education, one out of every seven in the country participated in an organized educational program

Table 1: Continued

(1) Water:

a. Aquire, analyze, and store hydrological data, other technical data, and demographic and economic data related to water resources development and use

b. Undertake research programs on:

1. Recharge of wells
2. Use of remorte sensing
3. Reclamation of brakish water
4. Reduction of water losses and re-use of water

c. Undertake research program in desalination technologies, economics, and material supplies for desalination plants

(2) Agriculture:

Center	Subjects
Hofuf	Dairy, cattle, sheep, irrigation, re-use of drainage-water, rice, agro-climatology
Qatif	Poultry, grapes, dates, melons, vegatables
Unayzah	Citrus fruits, vegatables, cereals, dates, grapes, olives
Jaizan	Cereals, vegatables, cotton, irrigation
Dirab	Cereals, dairy, horse breeding, goats
al-Kharj	Cereals, vegatables, grapes, melons, citrus fruits, irrigation
Jiddah	Locust and insect control
Haddah Asham	Tropical and citrus fruits,vegetables
Baljarshi	Deciduous fruit, irrigation
Bishah	Citrus fruits, dates, grapes, cereals
Medina	Poultry, dairy, cattle
Marine Devlo. (Jeddah)	Fish movement and classification, fishing, training
Range Devlo.	Water spreading, extension, training, fodder storing
Central Research Lab, Riyadh	Soil and water analysis; Plant production, animal disease
Range and Forest Station, Tayif	Water spreading, extension, training, fodder storing

Table 2: Summary of Research Activities at the Main Research Centers

(3) Petroleum:

a. Accelerate the technical programs which provide understanding of advanced development in world energy technologies, including major new forms of energy in the long-range outlook and the future role of petroleum as energy and raw material.

b. Extend seismic investigation to cover all areas of the country and introduce advanced techniques in data processing and interpretation as developed by seismic work

c. Carry new investigations on the existing pipelines, treatment, and storage installations, to inventory their adequacy, efficiency, and maintainance and replacement requirements

(4) Geological and Geophysics:

Supporting services and research carried out at the centers for:

Chemical analysis
Topographic services
Photo laboratories
Petrological section
Computer center
Electronic engineering department
Drilling Center
Geochronology analysis
Underground exploration center
Geochemical prospecting central laboratories

Table 2: **Continued**

Year	No. Population $(10)^6$	% Incr. in Yearly Electricity Consump. (% $P_{incr.}$)	Yearly Electricity Consump. (P) $(10)^9$ KWh/y	Yearly Electricity Consump. per cap. (P/cap) $(10)^3$	% Incr. in Yearly Electricity Consump. per cap. (%) $P_{incr.}$/cap	Average Year Demand MW(e)	Necessary Expansion in Installed Capacity MW(e)
			Case A				
1980	2.723		21.56	7.92		2461	3692
1981	2.795	0.167	25.16	9.00	13.6	2872	4308
1982	2.870	0.157	29.11	10.14	12.7	3323	4985
1983	2.946	0.147	33.39	11.33	11.7	3812	5718
1984	3.025	0.137	37.96	12.55	10.8	4333	6500
1985	3.107	0.127	42.78	13.77	9.72	4884	7326
1986	3.188	0.117	47.76	14.98	8.78	5452	8178
1987	3.272	0.107	52.87	16.16	7.87	6035	9053
1988	3.357	0.097	57.99	17.27	6.87	6620	9930
1989	3.444	0.087	63.04	18.30	5.96	7196	10794
1990	3.534	0.077	67.89	19.21	4.97	7750	11625
1991	3.612	0.067	72.44	20.06	4.42	8269	12404
1992	3.690	0.057	76.57	20.75	3.44	8741	13112
1993	3.770	0.047	80.17	21.27	2.50	9152	13728
1994	3.852	0.037	83.14	21.55	1.31	9491	14237
1995	3.935	0.027	85.38	21.69	0.65	9747	14621
1996	4.014	0.026	87.60	21.82	0.60	10000	15000
1997	4.093	0.025	89.79	21.94	0.55	10250	15375
1998	4.174	0.024	91.94	22.03	0.41	10495	15743
1999	4.257	0.023	94.05	22.09	0.27	10736	16104
2000	4.342	0.022	96.12	22.14	0.23	10973	16459
			Case C: 1980 - 1990 as Case A				
1990	3.534	0.077	67.89	19.21	4.97	7750	11625
1991	3.612	0.077	73.12	20.24	5.36	8347	12521
1992	3.690	0.077	78.75	21.34	5.43	8989	13485
1993	3.770	0.067	84.03	22.29	4.45	9592	14389
1994	3.852	0.067	89.66	23.28	4.44	10235	15353
1995	3.935	0.067	95.60	24.29	4.34	10913	16370
1996	4.014	0.057	101.12	25.19	3.71	11543	17315
1997	4.093	0.057	106.88	26.11	3.65	12200	18301
1998	4.174	0.057	112.97	27.07	3.68	12896	19344
1999	4.257	0.047	118.28	27.78	2.56	13502	20253
2000	4.342	0.047	123.84	28.52	2.67	14137	21205

% Incr. in Yearly Electricity Consump. (% $P_{incr.}$)	Yearly Electricity Consump. (P) $(10)^9$ KWh	Yearly Electricity Consump. per cap. (P/cap) $(10)^3$	% Incr. in Yearly Electricity Consump. per cap. (%) $P_{incr.}$/cap	Average Year Demand MW(e)	Necessary Expansion in Installed Capacity MW(e)
		Case B			
		As Case A			
0.077	67.89	19.21	4.97	7750	11625
0.077	73.12	20.24	5.36	8347	12521
0.067	78.02	21.14	4.45	8906	13360
0.067	83.24	22.08	4.45	9502	14253
0.057	87.96	22.83	3.40	10041	15062
0.057	92.98	23.60	3.37	10614	15921
0.047	97.35	24.25	2.75	11113	16670
0.047	101.93	24.90	2.68	11636	17453
0.037	105.70	25.32	1.69	12066	18099
0.037	109.61	25.75	1.69	12513	18769
0.027	112.57	25.93	0.70	12850	19276

Table 3: Results of the Electricity Projection Scenarios for the Period 1980-2000: District A

Year	Population $(10)^6$	% Incr. in Electr. Consumption (%) $P_{incr.}$	Yearly Electr. Consumption P $(10)^9$ (KWh/y)	Yearly Electr. Consumption per cap. $(10)^3$	% Incr. in Yearly Electr. Consumption per cap. (%) $P_{incr.}$/cap.	Average Yearly Demand MW(e)	Necessary Expansion in Installed Capacity
		Case A'					
1980	3.396		7.51	2.21		857	1286
1981	3.484	0.167	8.76	2.51	13.6	1000	1500
1982	3.575	0.157	10.14	2.84	13.1	1158	1736
1983	3.667	0.147	11.63	3.17	11.6	1328	1991
1984	3.763	0.137	13.22	3.51	10.7	1509	2264
1985	3.860	0.127	14.90	3.86	10.0	1701	2551
1986	3.949	0.117	16.64	4.21	9.07	1899	2849
1987	4.040	0.107	18.42	4.56	8.3	2103	3154
1988	4.133	0.097	20.21	4.89	7.2	2307	3461
1989	4.228	0.087	21.97	5.20	6.3	2508	3762
1990	4.325	0.077	23.66	5.47	5.2	2701	4051
1991	4.411	0.067	25.25	5.72	4.6	2882	4324
1992	4.499	0.057	26.69	5.93	3.7	3047	4570
1993	4.589	0.047	27.94	6.09	2.7	3189	4784
1994	4.681	0.037	28.98	6.19	1.6	3308	4962
1995	4.775	0.027	29.76	6.23	0.65	3397	5096
1996	4.871	0.026	30.53	6.27	0.64	3485	5228
1997	4.968	0.025	31.29	6.30	0.48	3572	5358
1998	5.067	0.024	32.04	6.32	0.32	3658	5486
1999	5.168	0.023	32.78	6.34	0.32	3742	5613
2000	5.272	0.022	33.50	6.35	0.16	3824	5736
		Case B' : 1980 - 1991 as Case A'					
1990	4.325	0.077	23.66	5.47	5.2	2701	4051
1991	4.411	0.067	25.25	5.72	4.6	2882	4329
1992	4.499	0.068	26.97	5.99	4.7	3079	4618
1993	4.589	0.069	28.83	6.28	4.8	3291	4937
1994	4.681	0.070	30.85	6.59	5.1	3522	5283
1995	4.775	0.071	33.04	6.92	5.0	3772	5658
1996	4.871	0.072	35.42	7.27	5.2	4043	6065
1997	4.968	0.073	38.00	7.65	5.2	4338	6507
1998	5.067	0.074	40.81	8.05	5.2	4659	6988
1999	5.168	0.075	43.87	8.49	5.5	5008	7512
2000	5.272	0.075	47.16	8.95	5.4	5384	8075

Table 4: Results of the Electricity Projection Scenarios for the Period 1980-2000: District B

Year	Population $(10)^6$			(P/cap) $(10)^3$ (KWh/y)/cap	P $(10)^9$ (KWh/y)	W $(10)^9$ (m^3/y)	W $(10)^6$ (m^3/d)	W/cap (m^3/d)/cap
	Dammam	Riyadh	Total					
According to Case A (Electricity Scenario)								
1980	0.527	1.474	2.001	7.92	15.85	0.19	0.52	0.26
1981	0.544	1.510	2.054	9.00	18.49	0.22	0.61	0.30
1982	0.561	1.548	2.109	10.14	21.39	0.26	0.70	0.33
1983	0.579	1.587	2.166	11.33	24.54	0.29	0.81	0.37
1984	0.598	1.627	2.225	12.55	27.92	0.34	0.92	0.41
1985	0.617	1.668	2.285	13.77	31.46	0.38	1.03	0.45
1986	0.635	1.709	2.345	14.98	35.12	0.42	1.16	0.50
1987	0.654	1.752	2.406	16.16	38.88	0.47	1.28	0.53
1988	0.674	1.795	2.469	17.27	42.64	0.51	1.40	0.57
1989	0.694	1.839	2.533	18.30	46.35	0.56	1.52	0.60
1990	0.715	1.885	2.600	19.21	49.94	0.60	1.64	0.63
1991	0.733	1.923	2.656	20.06	53.27	0.64	1.75	0.66
1992	0.751	1.961	2.712	20.75	56.27	0.68	1.89	0.68
1993	0.770	2.000	2.770	21.27	58.91	0.71	1.94	0.70
1994	0.789	2.04	2.829	21.55	60.97	0.73	2.00	0.71
1995	0.809	2.08	2.889	21.69	62.66	0.75	2.06	0.71
1996	0.825	2.122	2.947	21.82	64.30	0.77	2.11	0.72
1997	0.841	2.164	3.005	21.94	65.94	0.79	2.17	0.72
1998	0.858	2.207	3.065	22.03	67.53	0.81	2.22	0.72
1999	0.875	2.251	3.126	22.09	69.06	0.83	2.27	0.73
2000	0.893	2.296	3.189	22.14	70.60	0.85	2.32	0.73
According to Case C (Electricity Scenario)								
1990				19.21	49.99	0.60	1.64	0.63
1991				20.24	53.75	0.65	1.77	0.67
1992				21.34	57.87	0.69	1.90	0.70
1993				22.29	61.74	0.74	2.03	0.73
1994				23.28	65.86	0.79	2.17	0.77
1995	As Above			24.29	70.17	0.84	2.31	0.80
1996				25.19	74.23	0.89	2.44	0.83
1997				26.11	78.47	0.94	2.58	0.86
1998				27.07	82.98	1.00	2.73	0.89
1999				27.78	86.85	1.04	2.86	0.91
2000				28.52	90.95	1.09	2.99	0.94

Table 5: Results of the Water Projection Scenarios for the Period 1980-2000 ($R_{W/P}$=0.012): District A

Year	Population $(10)^6$	P $(10)^9$ (KWh/y)	W $(10)^9$ (m^3/y)	W $(10)^6$ (m^3/d)	W/cap (m^3/d)/cap
According to Case A′ (Electricity Scenario)					
1980	3.396	7.51	0.14	0.39	0.12
1981	3.484	8.76	0.17	0.46	0.13
1982	3.575	10.14	0.19	0.53	0.15
1983	3.667	11.63	0.22	0.61	0.17
1984	3.763	13.22	0.25	0.69	0.18
1985	3.860	14.90	0.28	0.78	0.20
1986	3.949	16.64	0.32	0.87	0.22
1987	4.040	18.42	0.35	0.96	0.24
1988	4.133	20.21	0.38	1.05	0.26
1989	4.228	21.97	0.42	1.14	0.27
1990	4.325	23.66	0.45	1.23	0.29
1991	4.411	25.25	0.48	1.31	0.30
1992	4.499	26.69	0.51	1.39	0.31
1993	4.589	27.94	0.53	1.45	0.32
1994	4.681	28.98	0.55	1.51	0.32
1995	4.775	29.76	0.57	1.55	0.32
1996	4.871	30.53	0.58	1.59	0.33
1997	4.968	31.29	0.59	1.63	0.33
1998	5.067	32.04	0.61	1.67	0.33
1999	5.168	32.78	0.62	1.71	0.33
2000	5.272	33.50	0.64	1.74	0.33
According to Case B′ (Electricity Scenario)					
1990	As Above	23.66	0.45	1.23	0.29
1991		25.25	0.48	1.31	0.30
1992		26.97	0.51	1.40	0.31
1993		28.83	0.55	1.50	0.33
1994		30.85	0.59	1.61	0.34
1995		33.04	0.63	1.72	0.36
1996		35.42	0.67	1.84	0.38
1997		38.00	0.72	1.98	0.40
1998		40.81	0.78	2.12	0.42
1999		43.87	0.83	2.28	0.44
2000		47.16	0.90	2.46	0.47

Table 6: Results of the Water Projection Scenarios for the Period 1980-2000 ($R_{W/P}$=0.019): District B

Year	District A						District B					
	Case A			Case C			Case A'			Case B'		
	Yearly Electricity Addition Requirement MW(e)	Suitable Unit Size (s) MW(e)	% of Installed Capacity for the Largest Unit Size	Yearly Electricity Addition Requirement MW(e)	Suitable Unit Size (s) MW(e)	% of Installed Capacity for the Largest Unit Size	Yearly Electricity Addition Requirement MW(e)	Suitable Unit Size (s) MW(e)	% of Installed Capacity for the Largest Unit Size	Yearly Electricity Addition Requirement MW(e)	Suitable Unit Size (s) MW(e)	% of Installed Capacity for the Largest Unit Size
1981	616	400;250	9.3	As Case A	As Case A	As Case A	214	150;100	10	As Case A'	As Case A'	As Case A'
1982	677	450;200	9.0				236	200	11.5			
1983	733	500;250	8.7				255	200;100	10			
1984	782	550;250	8.5				273	250	11			
1985	826	600;200	8.2				287	300	11.8			
1986	852	600;250	7.3				298	300	10.5			
1987	875	600;300	6.6				305	300	9.7			
1988	877	700;200	7.0				307	300	8.7			
1989	864	850	7.8				301	300	7.9			
1990	831	900	7.7				289	300	7.4			
1991	1686	1000;600	8.1	1803	1200;600	9.6	601	400;200	9.2	601	400;200	9.2
1992	1151	1200	9.2	1407	1300	9.6	395	400	8.8	443	500	10.8
1993	1187	1300	9.5	1475	1000;500	6.9	443	450	9.4	548	500	10.1
1994	1127	1000	7.0	1582	1000;600	6.5	332	300	6.0	500	500	9.5
1995	929	1000	6.8	1562	1000;600	6.1	295	300	5.9	536	550	9.7
1996	978	1000	6.6	1544	1000;600	5.8	308	350	6.7	583	600	9.9
1997	1025	1000	6.5	1636	1000;600	5.5	330	350	6.5	642	650	9.9
1998	1018	1000	6.4	1693	1000;600	5.2	428	400	7.3	781	750	10.7
1999	1111	1000	6.2	1659	1200;500	5.9	377	400	7.1	774	800	10.6
2000	1155	1200	7.3	1752	1200;500	5.7	423	400	6.9	863	850	10.5

Table 7: An Estimate for the Sizes of the Power-Only Production Stations During 1980-2000

Year	Electricity District A		Electricity District B	
	Case A	Case C	Case A'	Case B'
	MW(e)	MW(e)	MW(e)	MW(e)
1985	600			
1986	600			
1987	600	As Case A	Not nuclear	
1988	700			
1989	850			
1990	900			
1991	1000; 600	1200; 600	400	400
1992	1200	1300	400	500
1993	1300	1000	450	500
1994	1000	1000; 600	not nuclear	500
1995	1000	1000; 600	not nuclear	550
1996	1000	1000; 600	not nuclear	600
1997	1000	1000; 600	not nuclear	650
1998	1000	1000; 600	400	750
1999	1000	1200	400	800
2000	1200	1200	400	850

Table 8: Possible Sizes of the Nuclear Units for Power-Only Production Stations During 1985-2000

Plant Capacity		Nuclear Fueled cents/m^3		Fossile Fueled cents/m^3	
Water m^3/d	Power MW(e)	LWR	GCR	Low Pres.	High Pres.
18 925	50	18.44	18.44	20.90	20.49
37 850	100	14.67	15.57	17.73	16.50
75 700	200	12.55	13.40	15.77	14.74
113 550	300	12.10	12.51	15.29	14.39
151 400	400	11.46	11.84	14.58	13.38
189 250	500	10.11	10.94	13.92	12.89

Table 9: Comparison of Unit Water Cost from Nuclear and Fossile Fueled Dual Production Plants /22/

Type	Total Solid Contents (ppm)
Fresh Water	up to 1500
Brackish Water	1500 - 10 000
Salt Water	greater than 10 000
Sea Water	greater than 13 000 (x)
Normalized Sea Water	35 000

(x) Example of solid content in seas:

	ppm
Red Sea	43 000
Arabian Gulf	43 000
Mediterranean Sea	39 000
Atlantic Ocean	36 000
Pacific Ocean	33 000

Table 10: Saline Water Classification /16/

Constituent	Parts per Million
Mandatory Maximum	
Lead	0.10
Flouride	1.50
Arsenic	0.05
Selenium	0.05
Hexavelent Chromium	0.05
Recommended Maximum	
Phenolic Compounds	0.001
Iron and Manganese	0.30
Copper	3.00
Zinc	15.00
Magnesium	125.00
Chloride	250.00
Sulphate	250.00
Total Solids	
Desirable Limit	500.00
Permitted Limit	1000.00

Table 11: Standards for Drinking Water /16/

A. Processes that separate water from the solution

1. Distillation or evaporation
   a. Multiple-effect long-tube vertical
   b. Multistage flash
   c. Vapor compression
   d. Humidification (solar)

2. Crystallization or freezing
   a. Direct freezing
   b. Indirect freezing
   c. Hydrates

3. Reverse osmosis

4. Solvent extraction

B. Processes that separate salt from the solution

1. Electrodialysis
2. Osmionsis
3. Adsorbtion
4. Liquid extraction
5. Ion exchange
6. Controlled diffusion
7. Biological system

Table 12: Classification of Desalination Processes /10/

East Coast

Plant Identification	Capacity m^3/d $(10)^3$	Year of Operation	Gross Electricity Product MW(e)	Inter. Electr. Consumption MW(e)	Product Ratio = W/E = $(m^3/d)/KW(e)$
Al-Khobar Phase I	28.5	1974	10	3.0	2.85
Al-Khobar Phase II	190.00	1980	500	20	0.38
Khafji Phase I	0.455	1974	--	0.05	--
Khafji Phase II	19.00	1979	50	2.0	0.38
Jubail Phase I	9.00	1977	25	0.95	0.38
Jubail Phase II	76.00	1979	200	8.0	0.38

West Coast

Plant Identification	Capacity m^3/d $(10)^3$	Year of Operation	Gross Electricity Product MW(e)	Inter. Electr. Consumption MW(e)	Product Ratio = W/E = $(m^3/d)/KW(e)$
Jeddah Phase I	19.00	1970	50	2.0	0.38
Jeddah Phase II	38.00	1977	80	4.0	0.475
Jeddah Phase III	76.00	1980	200	8.0	0.38
Al-Waji Phase I	0.228	1970	--	0.024	--
Al-Waji Phase II	0.455	1976	--	0.05	--
Duba Phase I	0.228	1971	--	0.024	--
Duba Phase II	0.455	1976	--	0.05	--
Duba Phase III	19.00	1979	50	2.0	0.38
Hagl Phase I	0.455	1979	--	0.05	--
Hagl Phase II	5.700	1979	15	0.60	0.38
Medine Phase I	76.00	1980	200	8.0	0.38
Rabig Phase I	0.91	1977	--	0.096	--
Al-Lith Phase I	0.46	1979	--	0.048	--
Qunfudah	3.800	1979	10	0.4	0.38
Farasen Phase I	0.455	1977	--	0.05	--
Yenbu Phase I	19.00	1979	50	2.0	0.38

Table 13: The Dual Production Capacity up to 1980 in Saudi Arabia /11,12,13/

	Energy Requirement 1980 Technology (KWh/m^3) (not including power for auxiliary requirement)
Processes Using Heat:	
Multi Stage Flash Distillation	47.2
Vertical Tube Evaporator	47.2
Processes Using Electricity:	
Vapor Compression Distillation	27.86
Freezing	27.86
Reverse Osmosis	23.99
Electrodialysis (For Brakish Water)	11.61

Table 14: Comparison of Basic Heat Energy Requirement for Six Saline Water Conversion Processes (Single Plant System) /10/

Desalting Plant Location	Year of Operation	No. of Stages	Flash Ranges °C	Water Yield (cm^3/m^2)	Performance Ratio (kg/kj)
MEW "CAD" Shuwaik Kuwait	1957	4	25	1.6×10^3	1.35
MEW Shuwaik Kuwait	1960	19	33	3.9×10^3	2.43
Shell-Curaco Netherlands	1963	18	62	6.7×10^3	2.56
Island Government, Netherlands	1963	30	32	2.8×10^3	3.22

Table 15: Comparison of Different Desalination Plants Characteristics /17/

Year	Case A					
	Yearly Water Production Requirement W $(10)^3$ m^3/d	Maximum Electricity Production as limited by the Electricity Grid $(10)^3$KW(e)	Maximum Water Production as limited by the Ratio W/E = 0.38 $(10)^3$ m^3/d	Difficiency in Meeting Yearly Water Demand $(10)^3$ m^3/d	Surplus in Water Production Capacity $(10)^3$ m^3/d	Quantity of Surplus Water for Storage $(10)^5$ m^3/y
1981	285.04	400	152	133.04	-	-
1982	95	450	171	57.04	-	-
1983	104	500	190	-	29	106
1984	111	550	209	-	127	464
1985	116	-	-	-	11	40
1986	122	600	228	-	117	427
1987	122	-	-	5	-	-
1988	123	700	266	-	143	522
1989	123	-	-	-	20	73
1990	147	900	342	-	215	785
1991	109	-	-	-	106	387
1992	99	-	-	-	7	26
1993	96	1300	494	-	405	1478
1994	67	-	-	-	338	1234
1995	151	-	-	-	187	683
1996	244	1000	380	-	323	1179
1997	54	-	-	-	269	982
1998	52	-	-	-	217	792
1999	50	-	-	-	167	610
2000	51	-	-	-	116	423

Year	Case C					
	Yearly Water Production Requirement W $(10)^3$ m^3/d	Maximum Electricity Production as limited by the Electricity Grid $(10)^3$KW(e)	Maximum Water Production as limited by the Ratio W/E = 0.38 $(10)^3$ m^3/d	Difficiency in Meeting Yearly Water Demand $(10)^3$ m^3/d	Surplus in Water Production Capacity $(10)^3$ m^3/d	Quantity of Surplus Water for Storage $(10)^5$ m^3/y
1981–1990	As Case A	As Case A	As Case A	As Case A	As Case A	As Case A
1991	121	-	-	-	94	343
1992	136	1300	494	-	452	1650
1993	135	-	-	-	317	1157
1994	135	-	-	-	182	664
1995	237	600	228	-	173	632
1996	324	1000	380	-	229	803
1997	139	-	-	-	90	329
1998	148	1000	380	-	322	1175
1999	130	-	-	-	192	701
2000	135	-	-	-	57	208

(-) means zero value

Table 16a: The Dual Production Capacity During 1980-2000 at District A

Year	Case A'					
	Yearly Water Production Requirement W $(10)^3$ m^3/d	Maximum Electricity Production as limited by the Electricity Grid $(10)^3$KW(e)	Maximum Water Production as limited by the Ratio W/E = 0.38 $(10)^3$ m^3/d	Difficiency in Meeting Yearly Water Demand $(10)^3$ m^3/d	Surplus in Water Production Capacity $(10)^3$ m^3/d	Quantity of Surplus Water for Storage $(10)^5$ m^3/y
1981	195.85	250	95	101	-	-
1982	72	200	76	97	-	-
1983	77	300	114	60	-	-
1984	83	250	95	48	-	-
1985	88	300	114	22	-	-
1986	109.22	300	114	17	-	-
1987	93.228	300	114	-	4	15
1988	93	300	114	-	25	91
1989	92	300	114	-	47	172
1990	88	300	114	-	73	267
1991	82	-	-	9	-	-
1992	75.91	400	152	-	67	245
1993	103.91	450	171	-	135	493
1994	55	-	-	-	80	292
1995	88.415	-	-	8	-	-
1996	192	350	133	67	-	-
1997	40	350	133	-	26	95
1998	39	400	152	-	139	507
1999	38	-	-	-	101	369
2000	38	-	-	-	63	230

Year	Case B'					
	Yearly Water Production Requirement W $(10)^3$ m^3/d	Maximum Electricity Production a as limited by the Electricity Grid $(10)^3$KW(e)	Maximum Water Production as limited by the Ratio W/E = 0.38 $(10)^3$ m^3/d	Difficeincy in Meeting Yearly Water Demand $(10)^3$ m^3/d	Surplus in Water Production Capacity $(10)^3$ m^3/d	Quantity of Surplus Water for Storage $(10)^5$ m^3/y
1981						
1982						
1983						
1984						
1985						
1986						
1987						
1988	As Case A'	As Case A'	As Case A'	As Case A'	As Case A'	As Case A'
1989						
1990						
1991						
1992	90.91	500	190	-	166	606
1993	135.91	-	-	-	30	110
1994	105	500	190	-	115	420
1995	162.145	550	209	-	162	591
1996	276	600	228	-	114	416
1997	134	650	247	-	227	829
1998	146	-	-	-	81	296
1999	160	800	304	-	225	821
2000	171	-	-	-	54	197

(-) means zero value

Table 16b: The Dual Production Capacity During 1980-2000 at District B

Year	Electricity District A				Electricity District B			
	Case A		Case C		Case A'		Case B'	
	Mixed Grids		Mixed Grids		Mixed Grids		Mixed Grids	
	Dual Unit Size MW(th)	Single Unit Size MW(e)	Dual Unit Size MW(th)	Single Unit Size MW(e)	Dual Unit Size MW(th)	Single Unit Size MW(e)	Dual Unit Size MW(th)	Single Unit Size MW(e)
1985	-	600			1236	-		
1986	2516	-			1236	-		
1987	-	600			1236	-		
1988	2935	-	As Case A		1236	-	As Case A'	
1989	-	850			1236	-		
1990	3773	-			1236	-		
1991	-	1000;600	-	1200;600	-	400	-	400
1992	-	1200	5450	-	1648	-	2060	-
1993	5450	-	-	1000	1854	-	-	500
1994	-	1000	-	1000;600	-	Not nucl.	2060	-
1995	-	1000	2516	1000	-	Not nucl.	2266	-
1996	4192	-	4192	600	1442	-	2472	-
1997	-	1000	-	1000;600	1442	-	2678	-
1998	-	1000	4192	600	1648	-	-	750
1999	-	1000	-	1200	-	400	3295	-
2000	-	1000	-	1200	-	400	-	850

Table 16c: Possible Sizes of the Nuclear Units for the Mixed Grids: Power-Only and Dual Production Stations

Nuclear Unit Size, MW(e)		
Year	Development Possibility One	Development Possibility Two
1985	600	600
1986	600	600
1987	600	600
1988	700	700
1989	850	850
1990	900	900
1991	1200; 600; 400	1000; 600; 400
1992	1300; 400	1200; 500
1993	1000; 500; 450	1300; 500
1994	1000; 600	1000; 500
1995	1000; 600	1000; 550
1996	1000; 600	1000; 600
1997	1000; 600	1000; 650
1998	1000; 600; 400	1000; 750
1999	1200; 500; 400	1000; 800
2000	1200; 500; 400	1200; 850

Table 17a: The Sizes of Nuclear Units for Power-Only Production During 1985-2000: Total Country Requirement

Year	Development Possibility One		Development Possibility Two	
	Nuclear Unit Size for Dual Production Station MW(th)	Nuclear Unit Size for Power-only Stations MW(e)	Nuclear Unit Size for Dual Production MW(th)	Nuclear Unit Size for Power-only Stations MW(e)
1981	1677 ; 1030	—	As for Development Possibility One	
1982	1887 ; 824	—		
1983	2097 ; 1236	—		
1984	2306 ; 1030	—		
1985	1236	600		
1986	2516 ; 1236	—		
1987	1236	600		
1988	2935 ; 1236	—		
1989	1236	850		
1990	3773 ; 1236	—		
1991	—	1200 ; 600 ; 400	—	1000 ; 600 ; 400
1992	5450 ; 1648	—	2060	1200
1993	1854	1000 ; 500	5450	500
1994	—	1000 ; 600	2060	1000
1995	2516	1000	2266	1000
1996	4192 ; 1442	600	4192 ; 2472	—
1997	1442	1000 ; 600	2678	1000
1998	4192 ; 1648	600	—	1000 ; 750
1999	—	1200 ; 500 ; 400	3295	1000
2000	—	1200 ; 500 ; 400	—	1200 ; 850

Table 17b: The Sizes of the Nuclear Units for Power-Only Production and Dual Production During 1980-2000: Total Country Requirement

	Water Cooled Reactors				Gas Cooled Reactors			Fast Breeder	
	PWR 1300 MW(e)	BWR 1300 MW(e)	PHWR 500 MW(e)	BHWR 100 MW(e)	Magnox 600 MW(e)	AGR 600 MW(e)	HTGR 1200 MW (e)	Sodium Cooled FBR 1000 MW	Helium Cooled FBR 1000 MW
<u>Fuel Data</u> Fuel Loading (t)	UO_2 102	UO_2 147	UO_2 93	UO_2 22	U-Metal 595	UO_2 120	UO_2-ThO_2 39	PuO_2 UO_2 (MOX) 19	PuO_2 UO_2 (MOX) 28
Fissile Nuclide (Reload Enrich.) Wt.%	3.2	2.7	Nat.	2.3	Nat.	2.3	4.1	11.5	12.7
Mean Discharge Burn-up MWd/t H.M.	31500	27500	8000	21000	3000	18000	98000	67000	73000
Fuel Rating KW(th)/ Kg H.M.	37	25	19	13.4	3.2	13	77	116	93
Fissile Rating MW(th)/ Kg fiss.	1.5	1.1	2.6	0.62	0.46	0.54	1.9	1.0	0.73
Power Density KW/l	93	56	9.4	11	0.9	2.7	8.4	380	259
Conversion Ratio	0.6	0.7	0.8	0.8	0.8	0.5	0.65	1.27	1.39
<u>Power Data</u> Driving Coolant Exit Date °C/atm	330/158 H_2O	286/71 H_2O	293/90 D_2O	283/65 H_2O	414/28 CO_2	648/40 CO_2	778/48 He	615/ 10 Na	568/114 He
Turbine-Cycle Temp. and Pressure °C/atm	284/68 H_2O	281/67 H_2O	251/42 H_2O	278/62 H_2O	401/47 H_2O	538/163 H_2O	510/166 H_2O	538/169 H_2O	510/180 H_2O
Net Efficiency as obtained by Designer %	33	34	29	32	31.4	42	38	42	36

<u>Table 18:</u> Characteristics of Different Reactor Systems /28,29/.

	ThO_2-UO_2 No Recycling		ThO_2-UO_2 With Recycling	Th-U, Metal No Recycling	Th-U, Metal With Recycling
No. of Assemblies (1 region)	64	(64)	64	64	64
Burnup, (MWd/t H.M.)	34500	(33000)	34500	25800	25800
Initial:					
Heavy Metal, Kg	27160	(28350)	27170	36520	36590
U-235, Kg	1099	(907)	657	1257	741
U-235 Makeup, Kg	-----		399	-----	340
U-233	-----		370	-----	426
Final:					
U-235, Kg	258	(234)	169	401	253
U-233, Kg	370	(203)(+)	441	426	537

Figures in parentheses correspond to UO_2 fuel (case no recycling)

(+)The number refers to fissile plutonium in kilograms

Table 19: Regionwise Mass Flow at Equilibrium Conditions for a 1000 MW(e) PWR /41/

Characteristic	UO_2 Once-Through		UO_2 Pu+U Recycling		ThO_2-UO_2 U-Recycling		Th-U-Metal U-Recycling	
Reference	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Burn-up (MWd/kg H. M.)[a]	33.0	(32.4)	33.0	(32.4)	34.5	(35.6)	25.8	25.0
Equilibrium Feed Fuel[a]	3.2% Enriched UO_2	(3.26%)	Enriched UO_2 + Recycled Pu + U		ThO_2 + U-235 + Recycled U		Th-Metal + U-235 + Recycled U	
Net Station Efficiency (%)	32.5	34.2	32.5	34.2	32.5	34.2	32.5	32.5
Specific Power (MW/t H. M.)	36.0	37.0	36.0	37.0	37.7	40.6	28.0	26.0
Equilibrium Net Feed Rates for 1 GW(e) at 80% Load Factor:								
Equivalent Natural Uranium (t U/y)	160	158	100	96	74	72	63	49
Thorium (t Th/y)	-	-	-	-	25	23	34	35
Separative Work (kg swu x 10^3/y)	130	129	96	84	96	93	82	64
H.M. to Reprocessing (t/y)	-	-	27	26	26	24	35	36
Net Production Rates for 1 GW(e) at 80% L.F. Fissile Pu (t/y)	0.194	0.163	-	-	-	-	-	-
"Inventory" for 1 GW(e) at 80% L.F.:								
Equivalent Natural Uranium (t U)[a]	(363)	(334)	(430)	(433)	(625)	(575)	(746)	(769)
Thorium (t Th)[a]	-	-	-	-	(84)	(72)	(114)	(124)
Separative Work (kg swu x 10^3)[a]	(253)	(230)	(300)	(342)	(817)	(752)	(975)	(1005)

Symbols:

(a) = Figures in parentheses are estimates of the author of ref. 40

(t) = ton

(H.M.) = Heavy Metal

(swu) = separative work unit

(L.F. = Load Factor)

References:

(1) Private communication between the author of ref. 40 and Lane, R.K. (including work performed by Hettergott, E.H.

(2) Hellens, R.L. et al., "A Survey of Thorium Fuel Cycles in PWRs", Trans. Am. Nucl. Soc. 23 (1976) 272, and private communication with author of ref. 40

(3) Zorzoli, G.B., "An Evaluation of a Near-Breeder , Low Cost, LWR Concept", Eng. Nucl. (Milan) 19 3(1972) 151

Table 20: Characteristics of Standard PWR Fuel Cycles /40/
Capacity = 1 GW(e)
Enrichment Tail = 0.2%
Out-Reactor Delay = 1 Year

Characteristic	UO_2 Once-Through		UO_2 with Pu Recycling	ThO_2 - UO_2 U-Recycling and U-235 Topping		
	Natural Uranium Feed	1.2% Enrichment Uranium Feed		High Burnup (H.B.)	Intermediate Burnup (I.B.)	Self Sufficient (S.S.)
Burnup (MWd/Kg H.M.)	7.5	20.8	18.0	37.4	19.5	10.0
Equilibrium Feed Fuel	Natural Uranium	1.2% Enr. Uranium	Nat. U + Recycled Pu	ThO_2 + Recycled U + U-235		
Net Station Efficiency (%)	29.1	29.1	29.1	29.1	29.1	29.1
Specific Power (MW/t H.M.)	23.4	23.4	23.4	26.3	26.3	26.3
Equilibrium Net Feed Rates for 1 GW(e) at 80% Load Factor: Equivalent Natural Uranium (tU/y)	133	94	56	26	10	0
Thorium (tTh/y)	-	-	-	26	51	99
Separative Work (Kg swu x 10^3/y)	-	34	-	34	13	0
H.M. to Reprocessing (t/y)	-	-	56	27	52	100
Net Production Rates for 1 GW(e) at 80% Load Factor: Fissile Pu (t/y)	0.360	0.158	-	-	-	-
"Inventory" for 1 GW(e) at 80% Load Factor: Equivalent Natural Uranium (t U)	140	190	194	680	719	871
Thorium (t Th)	-	-	-	79	91	115
Separative Work (Kg swu x 10^3)	-	68	-	882	973	1130

Table 21: Characteristics of Candu-PHWR Fuel Cycles /40/
Capacity = 1 GW(e)
Enrichment Tail = 0.2%
Out-Reactor Delay = 1 Year

PWR Standard Brunup			Candu-PHWR	
Fuel Cycle Alternative	Life-Time Uranium Requirement in Metric Tons ref. (1)	ref. (2)	Fuel Cycle Alternative	Life-Time Uranium Requirement in Metric Tons
Once-Through	5083	4995	Once-Through, Nat. U	4130
U+Pu Recycling	3380	3265	Slightly Enriched, 1.2%	3010
ThO_2-UO_2, U-Recyc.	2808	2699	Pu-Recycling	1874
Th-U, Met., U-Recyc.	2604	2214 (ref. 3)	ThO_2-UO_2, H.B.	1460
			ThO_2-UO_2, I.B.	1019
			ThO_2-UO_2, S.S.	871

(references 1, 2 and 3 as for Table 20)

Table 22: Life Time Uranium Requirement for PWR and Candu-PHWR of a 1 GW(e) /40/
Assumptions: 30 Years Life Time
80 % L.F.

	LEU-HTGR	THTGR
Ratio of carbon/heavy metal	400	240
Fuel lifetime, years	3	4
Conversion ratio	0.50	0.66
U-235 enrichment, average reload	11%	93%
U_3O_8 requirement, t/MW(e)		
30-years total, with recycling	3.9	2.3
30-years total, no recycling	4.9	3.9
Enrichment requirement, swu t /MW(e)		
30-years total, with recycling	3.9	2.5
30-years total, no recycling	4.5	4.3

Table 23: Fuel Cycle Parameters and Resources Requirements for HTGR /37/
Assumptions: Enrichment Tail = 0.2 %
All U + Pu Recycled for the Recycling Case
80 % L.F.

Symbol	PWR System			CANDU-PHWR System				Unit	Symbol	Value Common to Both Systems
	Once Through	U + Pu Recycling	ThO_2-UO_2 U-Recycling	Once Through	Pu Recycling	1.2% Enrichment	ThO_2-UO_2 I.B. U-Recycling			
m_u	$(10)^3$ 28.350	$(10)^3$ 19.889	$(10)^3$ 16.625	$(10)^3$ 133	$(10)^3$ 56	$(10)^3$ 48.032	$(10)^3$ 6.778	kg(Ui)	f_c V_u	2.205 1.005
u	6.067	4.892	4.305	U=1	U=1	1.951	4.892	kgU/ kgUi	V_m	1.01
t	4.746	3.441	3.018	t=1	t=1	0.698	3.656	kgswu/ kgUi	V_r	0.98
m_u u	$(10)^3$ 171.999	$(10)^3$ 97.270	$(10)^3$ 71.571	$(10)^3$ 133	$(10)^3$ 56	$(10)^3$ 94	$(10)^3$ 33.157	kgU	V_{rc}	0.995
u_{Th}	-	-	$(10)^3$ 25.0	-	-	-	$(10)^3$ 18.0	kgTh	t_u	1.25 year
ß	-	194	-	-	360	-	-	kgPu	t_c	1 year
P_c	5	5	5	-	-	5	5	$/ KgU	t_e	0.58 year
P_m	114	114	152	50	100	80	100	$/ kgUi	t_m	0.425 year
P_r	-	721	820	-	460	-	600	$/ kgUi	t_r	1.5 year
P_p	-	20	-	-	24-50	-	-	$/ kg Pu	t_p	2.0 year
P_s	100	-	-	25	-	100	-	$/ kgUi	i	10% per year

Notes:

1) The above values are extracted from ref. 38

2) P_u, P_e, P_{Th}, and P_D are applied parametrically in the following ranges:

	$/kg		$/kg
P_u	132-441 (60-200 $/lb)	P_{Th}	30-100
P_e	150-500	P_D	120-400

3) The first core requirements are assumed to equal 3 times the equilibrium core

4) D_2O requirement for the first core is 1 t/MW(e) for OTA and 0.8 t/MW(e) for other alternatives. And 2% loss (or make-up) per year.

5) For the case of recycling, the figure for the quantity m_u is calculated such that the compensation for uranium and plutonium credits are already included. This way, the FC expenditure can be calculated by adding all the cost involved e.g. cost of U_3O_8+ cost of conversion + cost of enrichment + cost of fabrication + cost of storage (for OTA only) + cost of reprocessing and re-fabrication (for the recycling cases only).

Table 24: Numerical Values Applied for the Determination of the Nuclear Fuel Cycle Cost of a 1000 MW(e) Unite Size of PWR and Candu-PHWR

Symbols	Explanation	Unit
m_u	Initial Feed to the Reactor	$kg(U_i)$
u	Specific quantity of Required UF_6	kg $U/kg\ U_i$
$m_u \cdot u$	Equivalent Natural Uranium, U_3O_8	kg(U)
u_{Th}	Thorium Supply	kg Th
ß	Fissile Plutonium	kg Pu
t	Specific Quantity of swu	kg swu/kg U_i
P_c	Price For Conversion	$/kg U
P_m	Price For Fuel Element Fabrication	$/kg U_i
P_r	Price For Reprocessing + Refabrication	$/kg U_i
P_p	Price For Fissile Plutonium	$/kg Pu
P_s	Price For Spent Fuel Element Storage	$/kg U_i
P_u	Price For U_3O_8	$/kg U
P_e	Price For Enrichment	$/kg swu
P_{Th}	Price For Thorium	$/kg Th
P_D	Price For D_2O	$/kg D_2O
f_c	Conversion Factor, kg to lb.	
V_u	Loss at Conversion (O.5%)	
V_m	Loss at Manufacturing (1%)	
V_r	Loss at Reprocessing (2%)	
V_{rc}	Loss at Reconversion to UF_6 (O.5%)	
t_u	Lead time For Payment For U_3O_8	
t_c	Lead time For Payment For Conversion	

Table 24 **(Continued):** Explanation of the Symbols

Symbols	Explanation	Unit
t_e	Lead Time For Payment For Enrichment	
t_m, t_r, t_p	Lead Time For Payment For Manufacturing, Reprocessing, and Plutonium Credit, respectively	
i	Discount Rate (Interest Rate)	
r	Ratio of finally to initially contained uranium	
$u_r=u$	Specific quantity of equivalent natural uranium	kg U/kg U_i
$s_r=t$	Specific quantity of equivalent swu	kg swu/kg U_i
fP	Quantity of fissile plutonium	kg
Th. E	Thermal efficiency	%
t_{ur}	Lag time for payment for uranium credit	
B_1	Burnup value of the first cycle	MWd/kg U
B_2	Burnup value of the second cycle	MWd/kg U
B_3	Burnup value of the third cycle	MWd/kg U
t_1	Lag time for revenues of the first cycle	
t_2	Lag time for revenues of the second cycle	
t_3	Lag time for revenues of the third cycle	

Table 24 (continued)

System	Alternative	Item	132.28 (60) / 30 / 150 / 120	176.37 (80) / 40 / 200 / 160	220.46 (100) / 50 / 250 / 200	264.55 (120) / 60 / 300 / 240	308.64 (140) / 70 / 350 / 280	352.73 (160) / 80 / 400 / 320	396.83 (180) / 90 / 450 / 360	440.92 (200) / 100 / 500 / 400
Price: U_3O_8 $/kg ($/lb); Price: Thorium $/kg; Price: swu $/kg; Price: D_2O $/kg										
PWR System	Once Through Alternative	First Core Invest. $(10)^9$ mills	4.62	5.92	7.22	8.52	9.82	11.12	12.42	13.72
		Equilibrium Core $(10)^9$ mills	59.54	76.99	94.45	111.90	129.36	146.81	164.27	181.72
		Total Cost $(10)^9$ mills	64.16	82.91	101.67	120.42	139.18	157.93	176.69	195.44
		mills/KWh	11.90	15.38	18.86	22.33	25.81	29.29	32.77	36.25
	U + Pu Recycling Alternative	First Core Invest. $(10)^9$ mills	6.17	7.47	8.77	10.07	11.37	12.67	13.97	15.27
		Equilibrium Core $(10)^9$ mills	43.67	53.11	62.56	72.01	81.45	90.89	100.35	109.78
		Total Cost $(10)^9$ mills	49.84	60.58	71.33	82.08	92.82	103.56	114.32	125.05
		mills/KWh	9.24	11.24	13.23	15.22	17.21	19.21	21.20	23.19
	ThO_2-UO_2 U-Recycling Alternative	First Core Invest. $(10)^9$ mills	7.58	8.97	10.36	11.76	13.15	14.54	15.93	17.32
		Equilibrium Core $(10)^9$ mills	44.23	54.02	63.82	73.61	83.41	93.20	103.00	112.79
		Total Cost $(10)^9$ mills	51.81	62.99	74.18	85.37	96.56	107.74	118.93	130.11
		mills/KWh	9.61	11.68	13.76	15.83	17.91	19.98	22.06	24.13
CANDU-PHWR System	Once Through Alternative	First Core Invest. $(10)^9$ mills	7.66	9.86	12.05	14.25	16.45	18.65	20.85	23.05
		Equilibrium Core $(10)^9$ mills	36.42	45.14	53.86	62.58	71.30	80.02	88.74	97.46
		Total Cost $(10)^9$ mills	44.08	55.00	65.91	76.83	87.75	98.67	109.59	120.51
		mills/KWh	8.18	10.2	12.22	14.25	16.27	18.30	20.32	22.35
	Plutonium Recycling Alternative	First Core Invest. $(10)^9$ mills	8.79	10.72	12.64	14.56	16.49	18.41	20.33	22.25
		Equilibrium Core $(10)^9$ mills	40.09	44.07	48.05	52.03	56.01	59.99	63.97	67.95
		Total Cost $(10)^9$ mills	48.88	54.79	60.69	66.59	72.5	78.4	84.30	90.20
		mills/KWh	9.07	10.16	11.26	12.35	13.45	14.54	15.63	16.73
	1.2% Enrichment (Once Through) Alternative	First Core Invest. $(10)^9$ mills	6.57	8.44	10.31	12.17	14.04	15.91	17.78	19.65
		Equilibrium Core $(10)^9$ mills	33.43	41.46	49.50	57.53	65.57	73.60	81.64	89.67
		Total Cost $(10)^9$ mills	40	49.9	59.81	69.70	79.61	89.51	99.42	109.32
		mills/KWh	7.42	9.25	11.09	12.93	14.76	16.60	18.44	20.28
	ThO_2-UO_2 U-Recycling I.B. Alternative	First Core Invest. $(10)^9$ mills	5.43	7.09	8.75	10.40	12.06	13.72	15.37	17.03
		Equilibrium Core $(10)^9$ mills	22.41	28.40	34.40	40.39	46.39	52.38	58.38	64.37
		Total Cost $(10)^9$ mills	27.84	35.49	43.15	50.79	58.45	66.10	73.75	81.40
		mills/KWh	5.16	6.58	8.00	9.42	10.84	12.26	13.68	15.10

Table 25: Energy Generating Cost with Respect to the Fuel Cycle Expenditure Only of a 1000 MW(e) Unit Size of PWR and Candu-PHWR

Case 1:

1. (ThO_2-UO_2, U-Recy.)-Candu-PHWR
2. (1.2% Enrch.)-Candu-PHWR
3. (Pu-Recy.)-Candu-PHWR
4. (OTA)-Candu-PHWR
5. (U+Pu-Recy.)-PWR
6. (ThO_2-UO_2, U-Recy.)-PWR
7. (OTA)-PWR

Case 2:

1. (ThO_2-UO_2, U-Recy.)-Candu-PHWR
2. (1.2% Enrch.)-Candu-PHWR
3. (OTA)-Candu-PHWR
4. (Pu-Recy.)-Candu-PHWR
5. (U+Pu-Recy.)-PWR
6. (ThO_2-UO_2, U-Recy.)-PWR
7. (OTA)-PWR

Case 3:

1. (ThO_2-UO_2, U-Recy.)-Candu-PHWR
2. (1.2% Enrch.)-Candu-PHWR
3. (OTA)-Candu-PHWR
4. (Pu-Recy.)-Candu-PHWR
5. (U+Pu-Recy.)-PWR
6. (ThO_2-UO_2, U-Recy.)-PWR
7. (OTA)-PWR

Case 4:

1. (ThO_2-UO_2, U-Recy.)-Candu-PHWR
2. (1.2% Enrch.)-Candu-PHWR
3. (Pu-Recy.)-Candu-PHWR
4. (OTA)-Candu-PHWR
5. (U+Pu-Recy.)-PWR
6. (ThO_2-UO_2, U-Recy.)-PWR
7. (OTA)-PWR

Table 26: Nuclear Fuel Cycle Alternatives Arranged in Descending Order of Priority with Respect to the "monetary gain"

Original Condition:

Main Line Track, composed of : 18 kg - 11.9 m rails on timber ties and with European and Middle East standard gauge, 1 435 mm.
The joints are made by four-hole fish plates.
The ties are treated timber 244 x 15 x 20 cm.

Renewal Program:

Replacement of the tracks with new rails of the type 45 kg - 11.9 m on new rails:
Since 1974 some 114 Km on the section Dammam-Hofuf have been renewed.

Operation Problems:

Ballast of limestone up to 50 mm size has originally been provided, but it is now mixed or covered with sand; There are no rivers, hence, no bridges, only a few small culverts, yet near Dammam the railroad is exposed to flooding from time to time.
Extensive maintainance is necessary in the form of: "keeping the track clear of sand", otherwise, dangerous obstruction for the train traffic can occur.

Composition of Daily Freight:

The rolling stock includes:
1200 units, 27 locomotives, 17 passenger cars, 10 refrigerated cars
Daily freight percentages:

- Local movements from Dammam port to the Customs yard and the Aramco center at Dahran (54% of total tonnage)
- Petroleum products from Dahran to Riyadh (19%)
- Cement from Judaidh to Dammam (7%)
- Fertilizer from Safco plant to the port (5%)
- All other traffic, most of it originating at the port (15%)

Table 27: Rail Road Conditions in the Country /61/

Component	Number	Approximate Weight (t)
Pressure vessel + head	1	490
Steam generator	4	470
Pressurizer	1	125
Core internals	1	125
Main coolant pumps	4	50
Motors for coolant pumps	4	40
Component cooling system cooler	4	25
Residual heat exchanger	4	15
Accumulator	8	25
Borated water storage tank	8	15
Fuel assembly cask	1	125
Other vessels	Appr. 20	5 - 15
Groups of sections of containment	100	15 - 25
Material airlock	1	85
Personnel airlock	1	25
HP-turbine	1	250
Rotor of LP-turbine	2 - 3	200
Feedwater storage tank	1	240
Water separator/reheater	2	230
LP-heater	3	90
LP-cooler	3	10
HP-condensate cooler	2	75
HP-heater	2	60
Transformer	1	570

Table 28: Heavy Load Components of a 1300 MW(e) PWR /62/

Reactor System	Type	Dimension (m)	Weight (t)
PWR (1300 MW(e))	Steel	13.2 o.h. 5.0 o.d. 250 mm thick	490 with head
BWR (1316 MW(e))	Steel	22.05 o.h. 6.7 o.d. 170 mm thick	800 with head
CANDU-PHWR (600 MW(e))	No Vessel instead: CALANDRIA (Steel)	7.82 o.l. 7.62 o.d.	390 with shell
PHWR-Vessel type (340 MW(e))	Steel	12.12 o.h. 5.36 o.d. 220 mm thick	470 without head
THTR-1000	PCRV	26.0 o.h. 27.3 o.d.	
LMFBR (1200 MW(e)) Superphenix	Steel (pool)	18.6 i.h. 21.0 i.d.	
GCFBR (1000 MW(e))	PCRV	33.0 o.h. 34.0 o.d.	

Table 29: Comparison of Type, Dimension, and Weight for the Pressure Vessels of Different Reactor Systems

		1200 MW(e)		1000 MW(e)		900 MW(e)		600 MW(e)	
		Wet Tower	Dry Tower	Wet Tower	Dry Tower	Wet Tower	Dry Tower	Wet Tower	Dry Tower
Generator Capacity MW(e)	J	1190.7	1090.8	992.7	909.0	893.0	818.1	595.3	545.4
	D	1200	1098.4	1000	915.3	900	823.8	600	549.2
	R	1218.0	1109.1	1015.0	924.3	913.5	831.8	609.0	554.6
Discharge Heat MW(th)	J	2301	2402	1917	2002	1726	1802	1150	1201
	D	2291	2394	1910	1995	1719	1796	1146	1197
	R	2274	2383	1895	1986	1705	1788	1137	1192
Cooling Water Flow kg/s	J	36670	35927	30560	29940	27500	26950	18335	17965
	D	36520	35810	30440	29840	27390	26860	18260	17905
	R	36240	35650	30200	29710	27175	26740	18120	17825
No. of Towers/ Rate of Evap. kg/s	J	1/823	2/ -	1/686	2/ -	1/617	2/ -	1/411	1/ -
	D	1/820	2/ -	1/684	2/ -	1/615	2/ -	1/410	1/ -
	R	1/823	2/ -	1/686	2/ -	1/617	2/ -	1/411	1/ -
Tower Dimension dia./height (m)	J	115/147	183/200	107/136	171/199	102/130	164/190	86/110	183/200
	D	123/156	183/199	113/144	170/198	108/137	163/189	91/116	183/199
	R	149/187	188/200	137/171	175/200	131/162	167/193	110/135	188/200
Make-up Requir. kg/s	J	1234	-	1028	-	926	-	617	-
	D	1231	-	1025	-	923	-	615	-
	R	1234	-	1029	-	926	-	617	-
Relative Tower Cost (%) (1300 MW(e) = 100%)	J	11.6	93.3	10.2	77.5	9.5	70.1	7.3	46.6
	D	12.8	92.2	11.2	76.7	10.5	69.4	8.0	46.1
	R	17.5	98.4	15.2	81.9	14.1	73.5	10.7	49.2

J = Jeddah
D = Dahran
R = Riyadh

Table 30: Results of Optimization Calculation of Wet and Dry Cooling Towers for Unit Sizes of 1200, 1000, 900 and 600 MW(e) PWRs

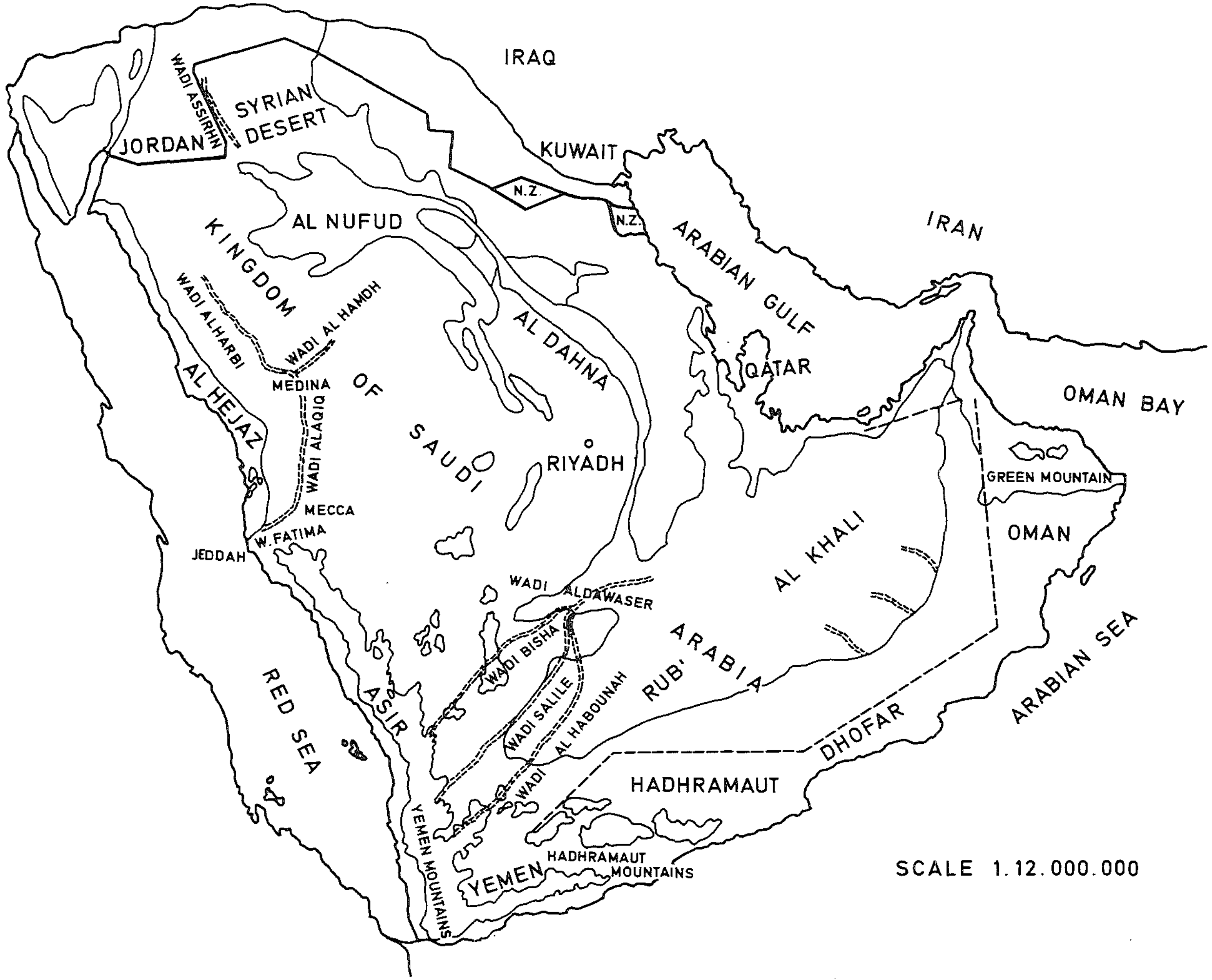


Figure 1: Kingdom of Saudi Arabia

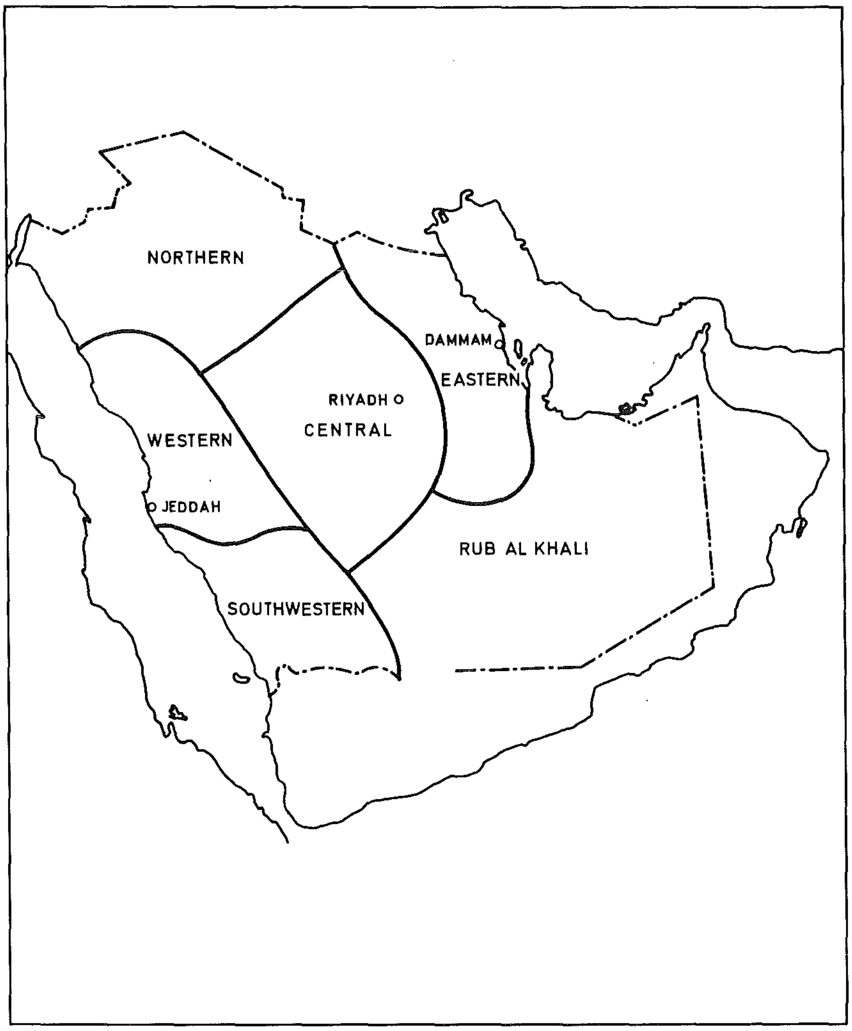
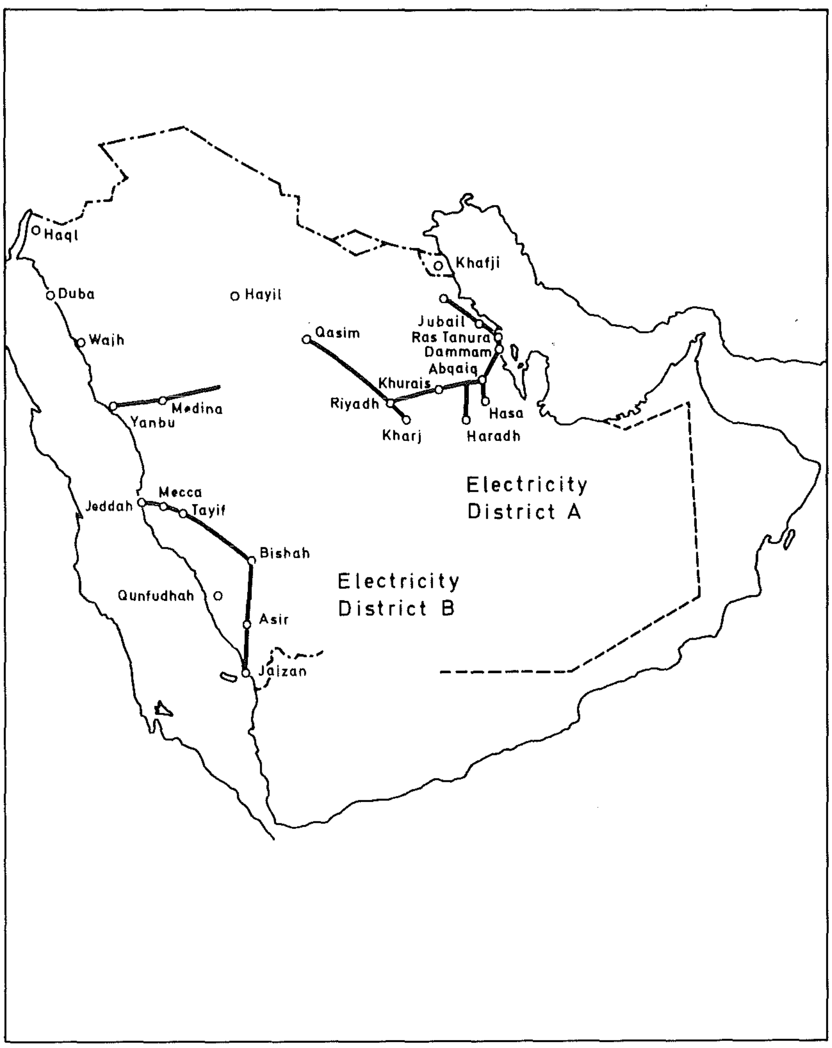


Figure 2: Boundary of the 5 Socio-Economic Study Regions



<u>Figure 3</u>: Two National Dual Production Grids as Conceived by the Central Planning Ministry

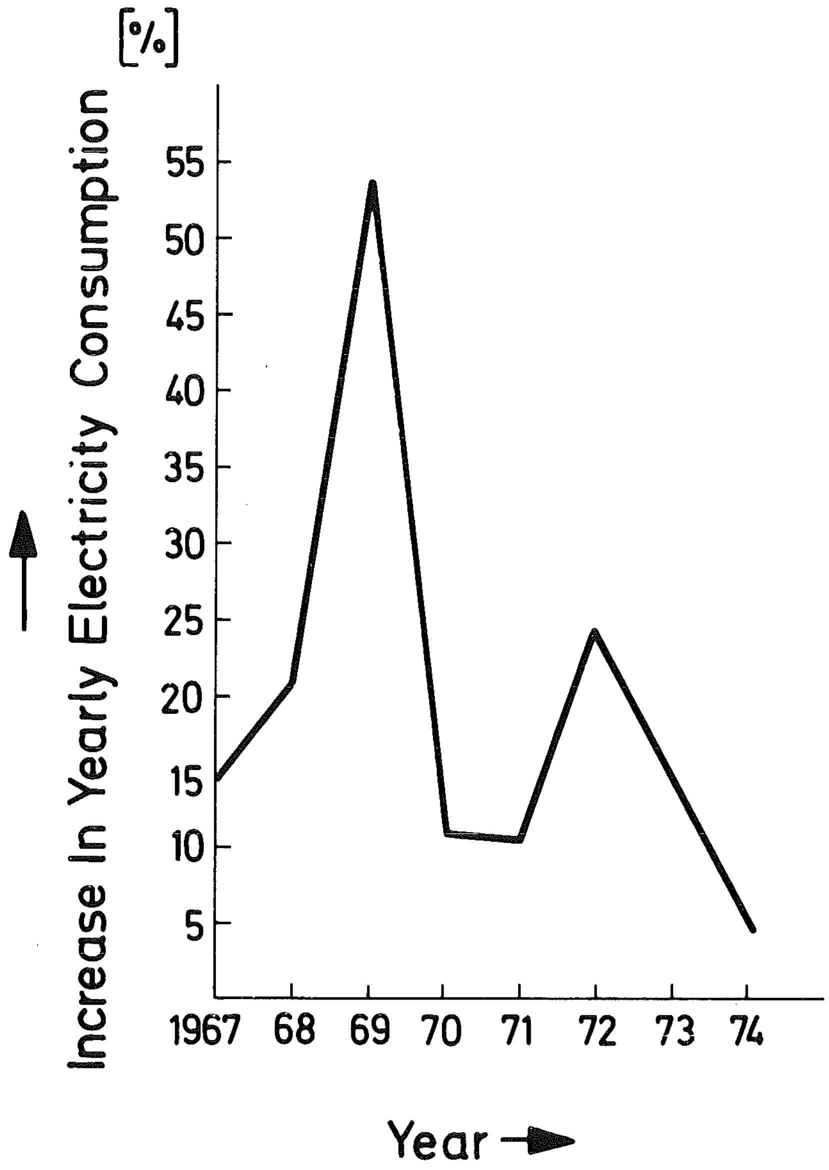


Figure 4: Recorded Percentage Increase in the Yearly Electricity Consumption /2/

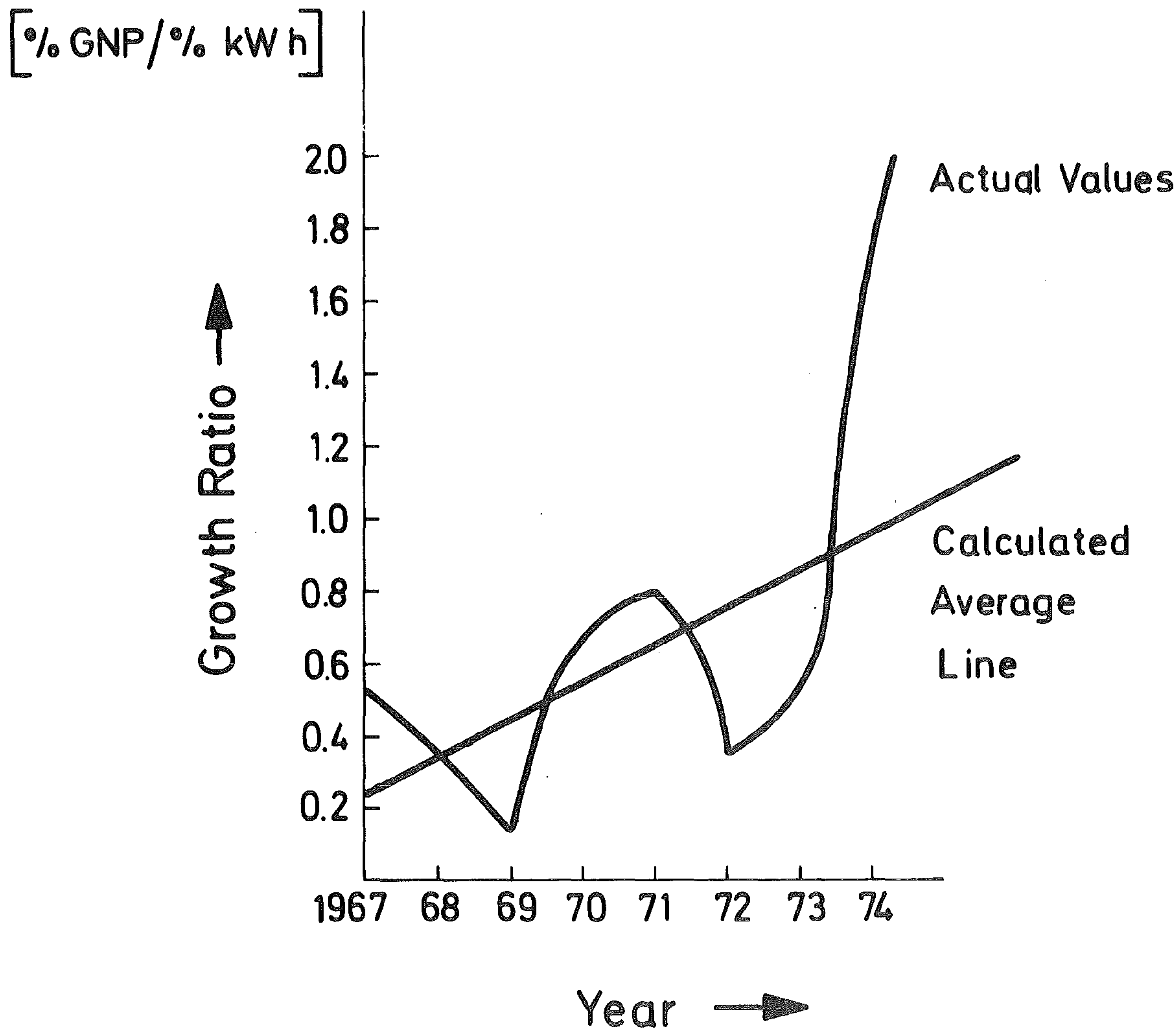


Figure 5: Determination of the Average Growth Ratio for the Period 1966-1974

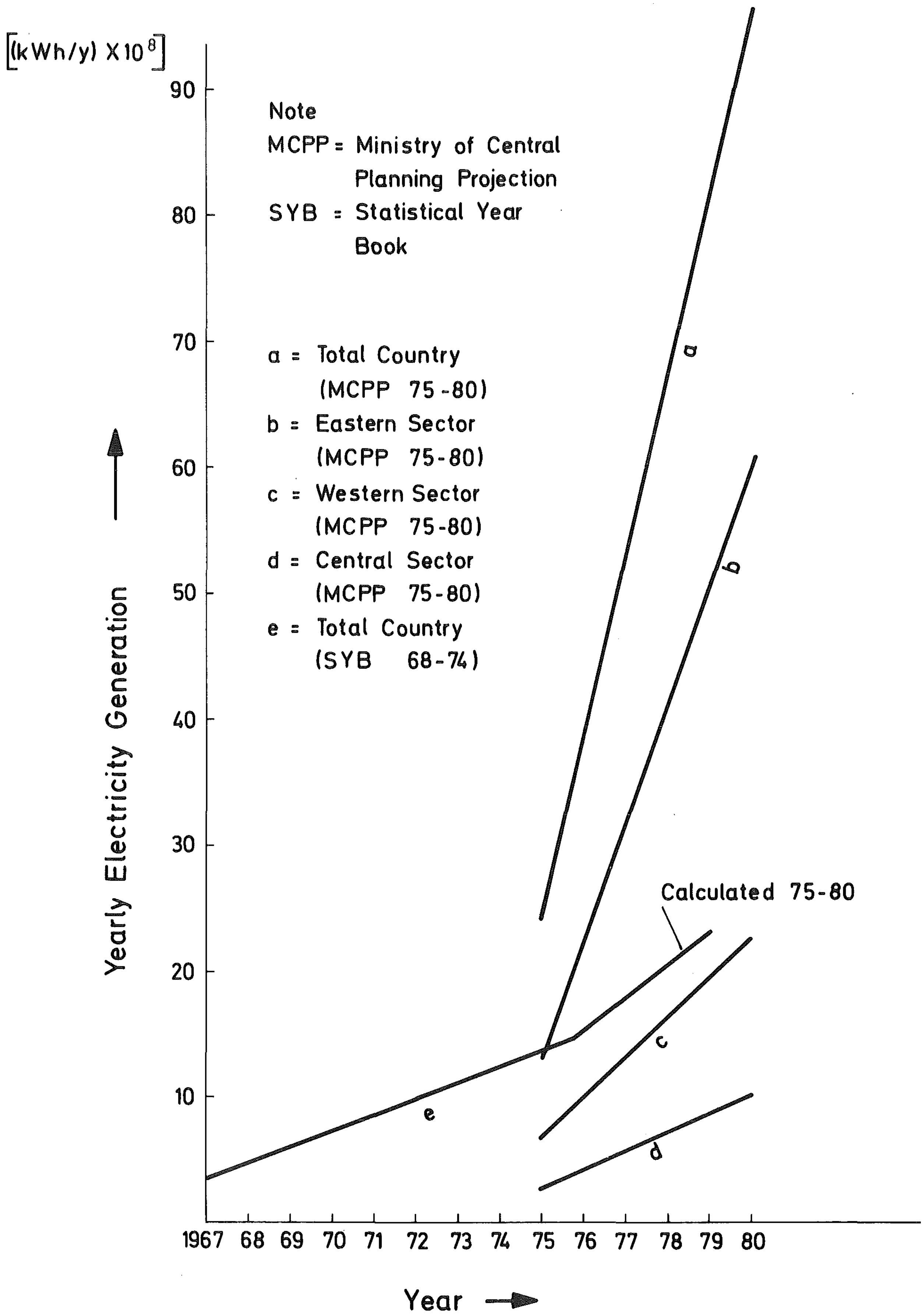


Figure 6: Growth in the Yearly Electricity Generation from 1968 to 1980 /2, 3/

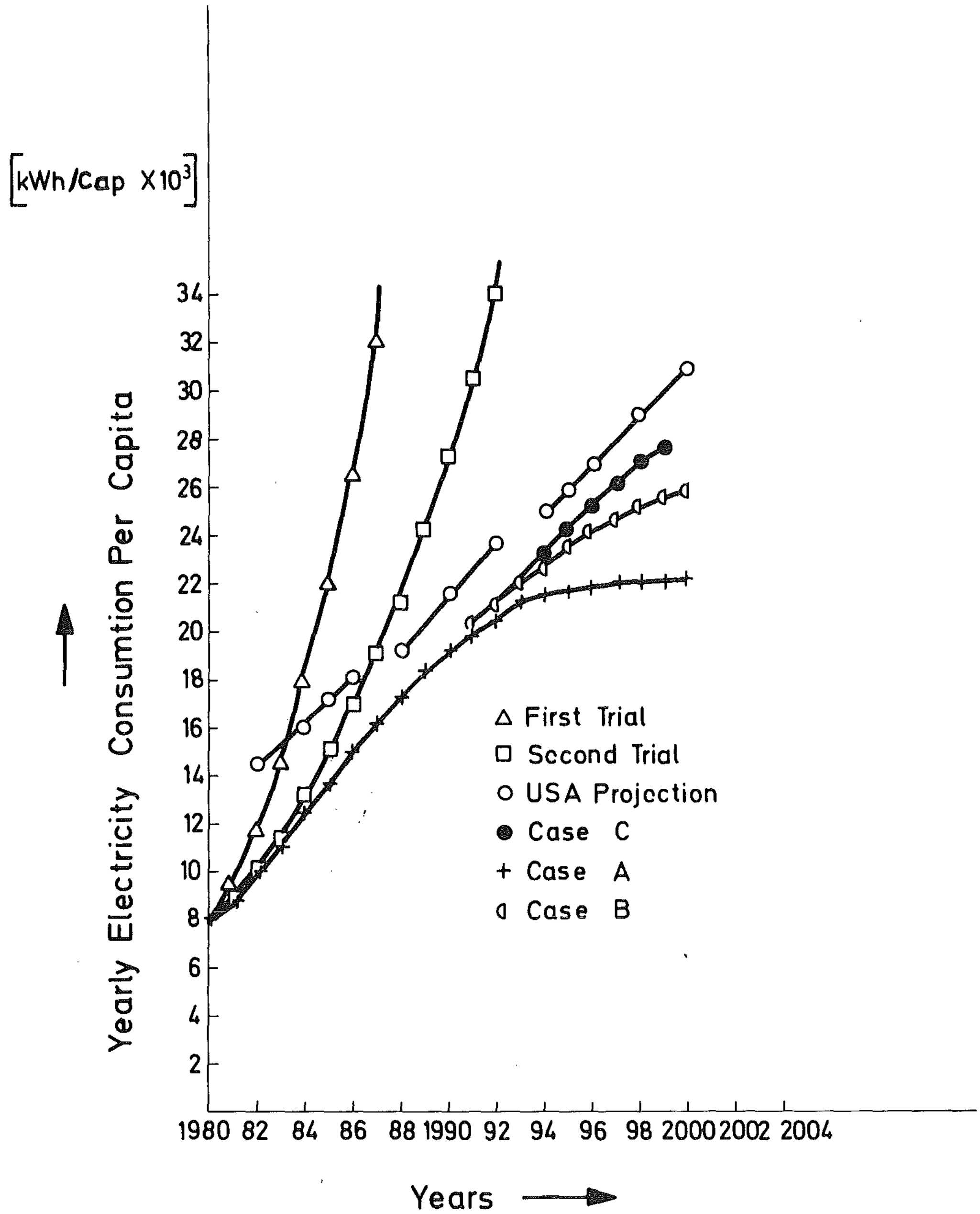


Figure 7: Projected Values for the Yearly Electricity Consumption Per Capita at District A and USA for the Period 1980-2000

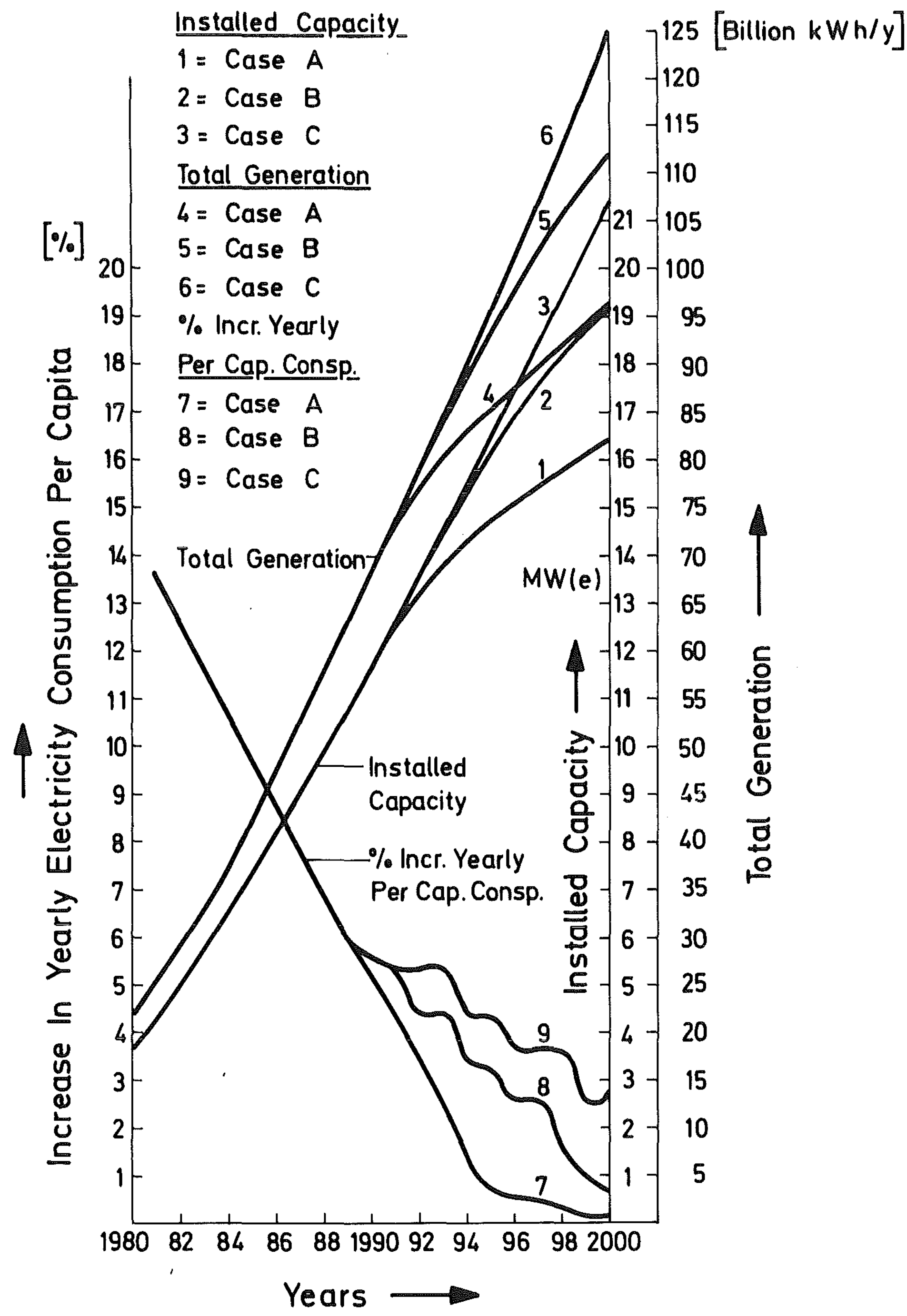


Figure 8: Results of the Electricity Projection Scenarios for the Period 1980-2000: District A

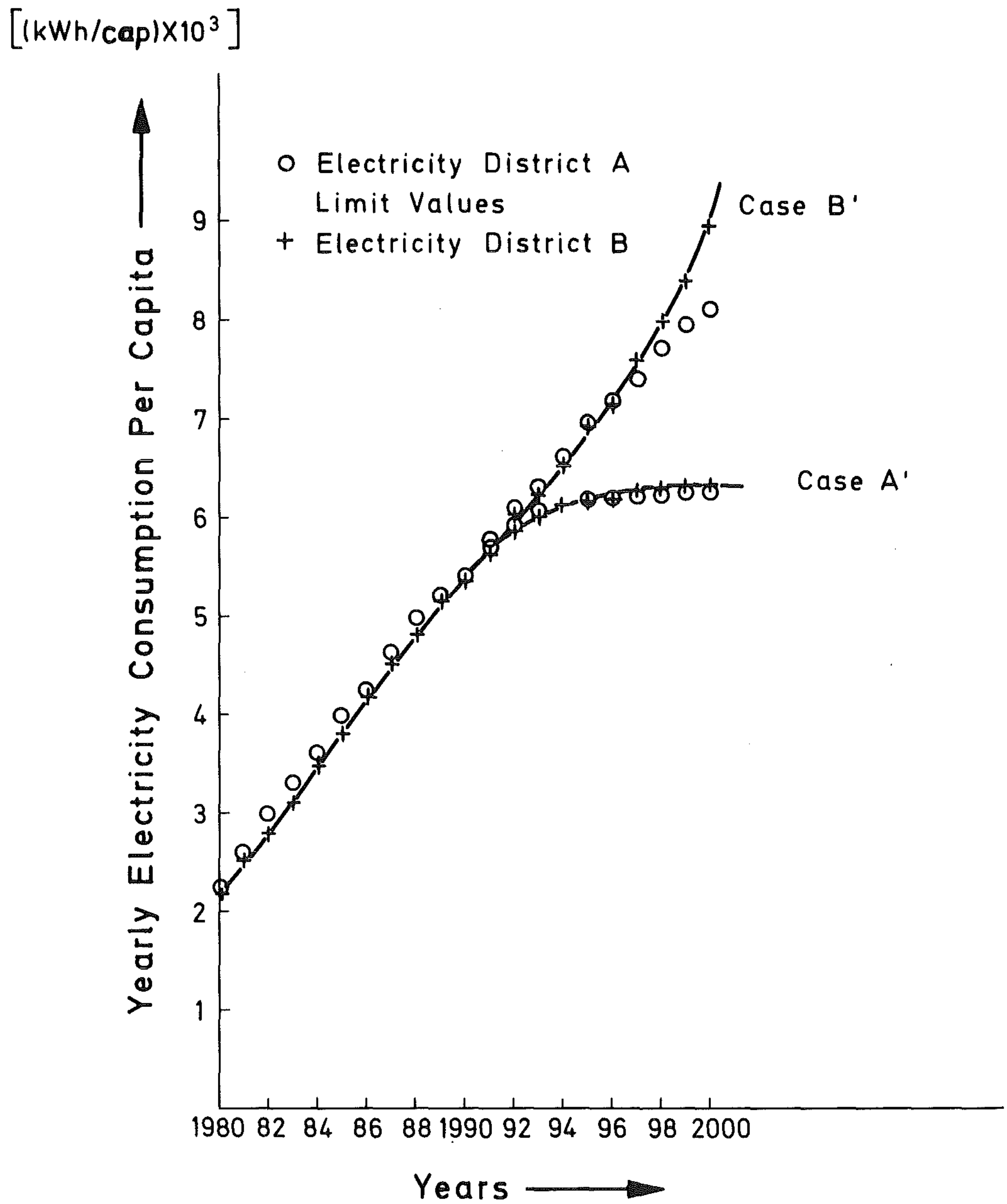


Figure 9: Projected Values for the Yearly Electricity Consumption Per Capita at District B for the Period 1980-2000

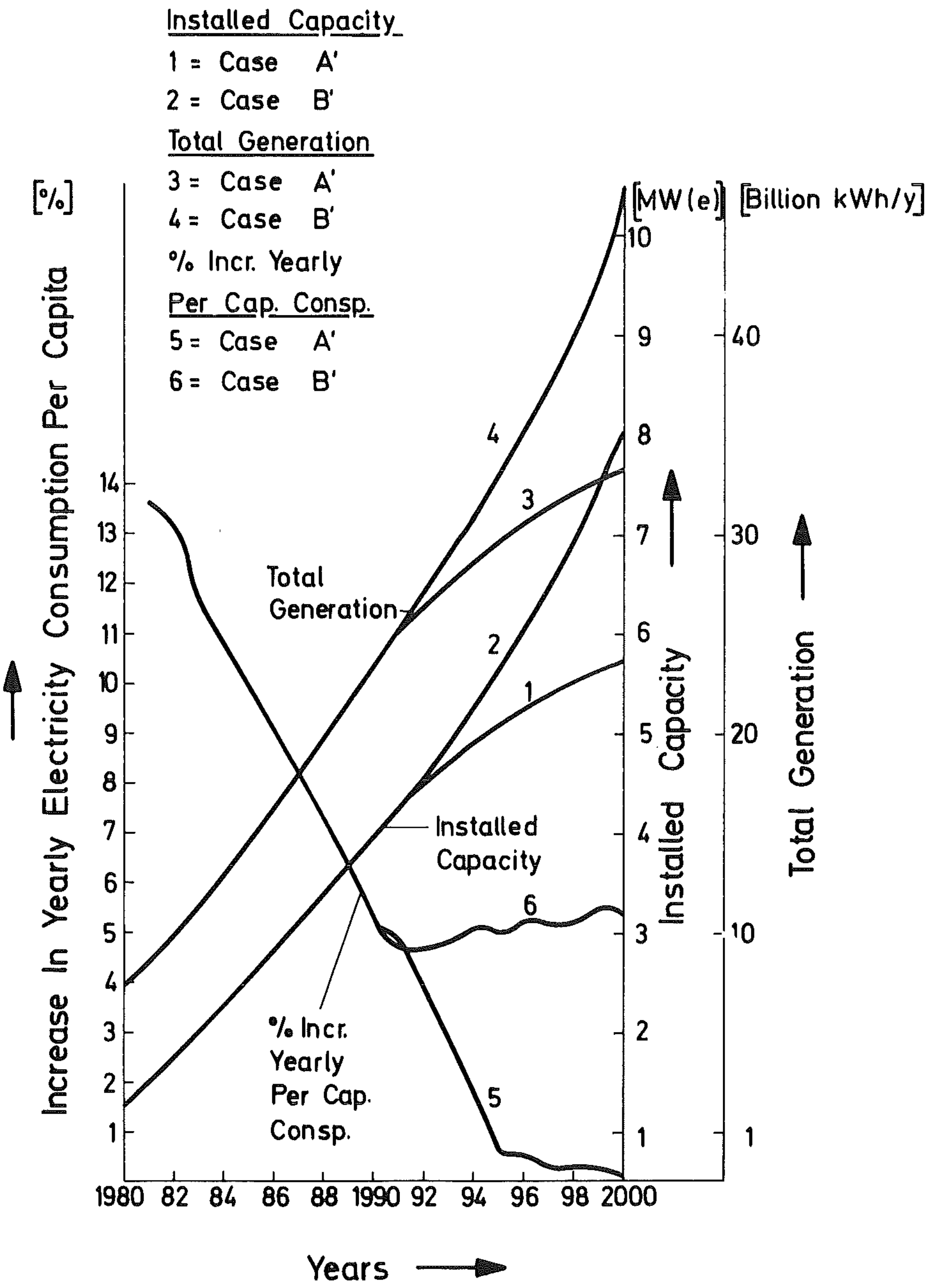


Figure 10: Results of the Electricity Projection Scenarios for the Period 1980-2000 : District B

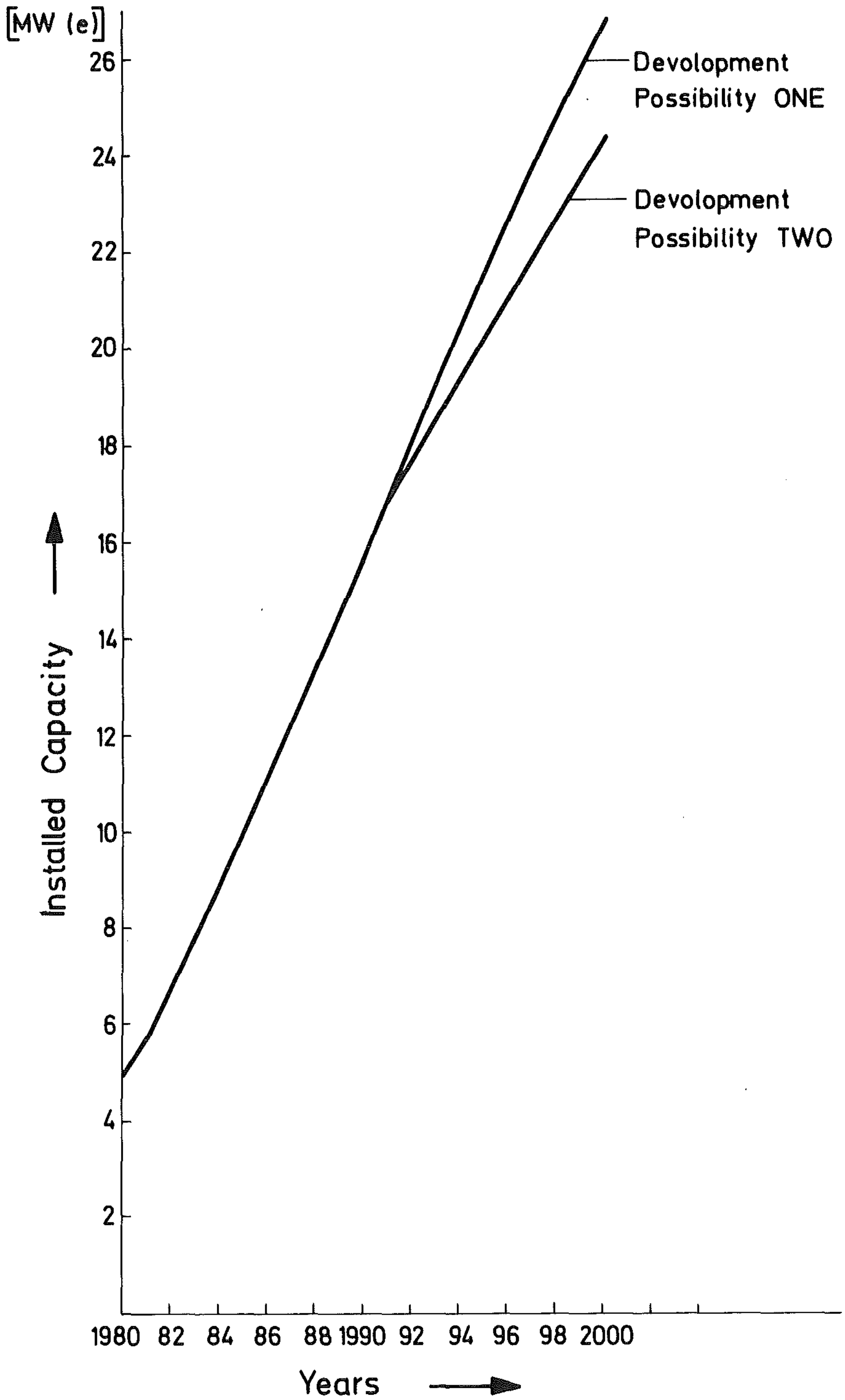


Figure 11: Projected Values for the Total Installed Capacity for the Period 1980-2000: A Comparison between Development Possibility One and Two

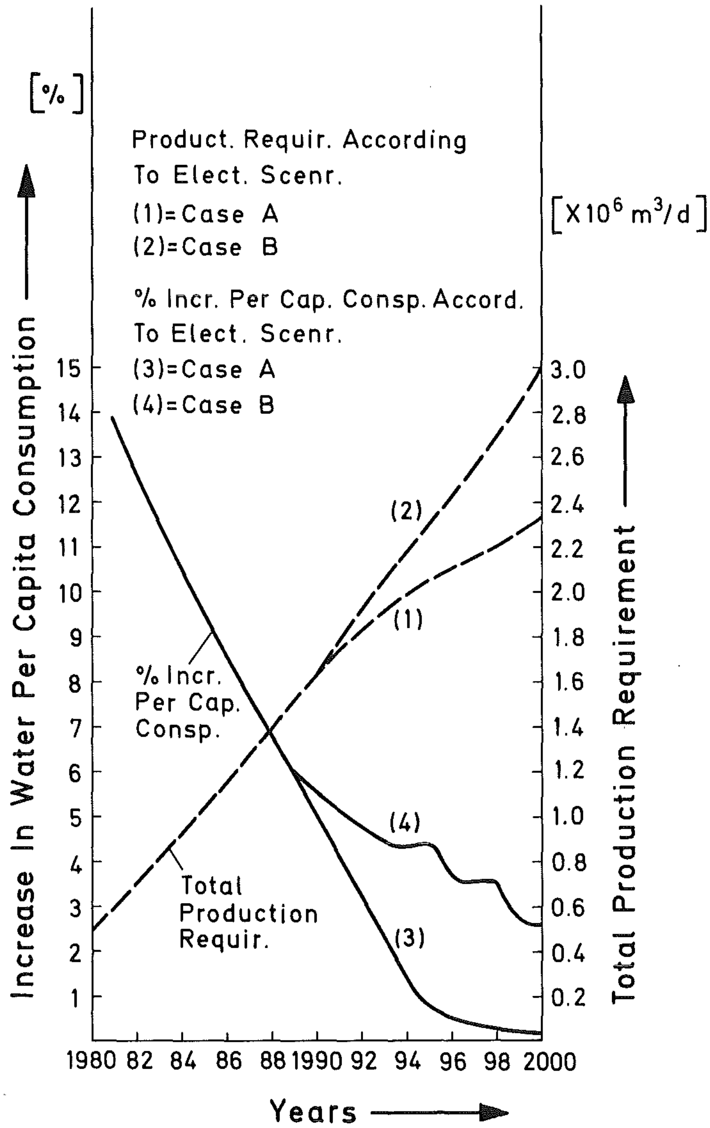


Figure 12: Results of the Water Projection Scenarios for the Period 1980-2000: District A

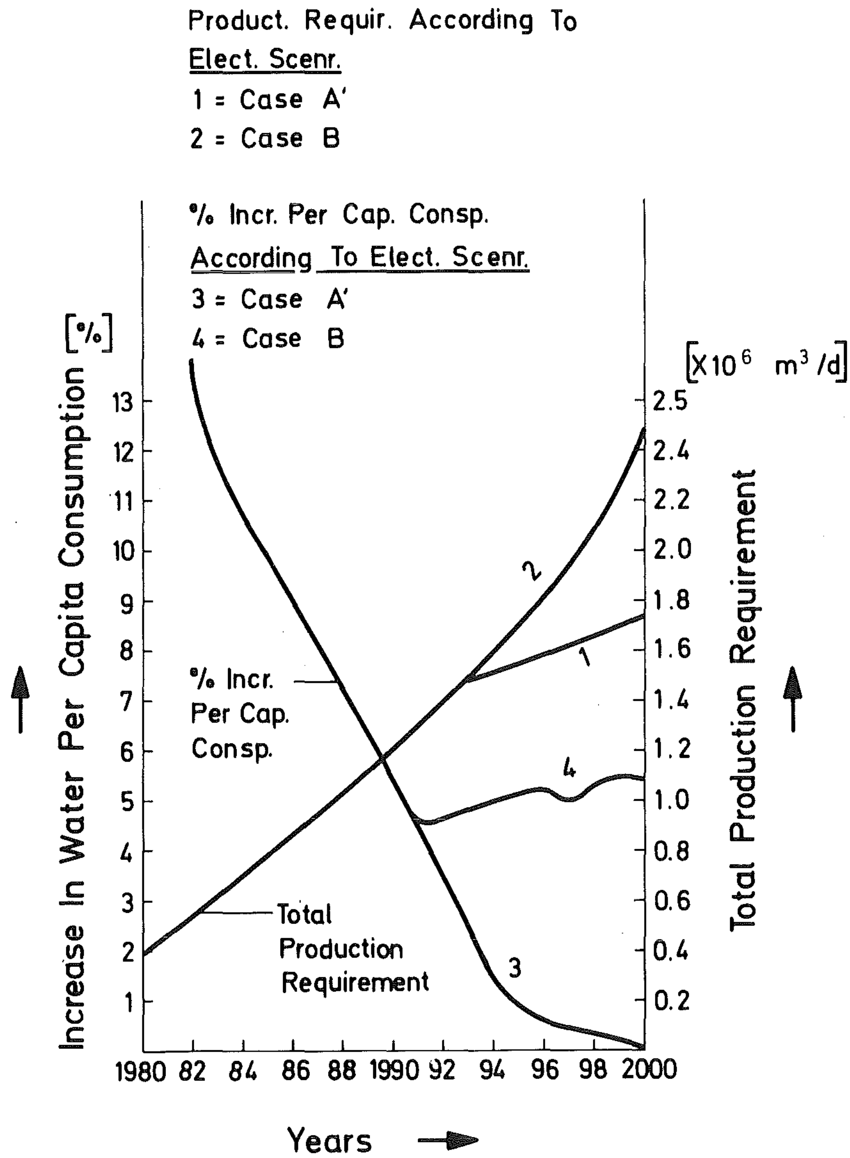
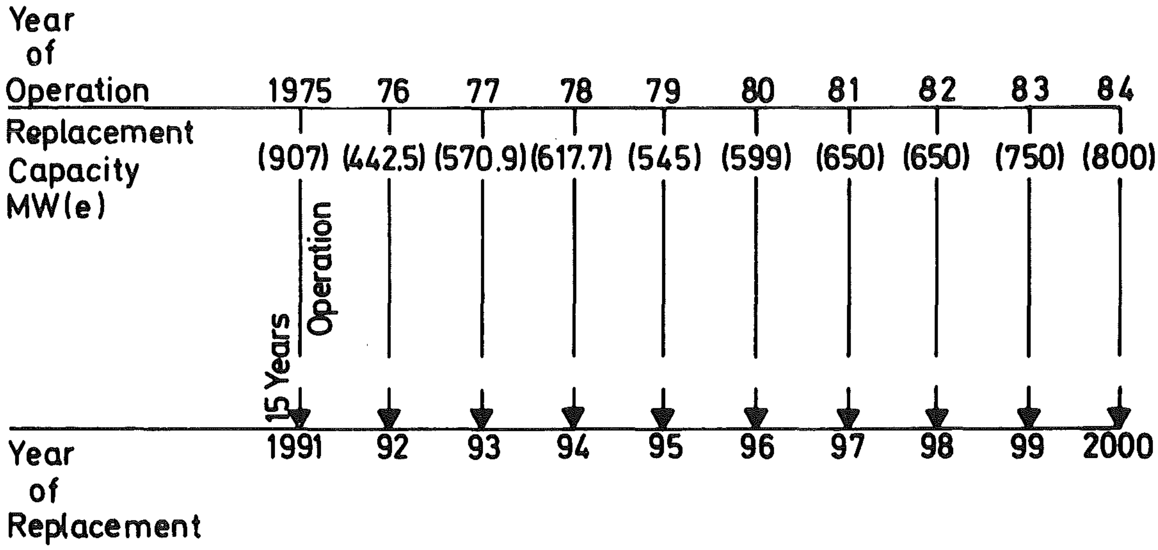


Figure 13: Results of the Water Projection Scenarios for the Period 1980-2000: District B

Electricity District A



Electricity District B

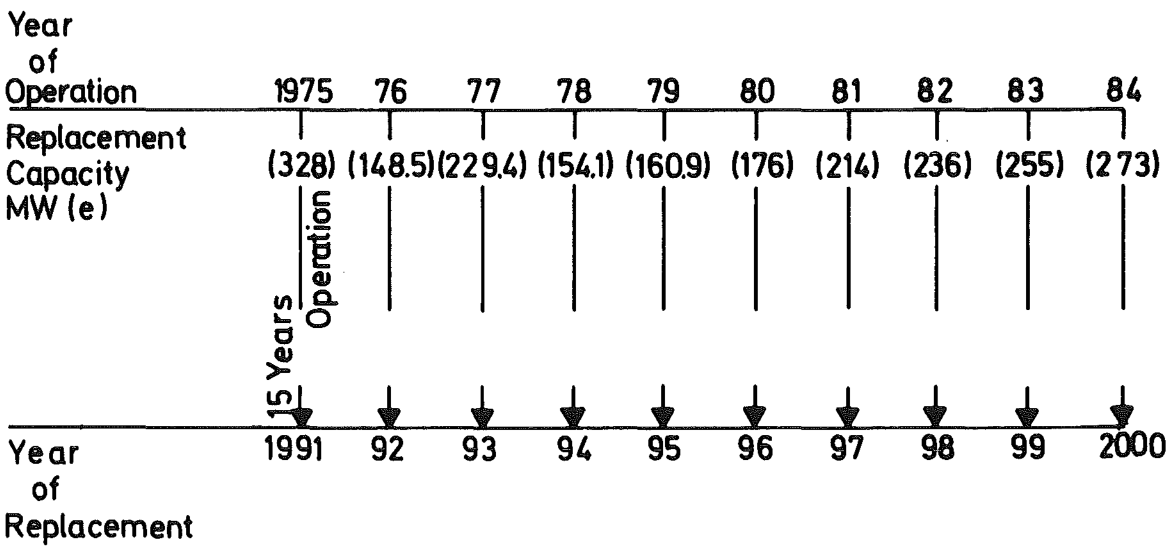


Figure 14: The Scheme for the Replacement of the Oil Fired Electrical Units in the Country

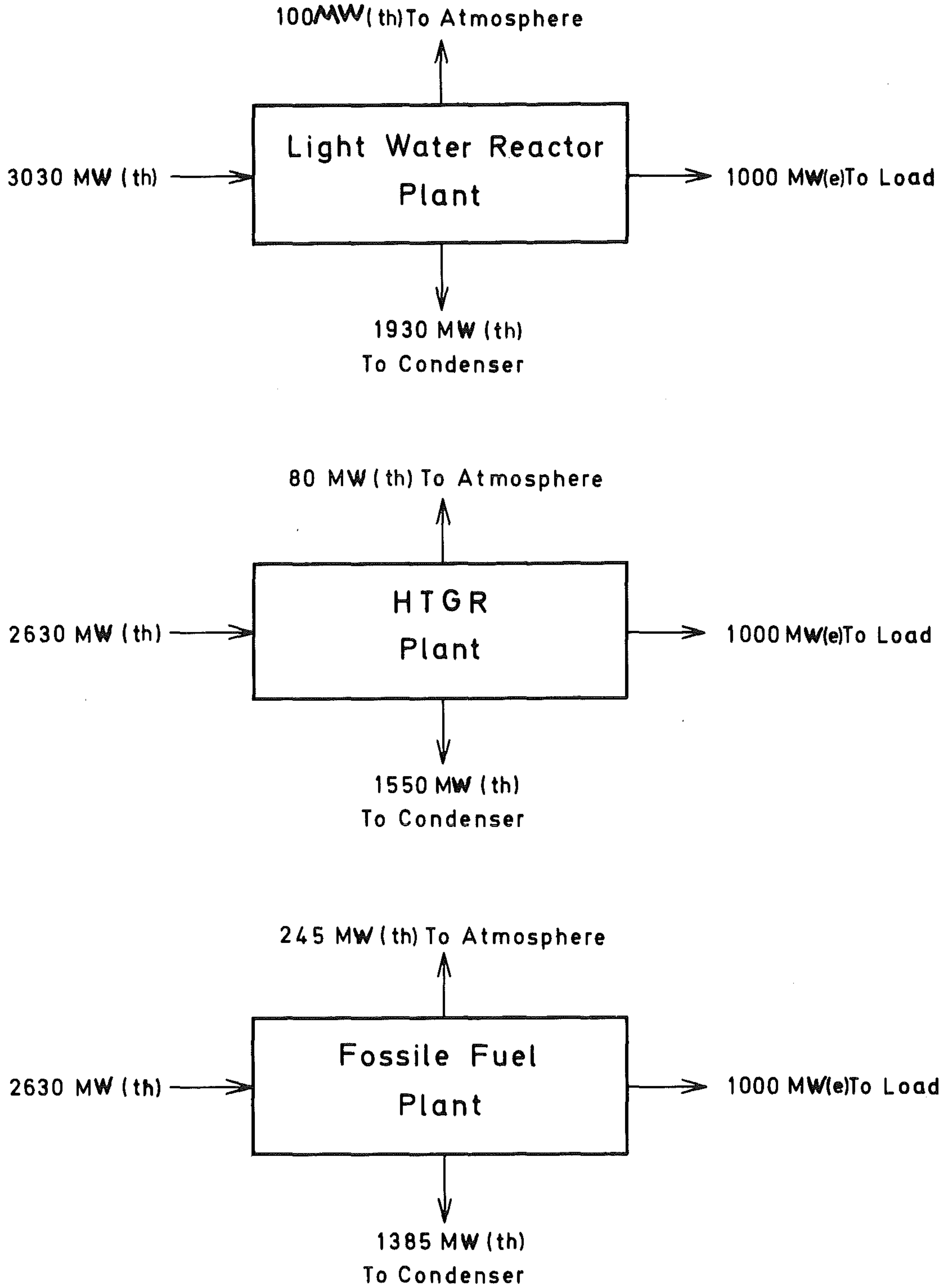


Figure 15: Comparison of the Waste Heat Discharge of Three Different Power Plants /8/

Note : The heat balance is based on the following assumptions : 1. 33% efficiency for LWR; 38% for HTGR and fossile fuelled plants. 2. 95% of the waste in LWR is carried off by the condenser, the rest are miscellaneous losses at different components, e.g. components cooling, primary water clean up, air conditioning, etc.

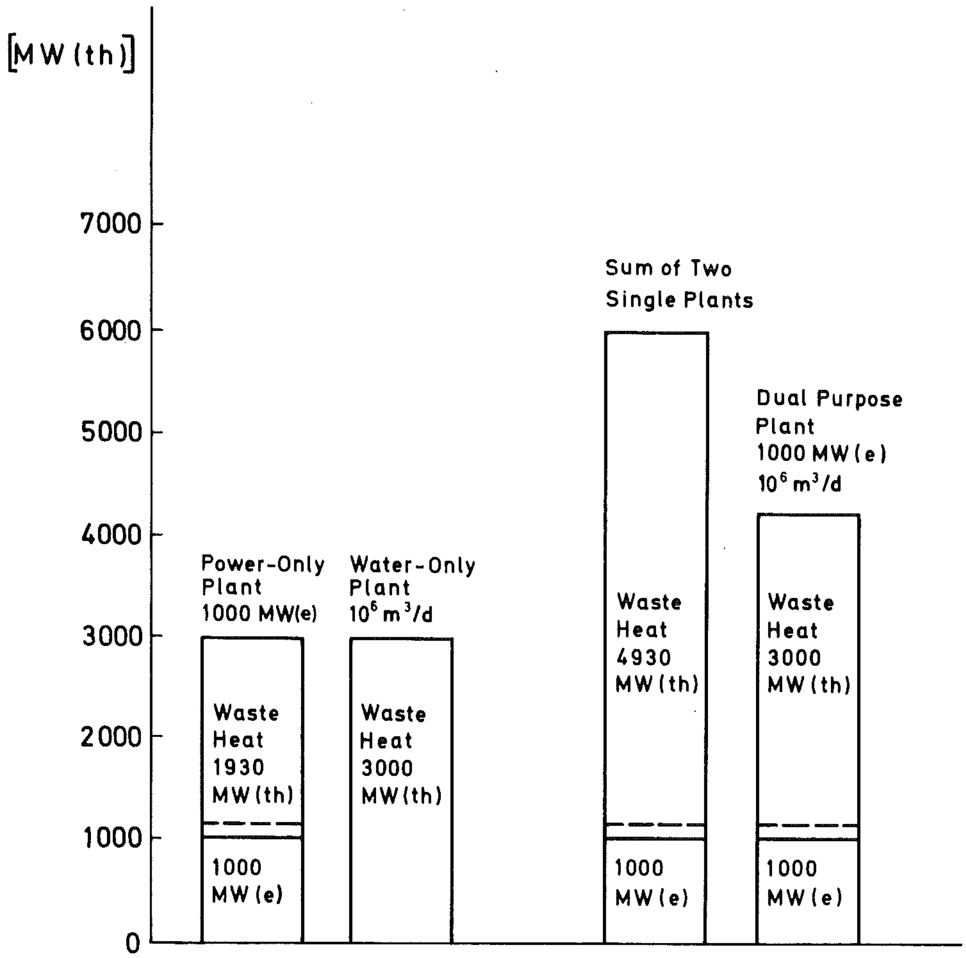


Figure 16: Waste Heat Discharge: A Comparison between a Single and Dual Production Plants /9/

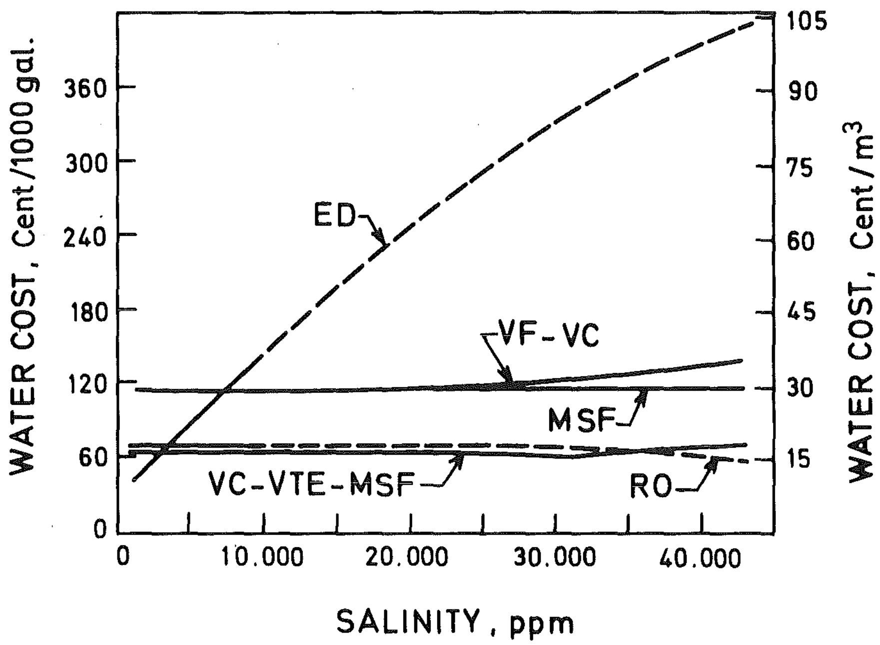


Figure 17: Desalted Water Production Cost in Relation to Water Salinity /23/

(Note: The dotted lines indicate the range of salinity which has not been demonstrate by the given process)

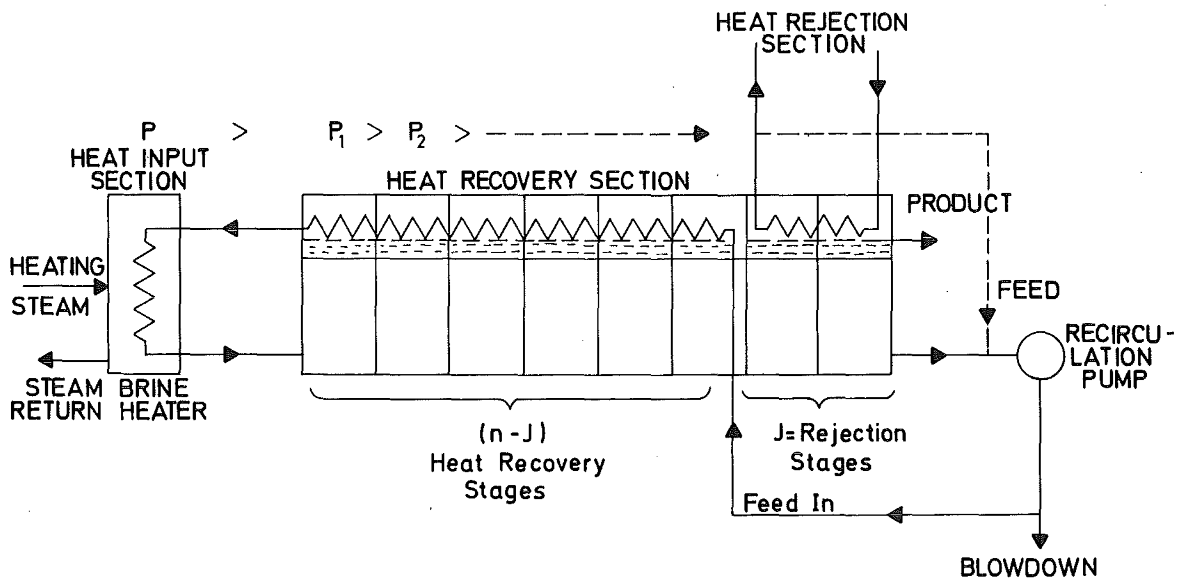


Figure 18: Schematics of the Multi Stage Flash Evaporation Plant

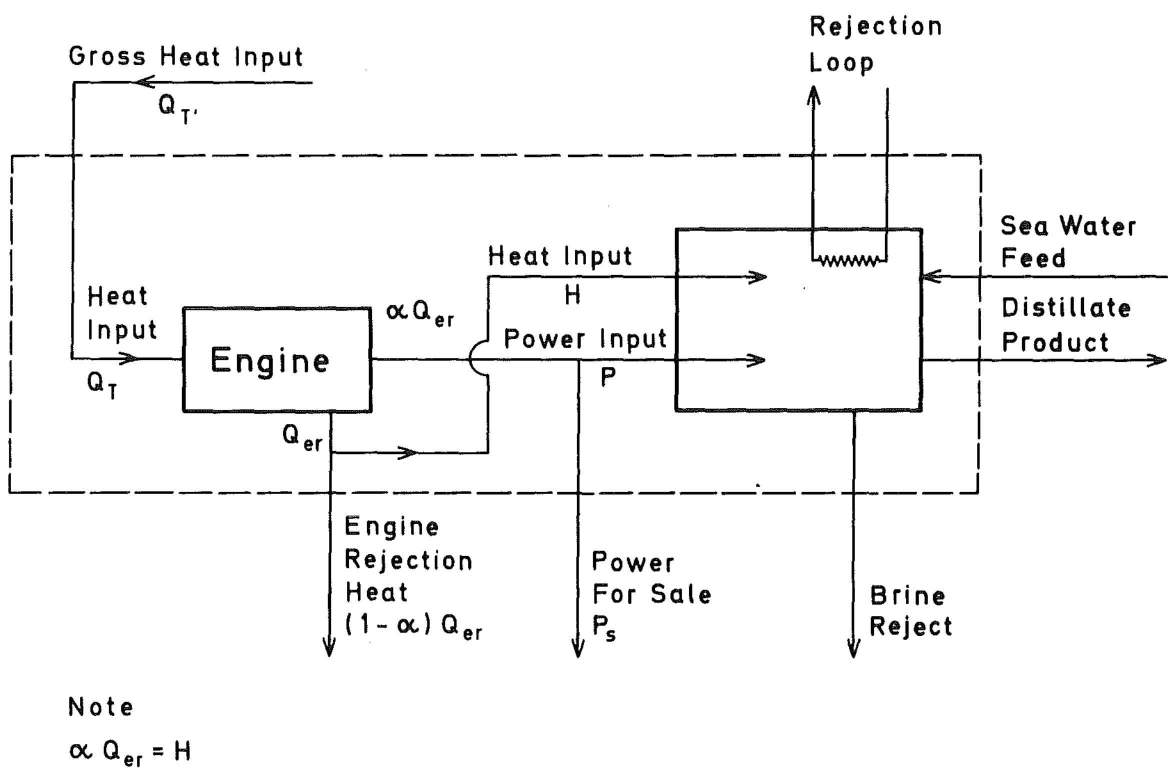


Figure 19: The Heat Balance for a Dual Production Plant /15/

East Coast

Year of Operation	1974	1977	1979	1980
Plant ε Replac. Power MW (th)	(1) KHOB-1 71.48 (2) KHAF-1 1.14	(1) JUB-1 22.60	(1) KHAF-2 47.66 (2) JUB-2 190.63	(1) KHOB-2 476.56
Total Replac. Power MW (th)	72.06	22.60	238.29	476.56
Year of Replac.	1990	1993	1995	1996

West Coast

Year of Operation	1970	1971	1976	1977	1979	1980
Plant ε Replac. Power MW (th)	(1) JED-1 47.66 (2) WAJ-1 0.572	(1) DUB-1 0.572	(1) WAJ 2 1.14 (2) DUB-2 1.14	(1) JED-2 95.3 (2) RAB-1 2.28 (3) FAR-1 1.14	(1) DUB-3 47.66 (2) YEN-1 47.66 (3) HAG-1 1.14 (4) HAG-2 14.30 (5) LTH-1 1.15 (6) QUN-1 9.53	(1) JED-3 190.63 (2) MED-1 190.63
Total Replac. Power MW (th)	48.23	0.572	2.28	98.72	238.29	381.26
Year of Replac.	1986	1987	1992	1993	1995	1996

Legend:

KHOB = Al-Khabar
JUB = Jubail
KHAF = Al-Khafji
JED = Jeddah
DUB = Duba
WAJ = Al-Wajh
RAB = Rabig
FAR = Farasan
YEN = Yenbu
HAG = Hagel
LTH = Al-Lith
QUN = Al-Qunfuda
MED = Al-Medina

Figure 20: The Scheme for the Replacement of the Heat Source of the Desalination Plants in Operation up to 1980

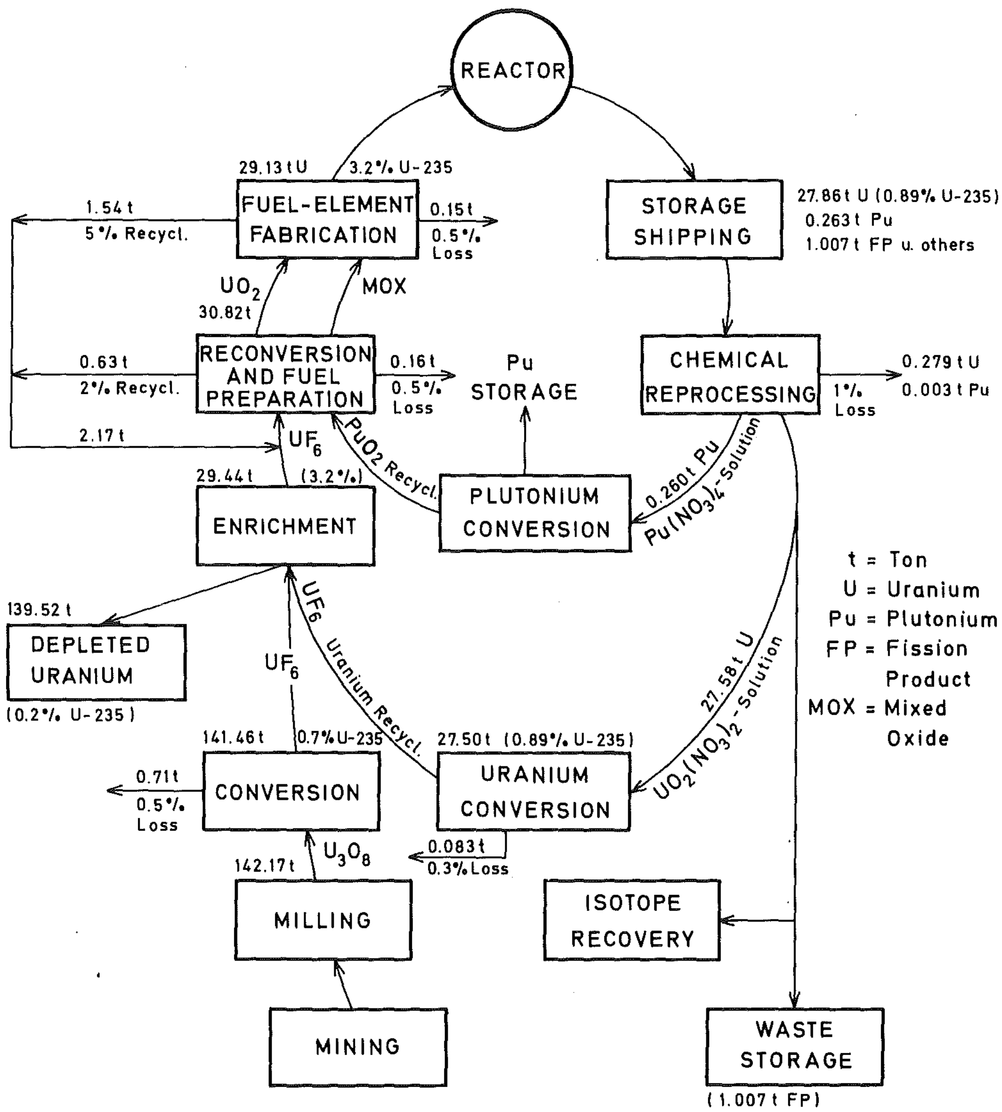


Figure 21: The Complete Nuclear Fuel Cycle of the Proven Reactor System

(Note: 1. The natural uranium reactors (e.g. HWR and Magnox) do not require enrichment. With these reactors, however, uranium recycling is not possible.

2. The numerals given in the figure are for a PWR of 1000 MW(e), 33000 MWd/t burn up, 32 % efficiency, and 85 % load factor /43/.

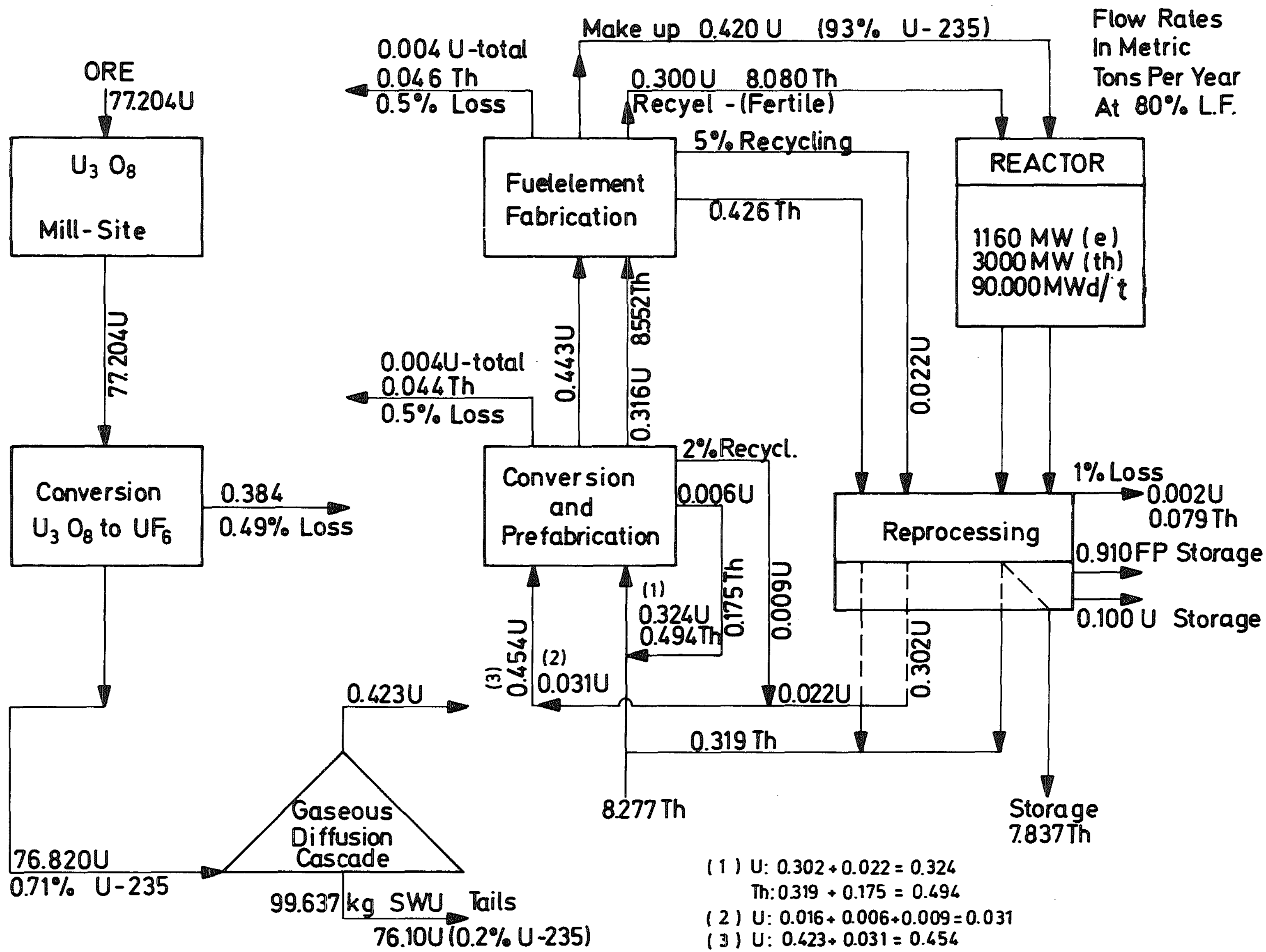


Figure 22: The Nuclear Fuel Cycle for a 1160 MW(e) HTGR at Equilibrium /43/

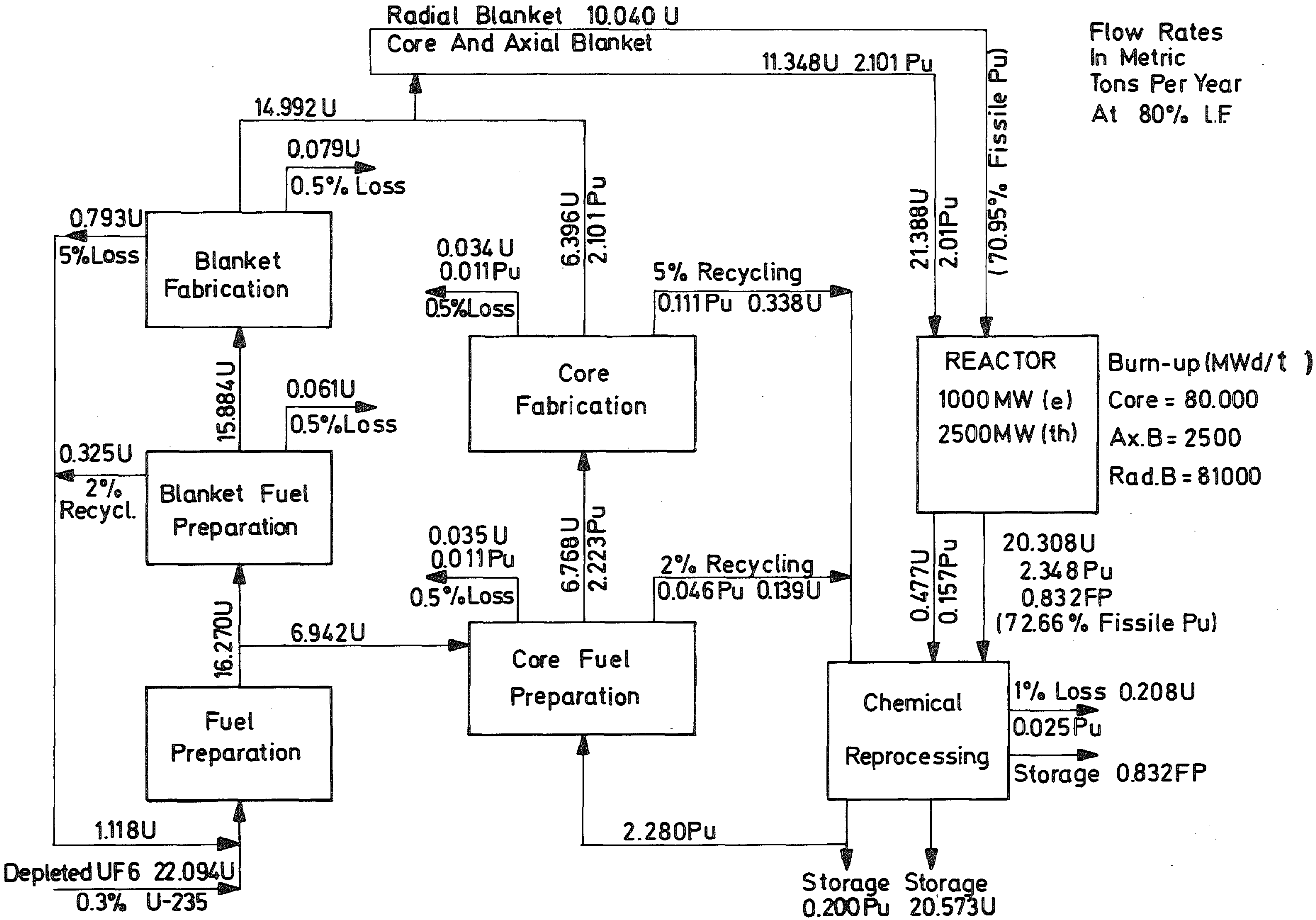


Figure 23: The Nuclear Fuel Cycle for a 1000 MW(e) LMFBR at Equilibrium /43/

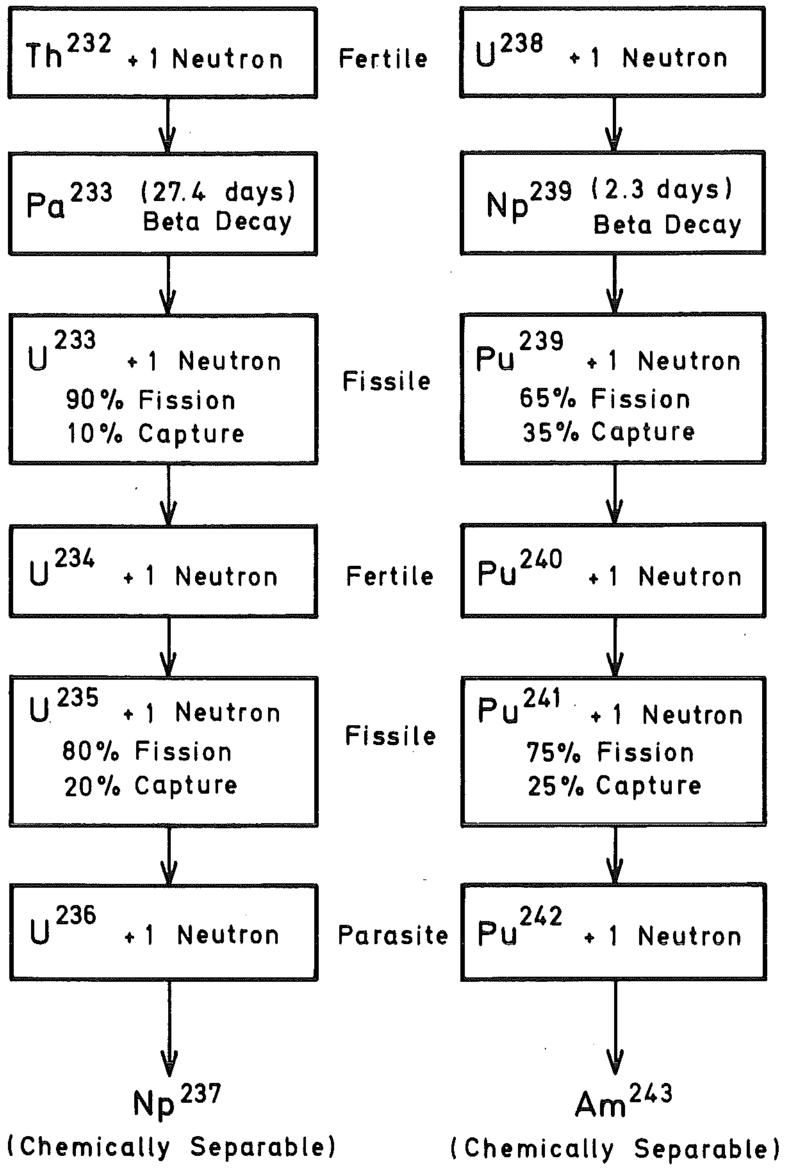


Figure 24: The Isotopic Build Up Chains in Th-232 and U-238 Nuclear Fuels /39/

Note: Th-232 chain differs from the U-238 chain in one important respect: The precurser of the bred U-2333, namely Pa-233 has the half-live of 27 days and a significant neutron absorption cross section.

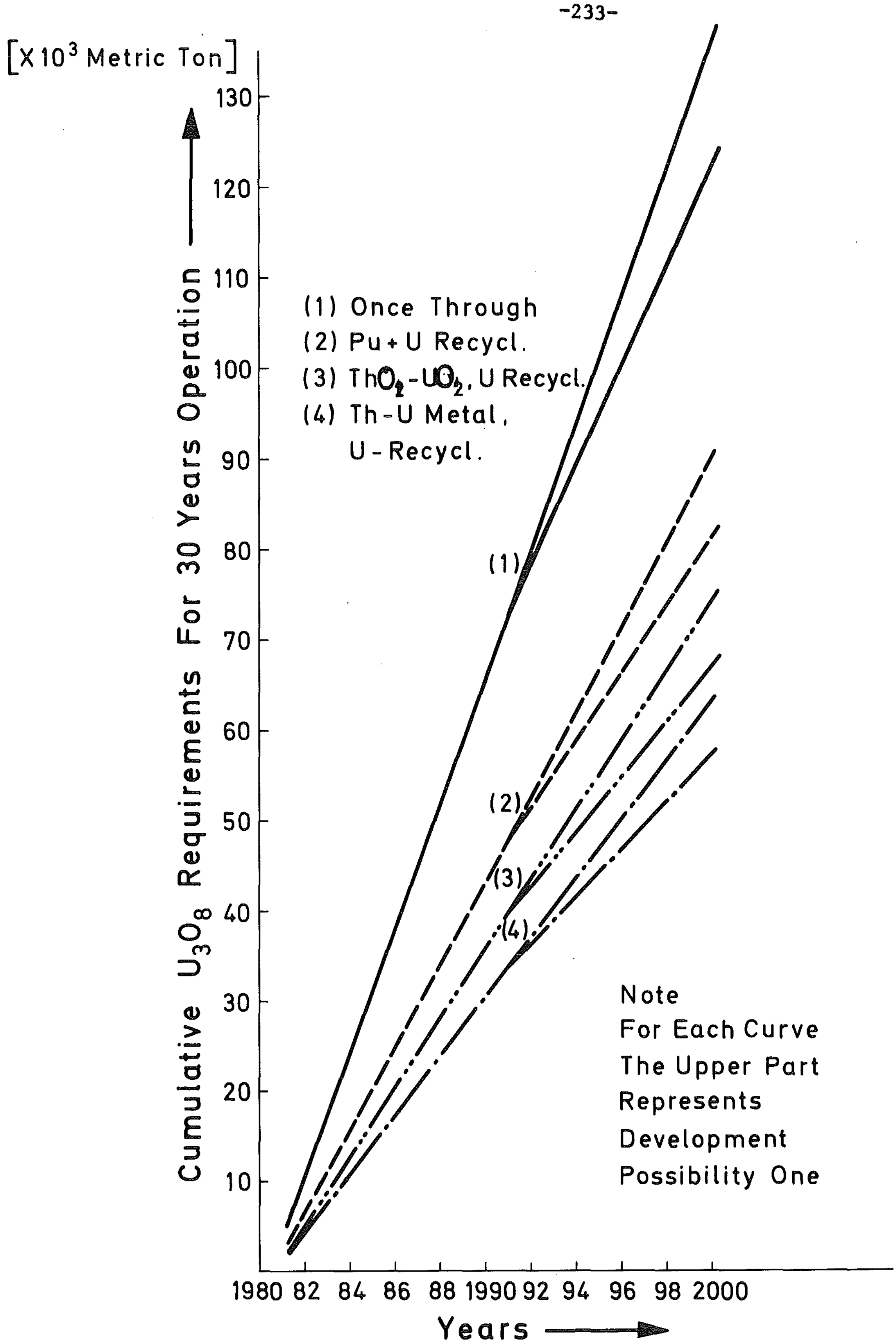


Figure 25: The Cumulative U_3O_8 Requirement for 30 Years Operation Life Time: A Comparison between the Selected Fuel Cycle Alternatives of the PWR System

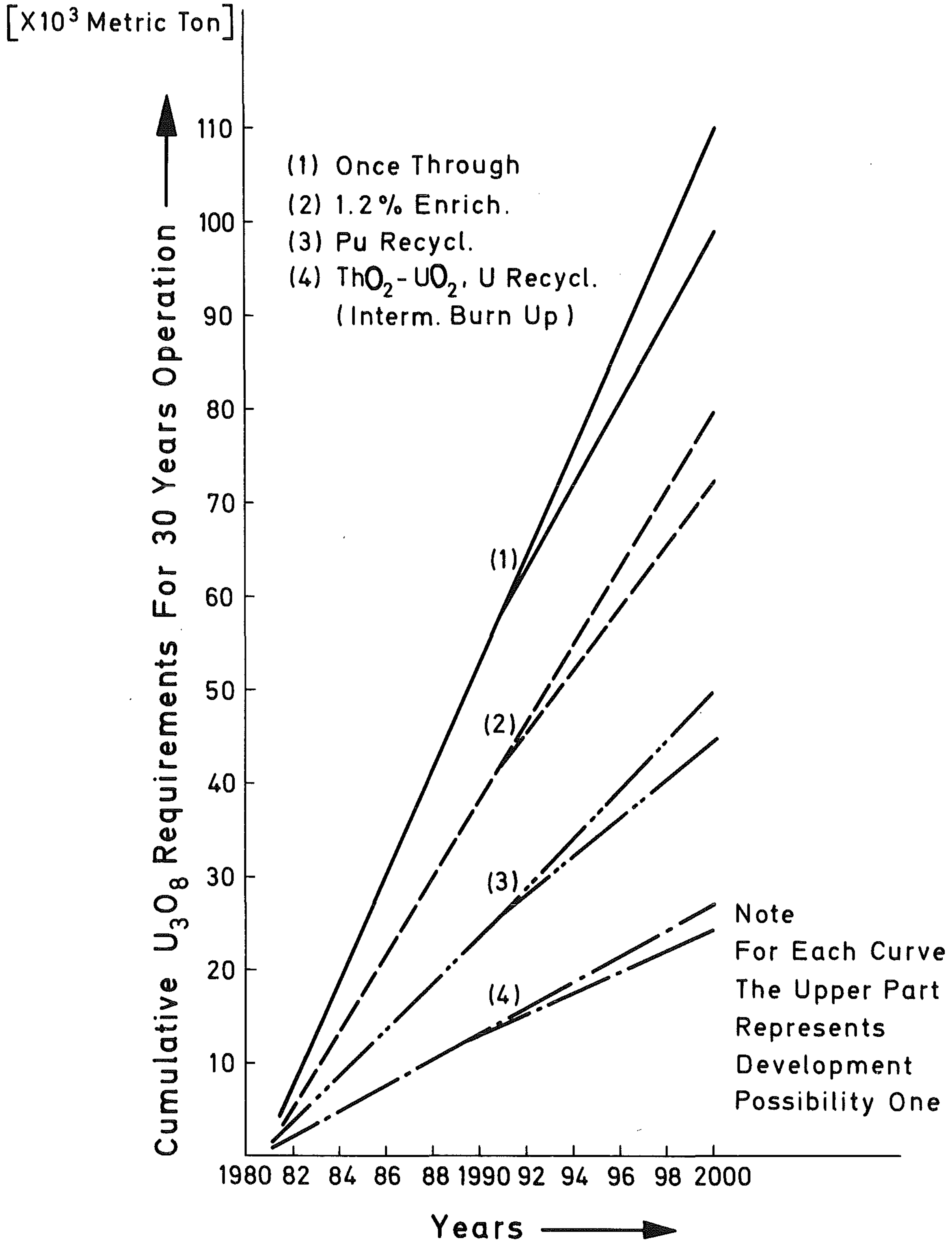


Figure 26: The Cumulative U_3O_8 Requirement for 30 Years Operation Life Time: A Comparison between the Selected Fuel Cycle Alternatives of the Candu-PHWR System

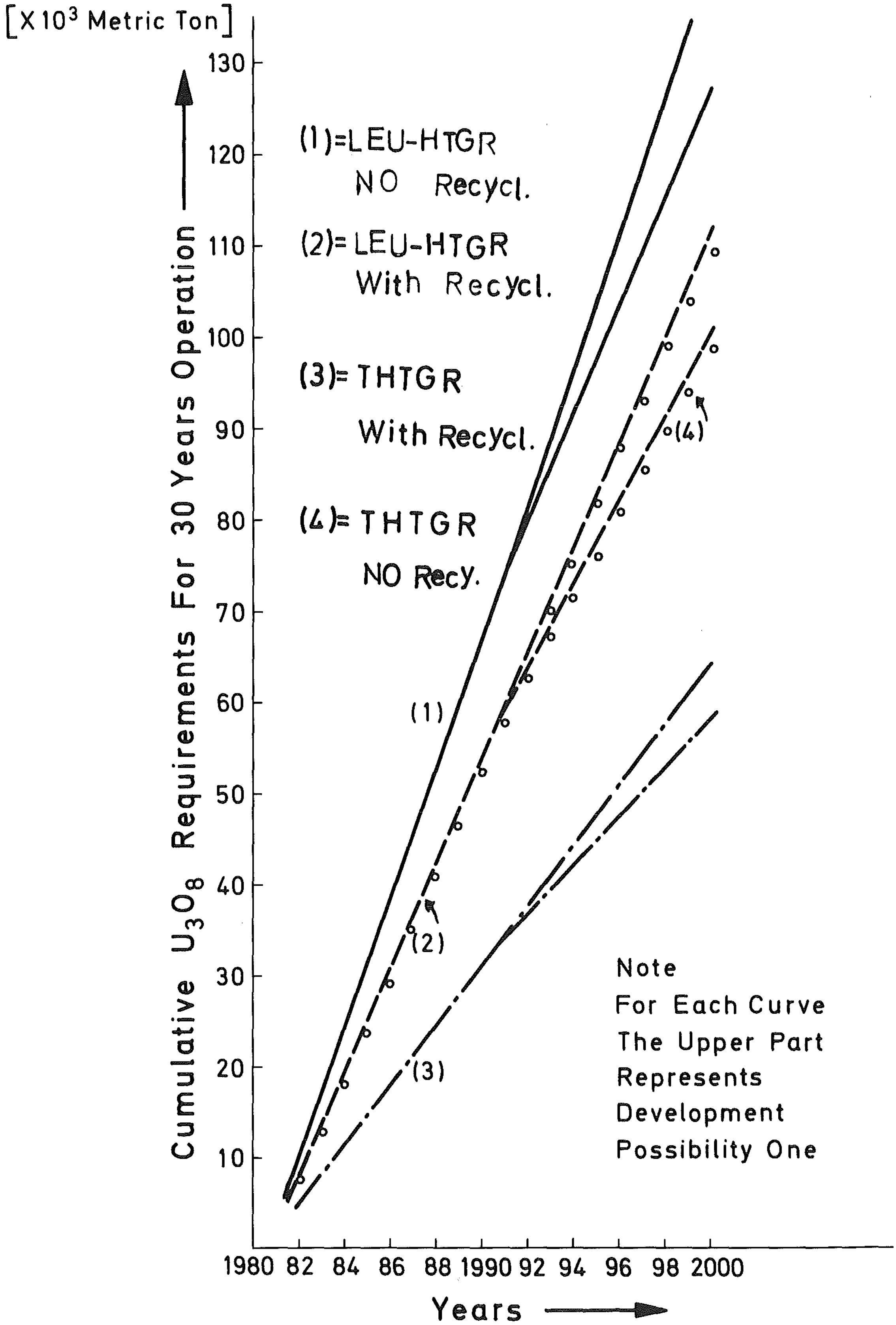


Figure 27: The Cumulative U_3O_8 Requirement for 30 Years Operation Life Time: A Comparison between the Selected Fuel Cycle Alternatives of the HTGR System

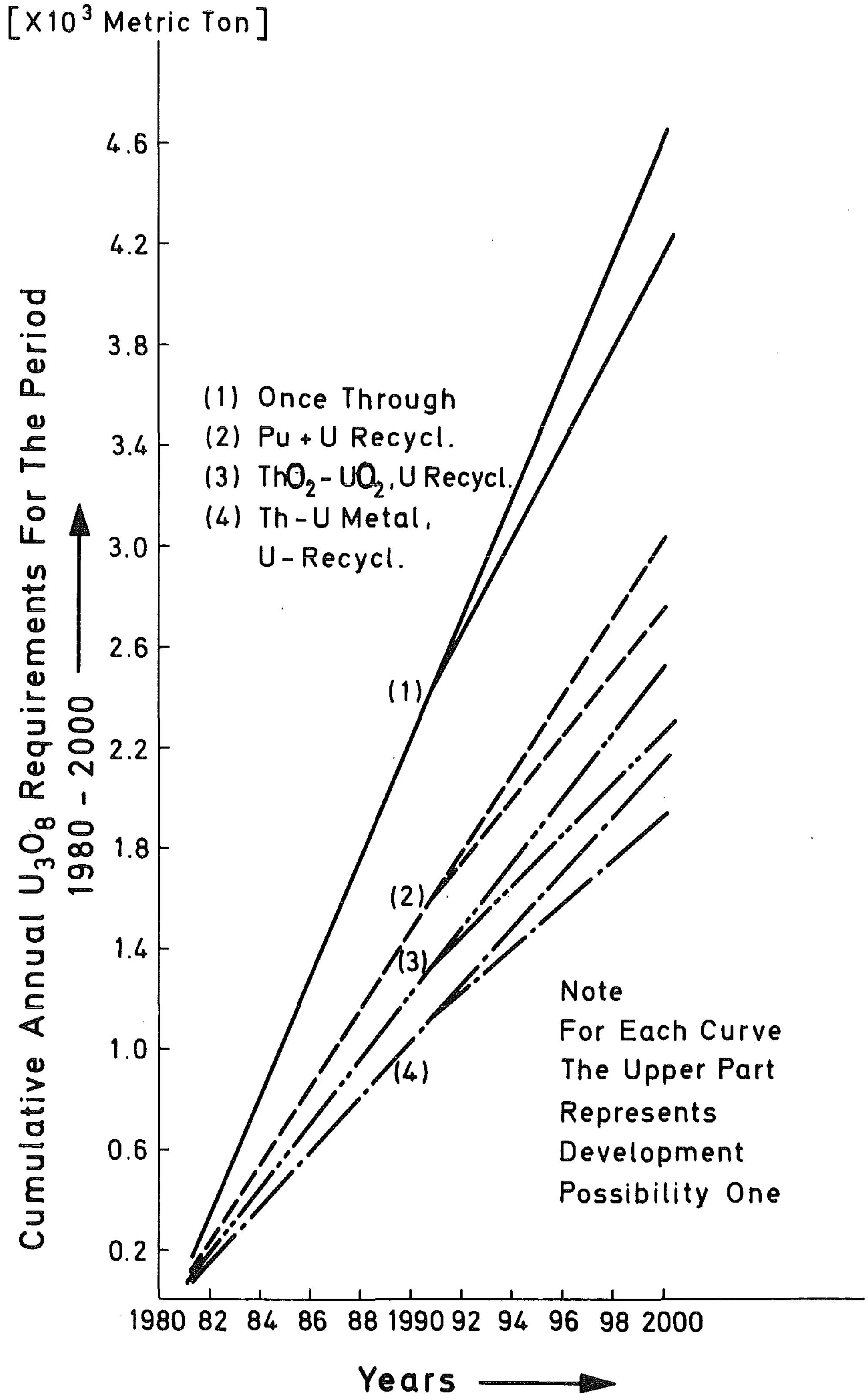


Figure 28: The Cumulative Annual U_3O_8 Requirement for the Operation Period of 1980-2000 Only: A Comparison between the Selected Fuel Cycle Alternatives of the PWR System

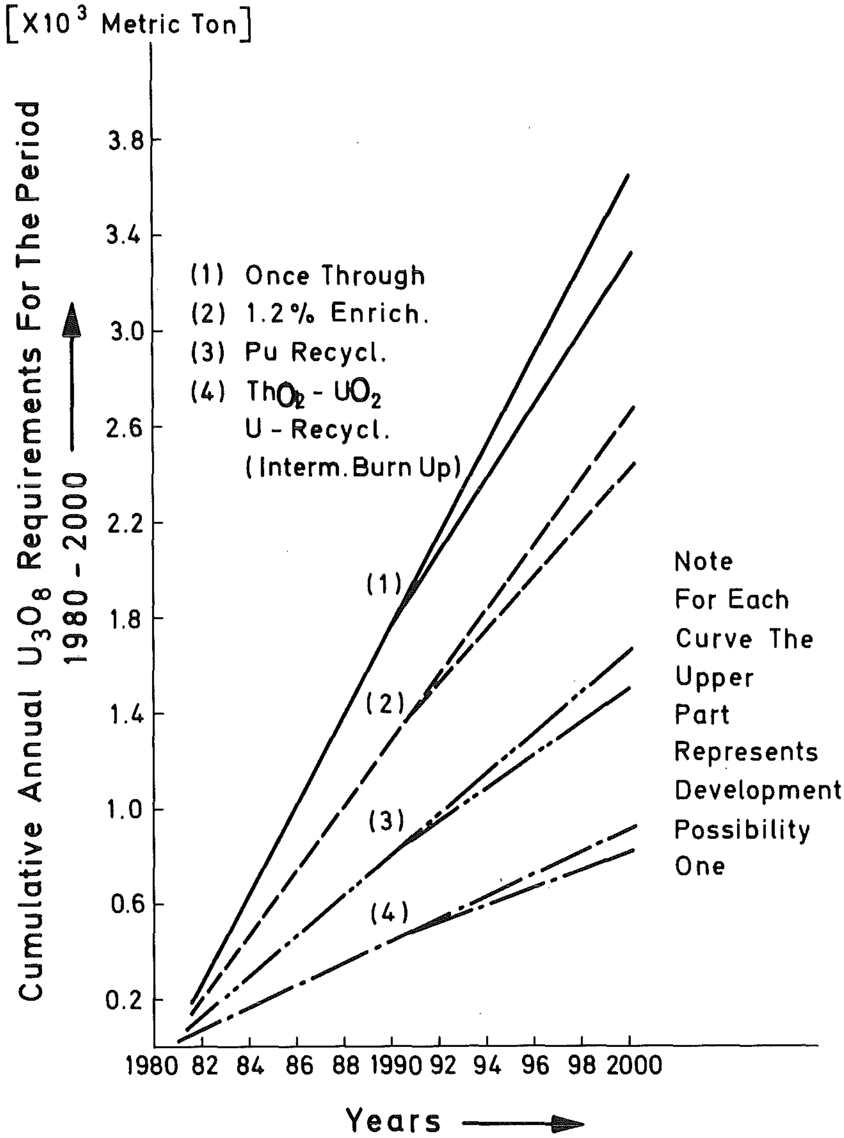
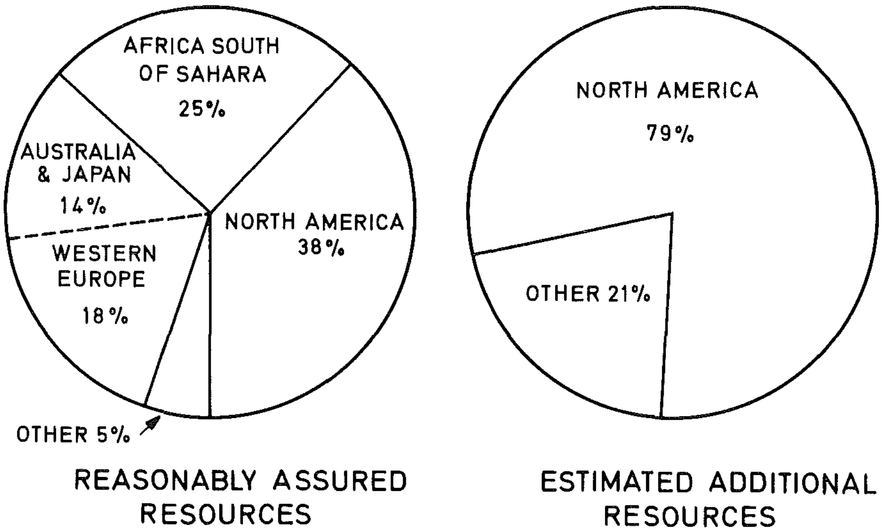


Figure 29: The Cumulative Annual U_3O_8 Requirement for the Operation Period of 1980-2000 Only: A Comparison between the Selected Fuel Cycle Alternatives of the Candu-PHWR System



(ton uranium)	World Region	(ton uranium)
825,000	1. North America	1'709,000
389,000	2. Western Europe	95,400
303,700	3. Australia, N.Z. & Japan	49,000
64,800	7. Latin America	66,200
32,100	8. Middle East & N. Africa	69,600
544,000	9. Africa S. of Sahara	162,900
3,000	10. East Asia	400
29,800	11. South Asia	23,700
2'191,700	Total World	2'176,200

Figure 30: Estimated World Resources of Uranium Recoverable at Costs up to $ 130/kg U as of January 1977 /56/

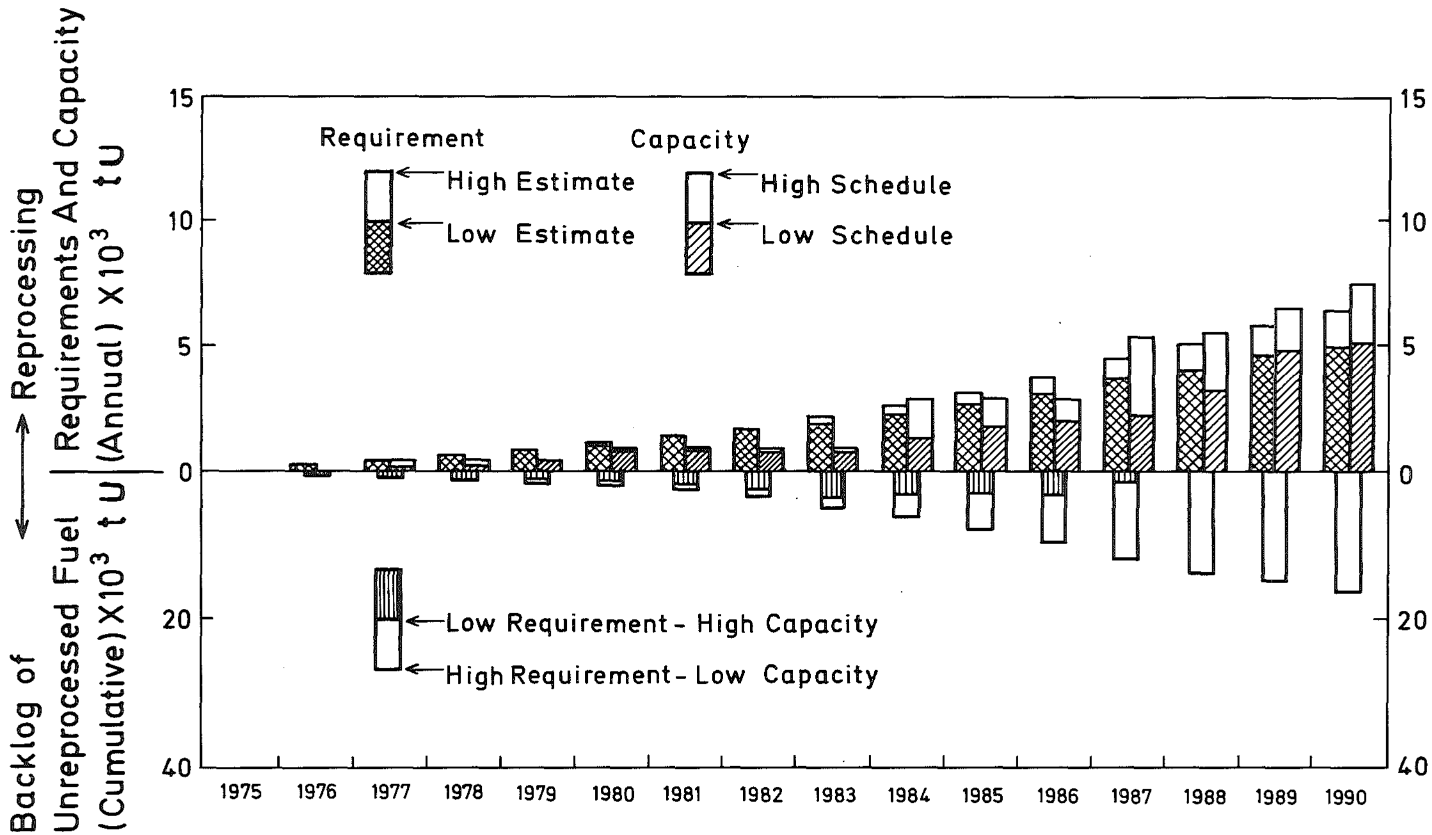


Figure 31: Reprocessing Requirement and Capacity in the OECD Countries, European Region /45/

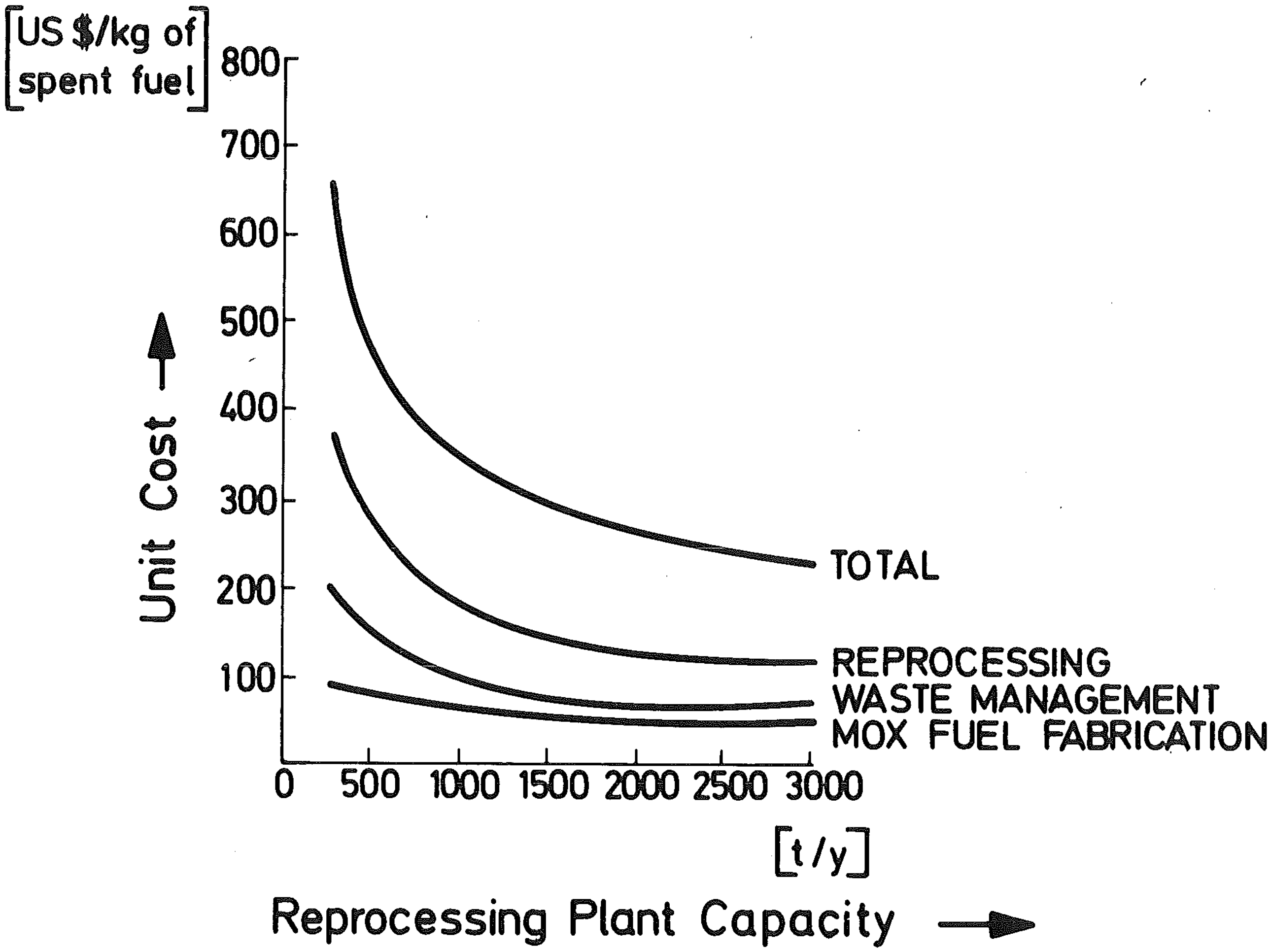


Figure 32: Economy of Scale Effect on Unit Cost of Reprocessing, MOX Fuel Fabrication, and Waste Management (Cost Per kg of Spent Fuel Element Reprocessed) /44/

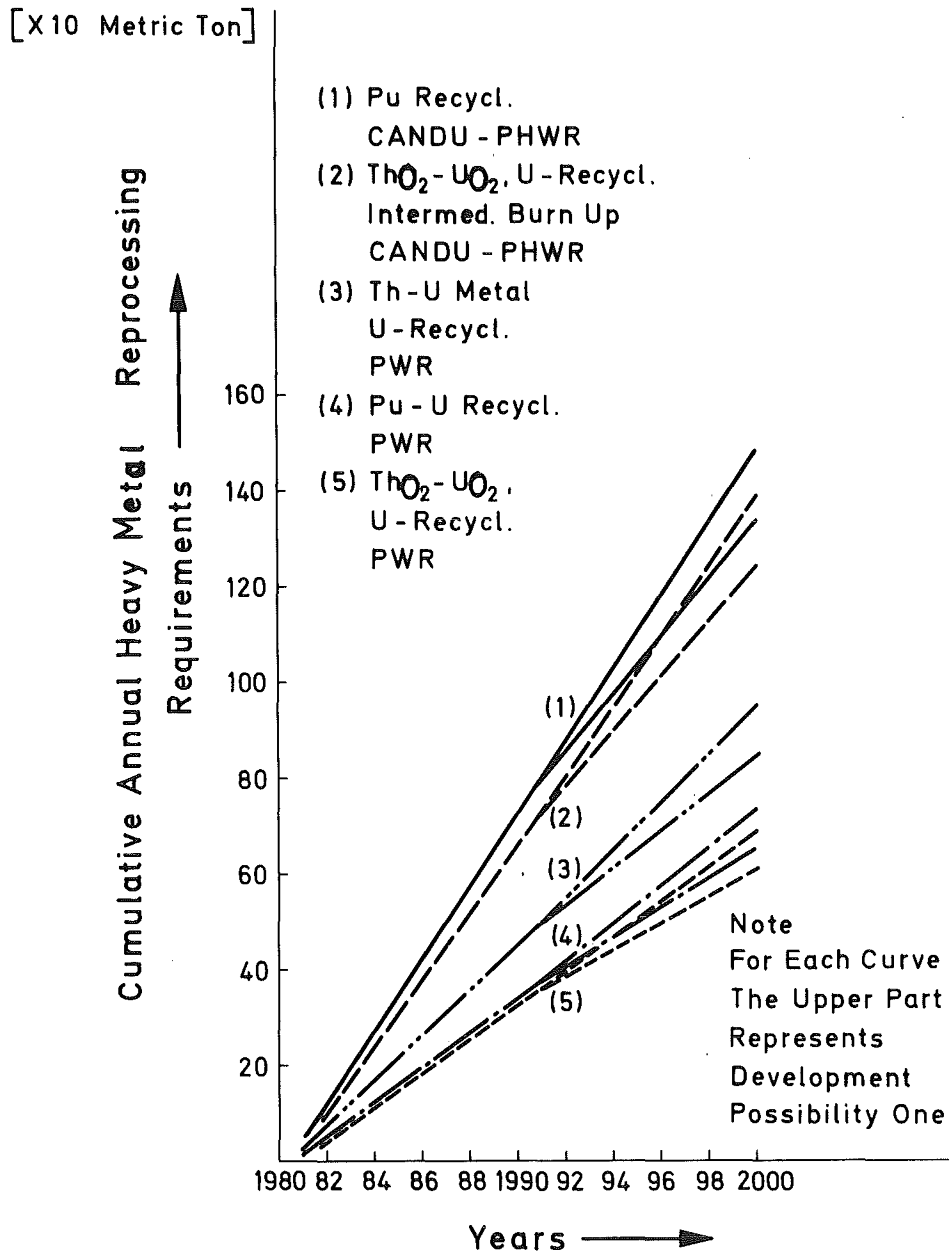


Figure 33: The Cumulative Heavy Metal Reprocessing Requirement for the Operation Period of 1980-2000 Only: A Comparison between the Selected Fuel Cycle Alternatives of PWR-System and Candu-PHWR System

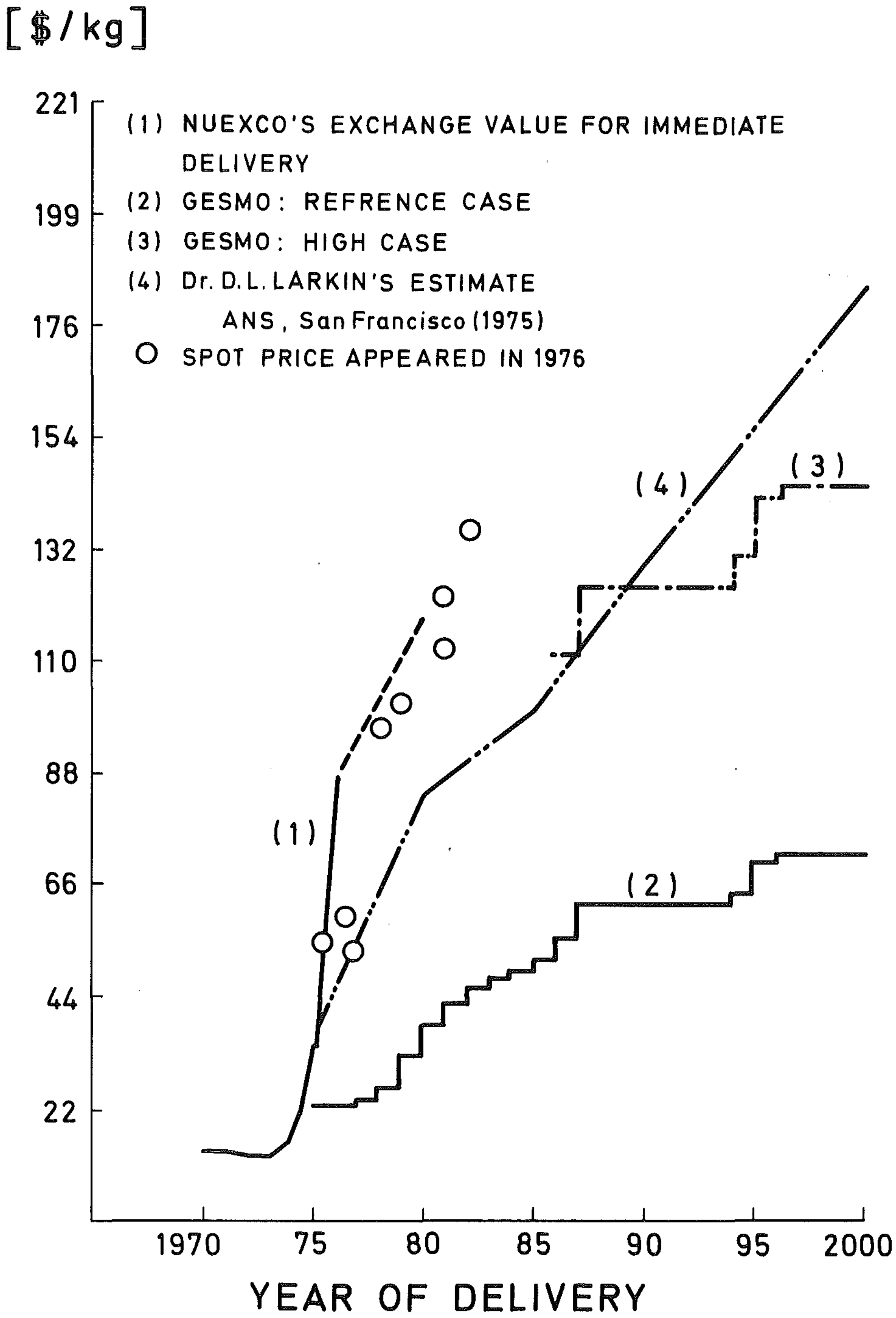


Figure 34: Historical Development of the Price for U_3O_8 /47/

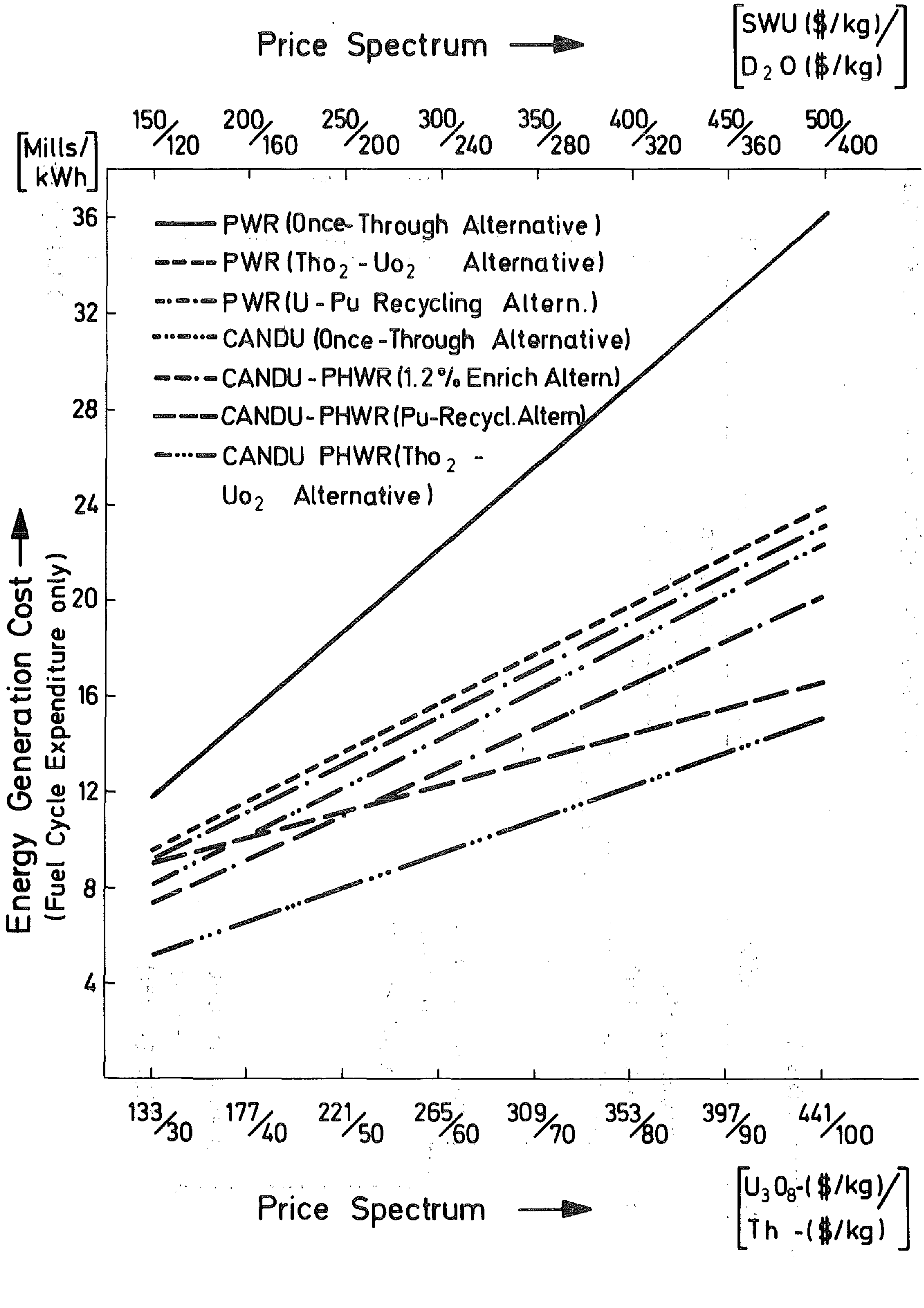


Figure 35: The Nuclear Fuel Cycle Cost in Relation to the Increasing Prices of Uranium, Thorium, Separative Work Unit, and Heavy Water: A Comparison between the Selected Fuel Cycle Alternatives of the PWR System and the Candu-PHWR System

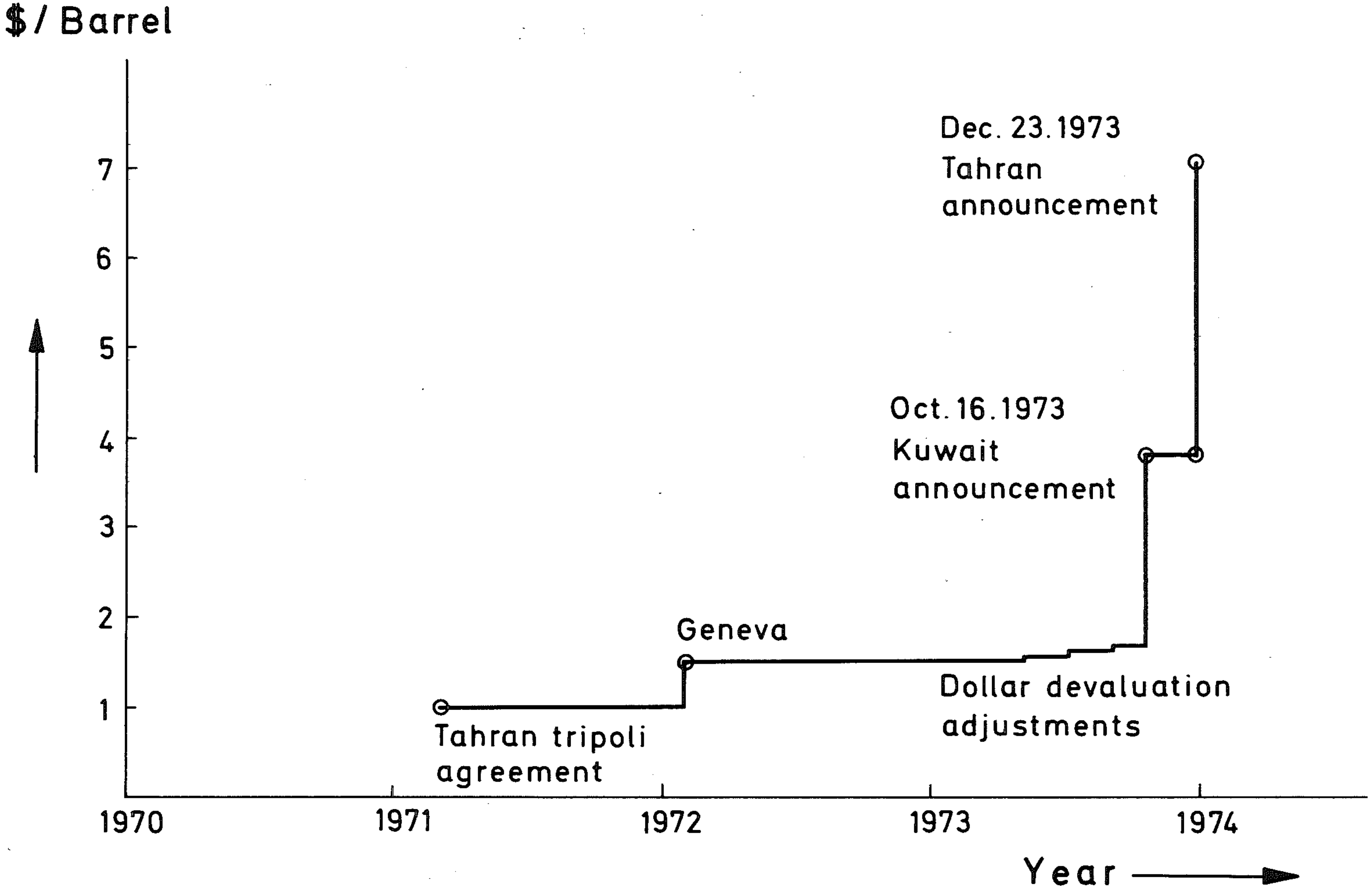


Figure 36: Oil Price Explosion /49, 51/

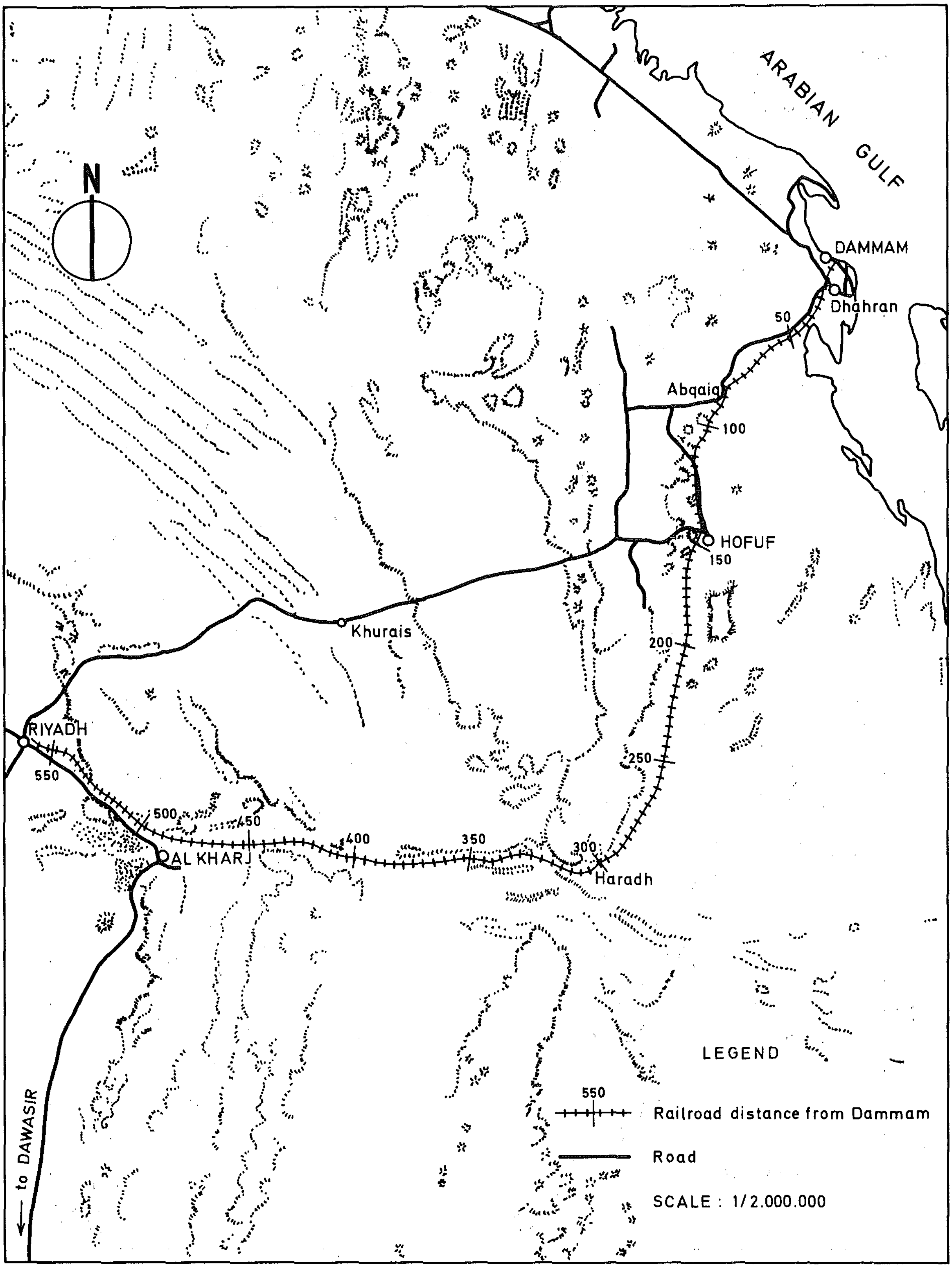


Figure 37: Rail Road Connection between Riyadh and Dahran

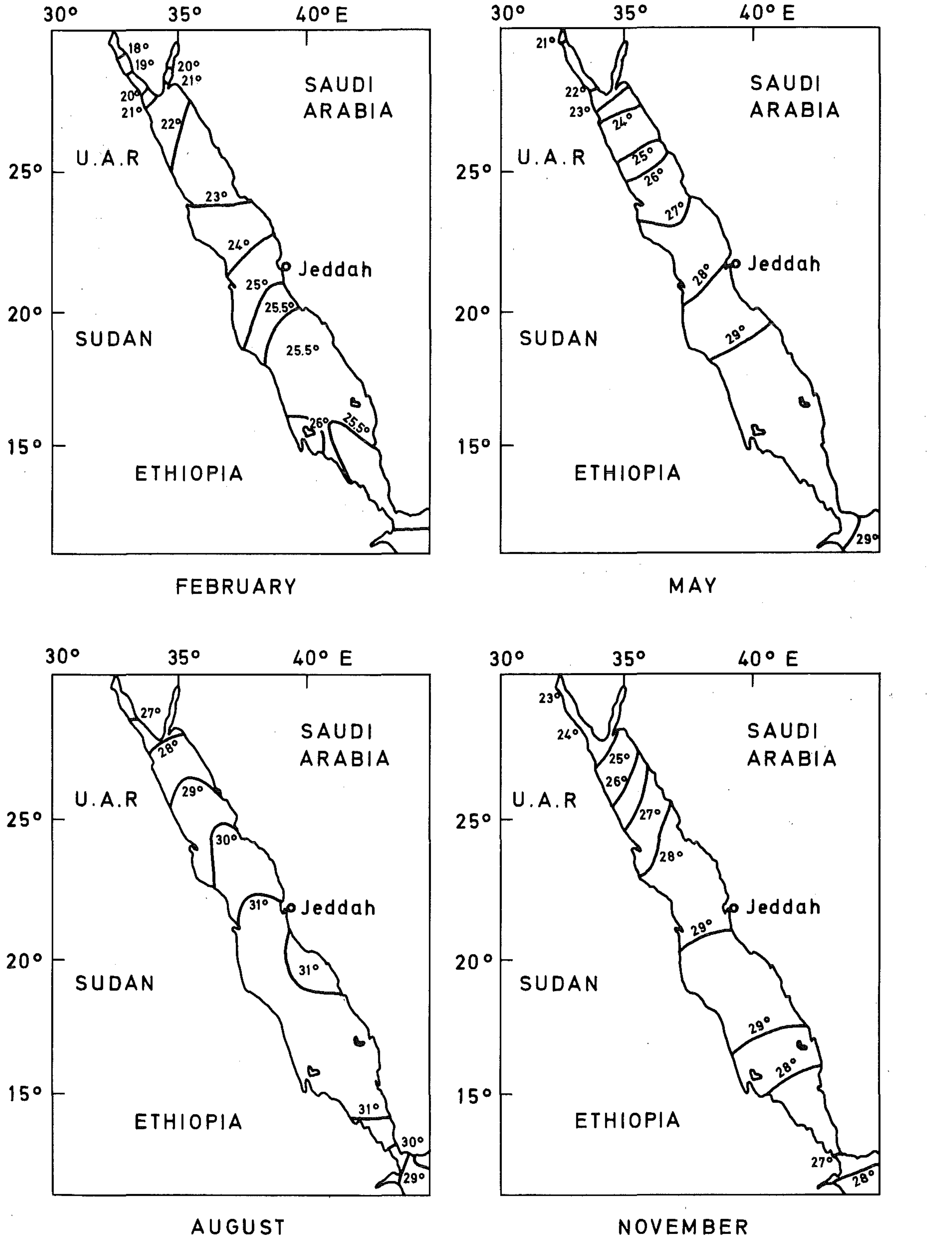


Figure 38-a : Surface Water Temperature Conditions in the Red Sea (in °C)

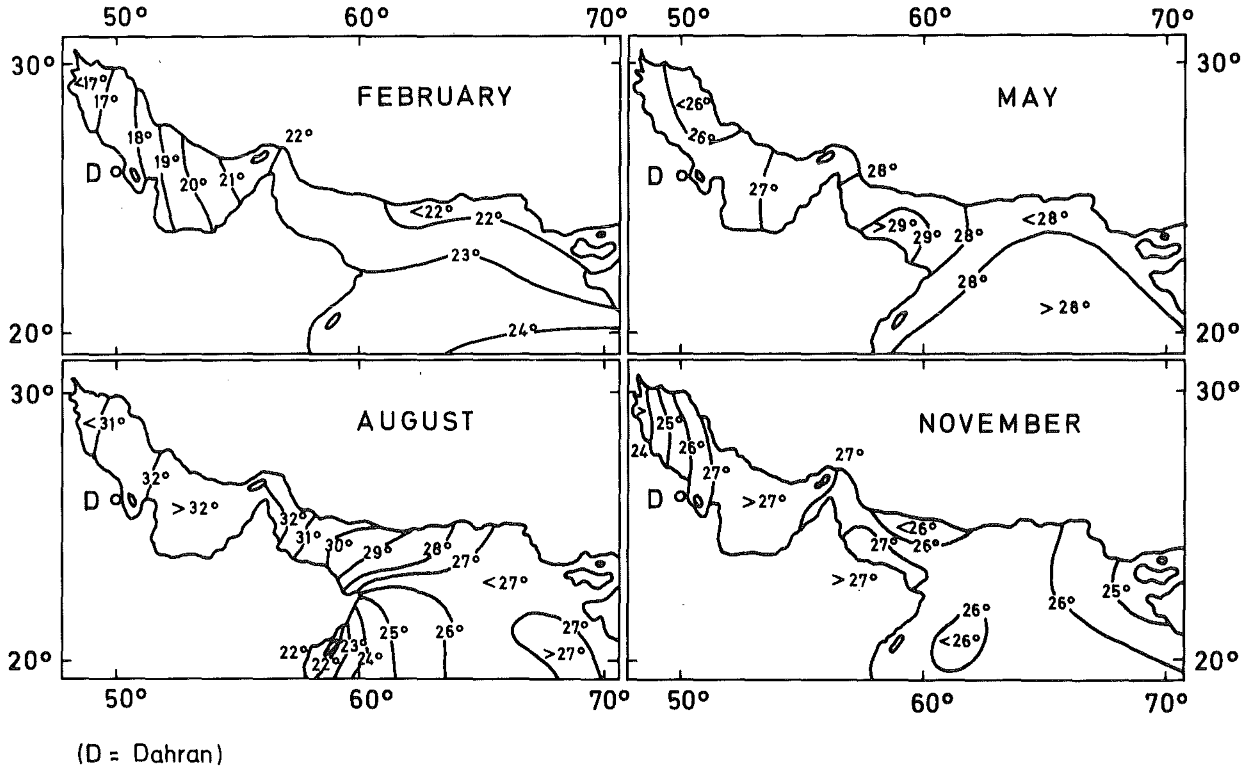


Figure 38-b : Surface Water Temperature Conditions in the Arabian-Persian Gulf (in °C)

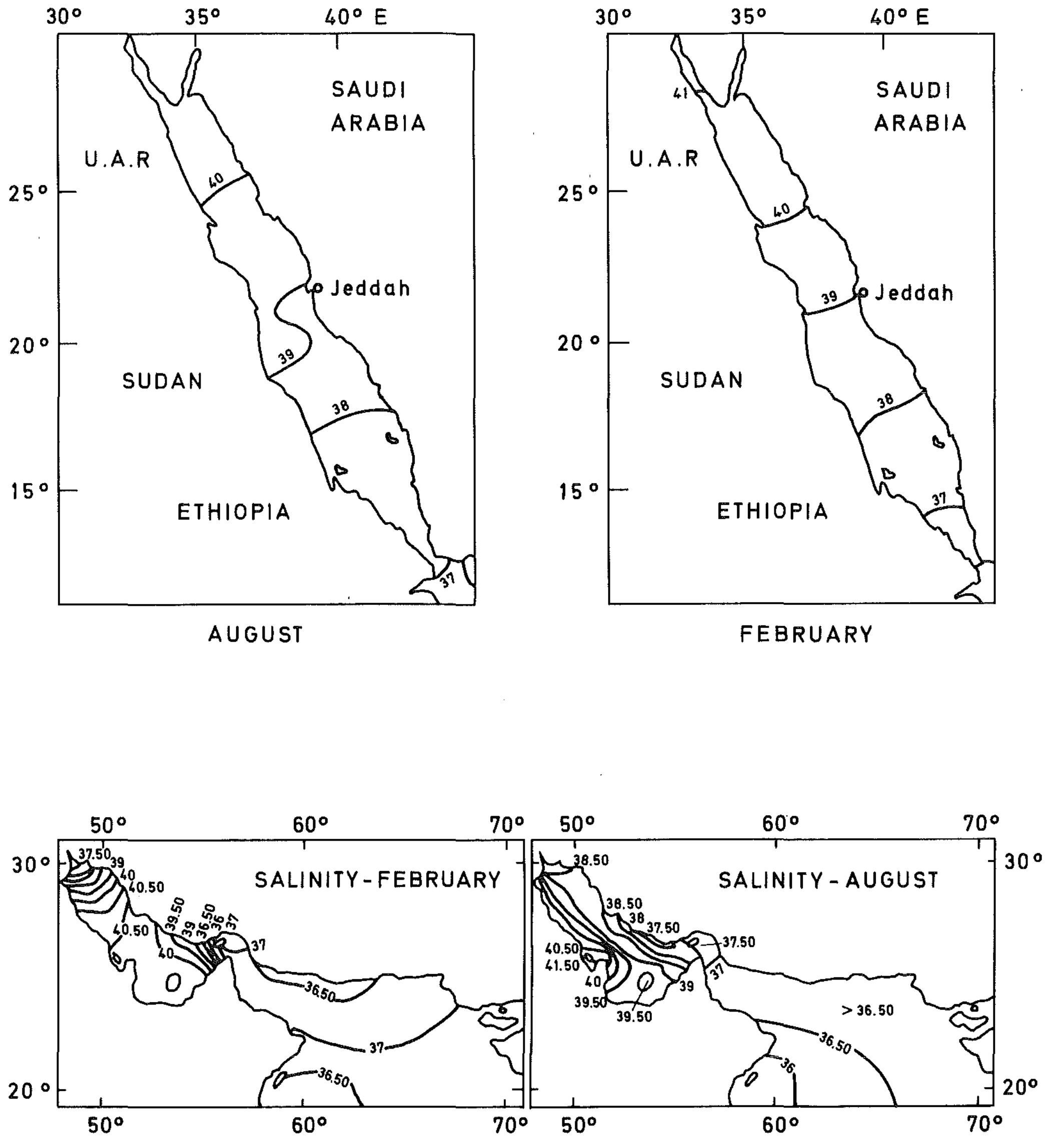


Figure 39: Salinity Conditions in the Red Sea and the Arabian-Persian Gulf (in ‰)

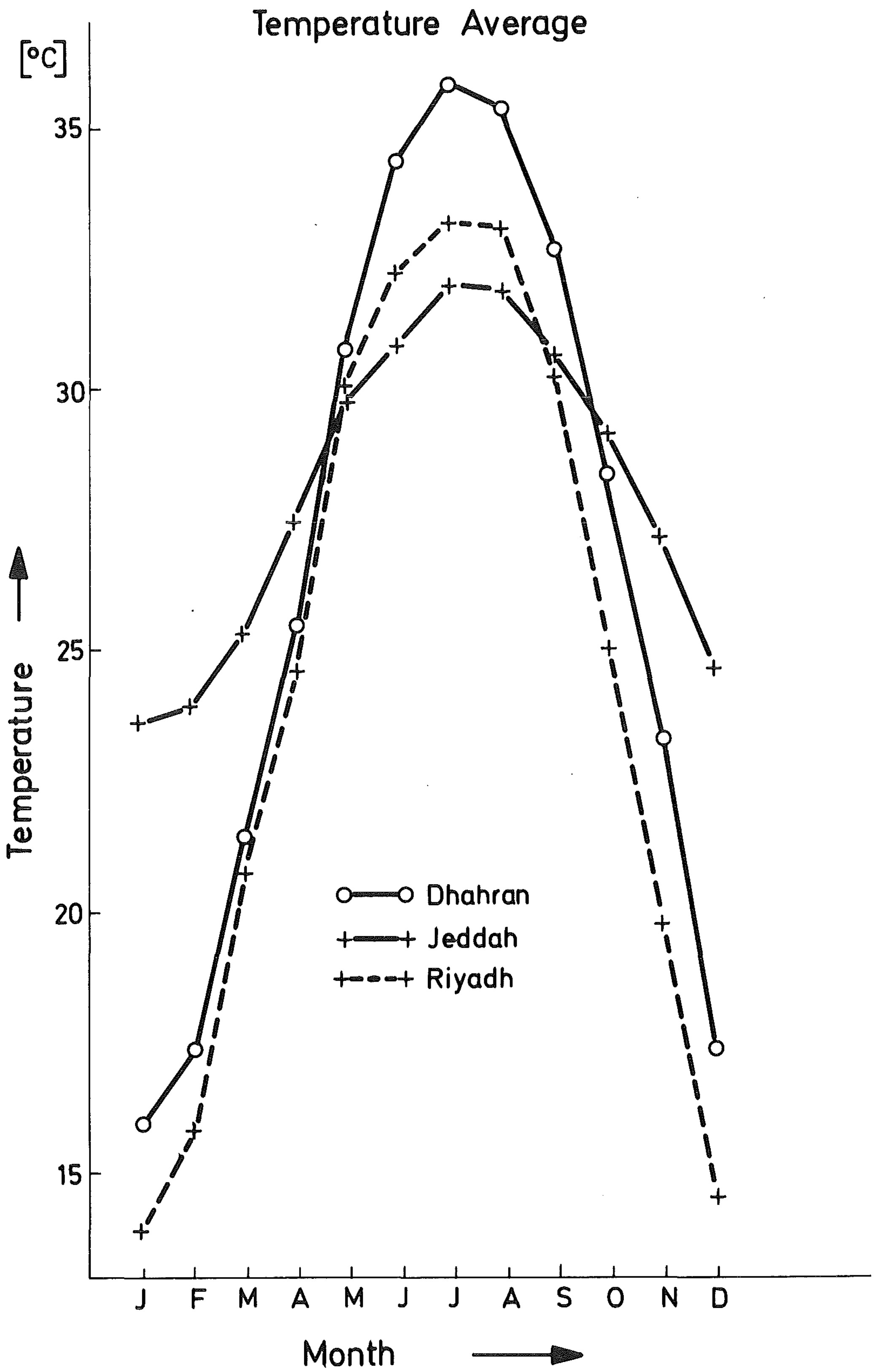


Figure 40: Recorded Monthly Values for the Average Temperature /68/

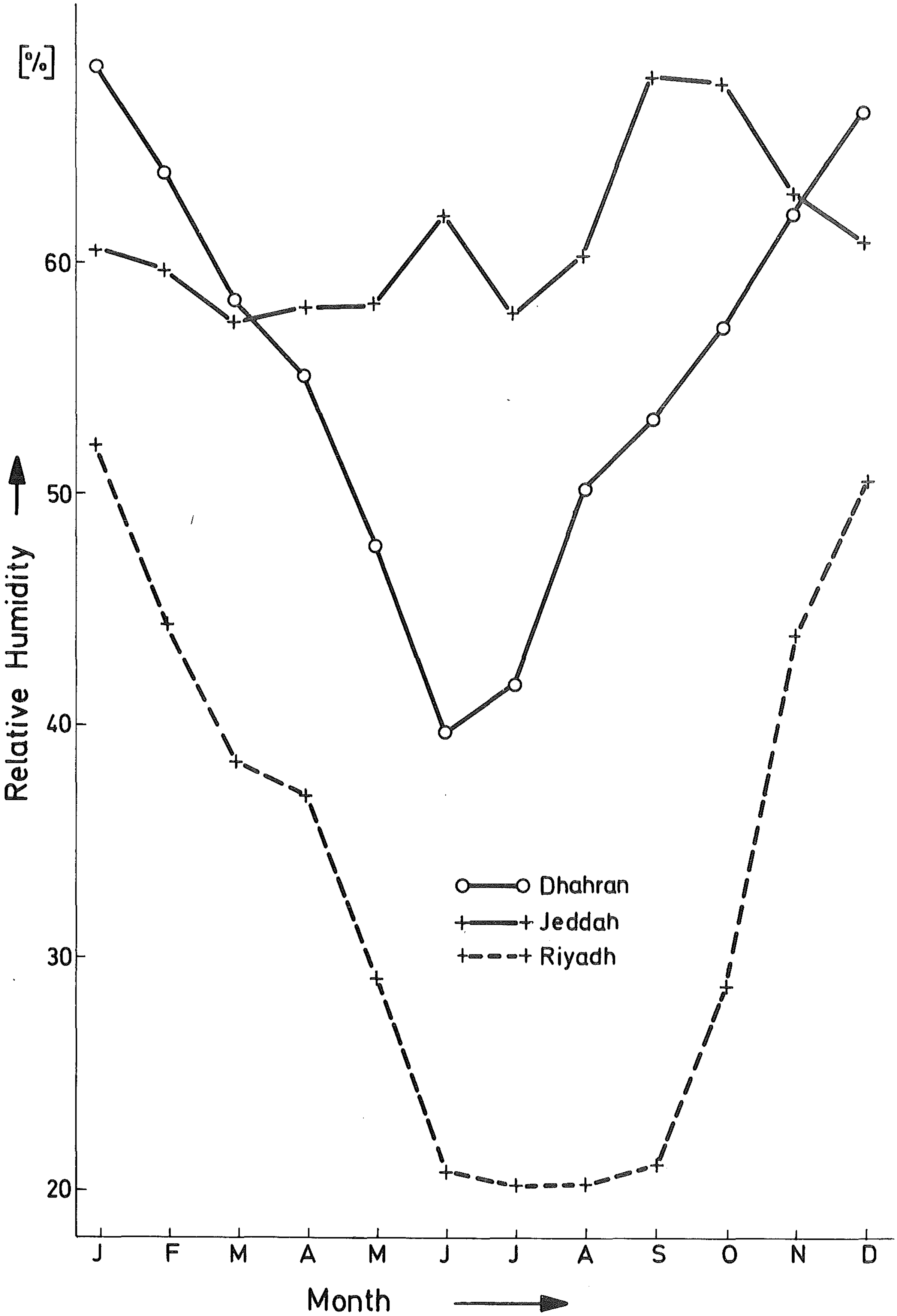


Figure 41: Recorded Monthly Values for the Average Relative Humidity /68/

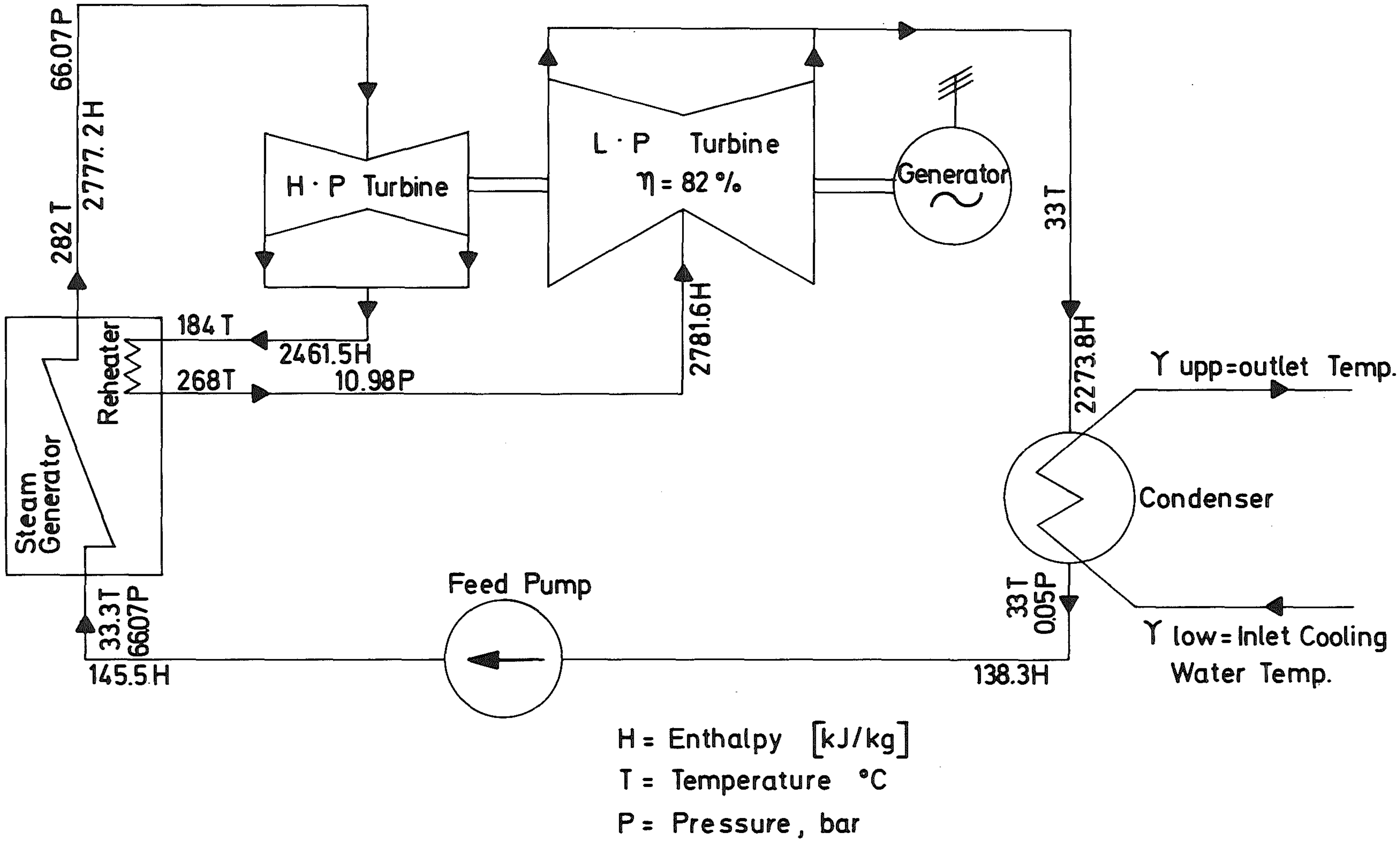


Figure 42: Simplified Flow Chart for a 1000 MW(e) PWR (Deduced from /70/)

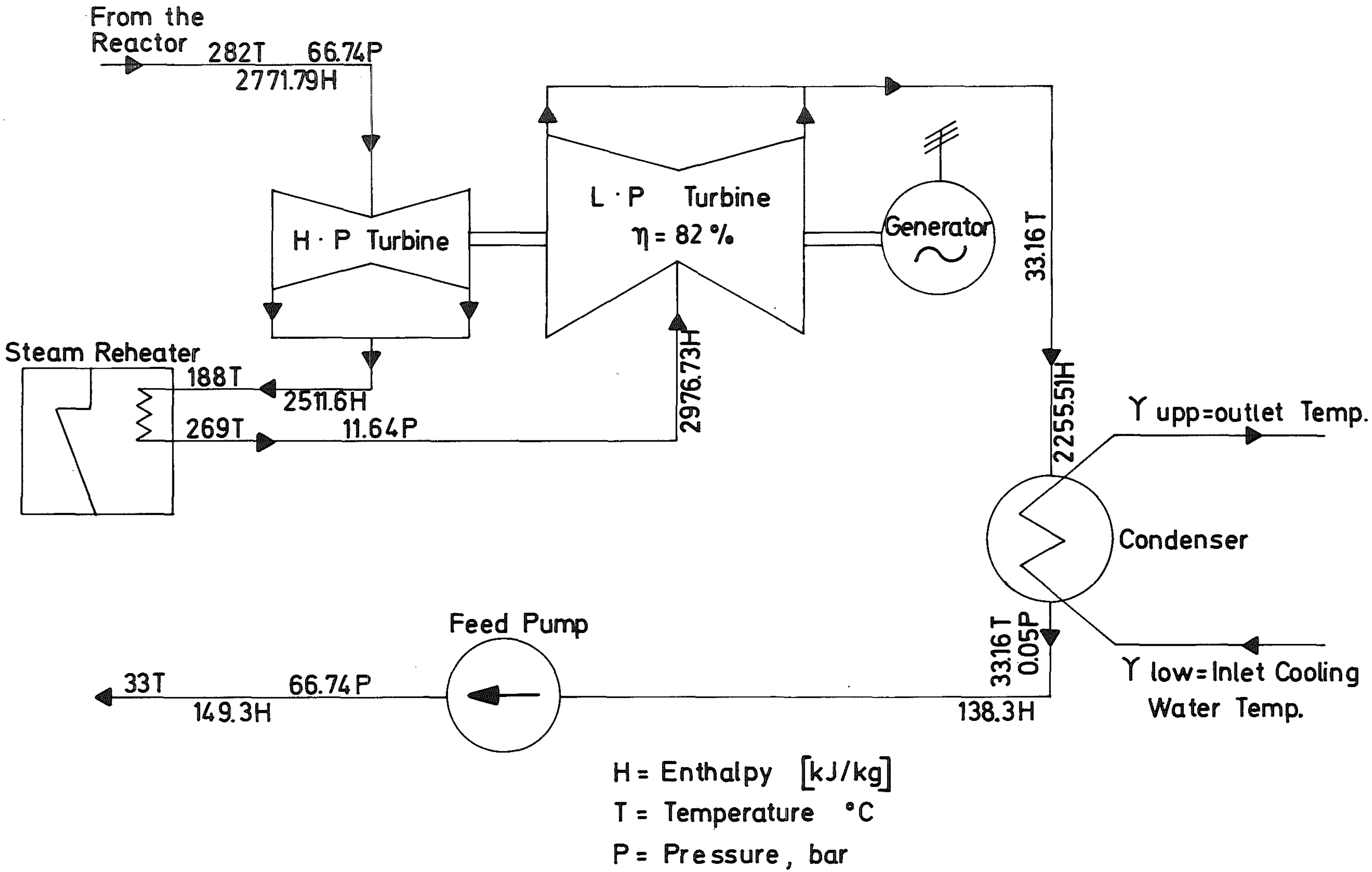


Figure 43: Simplified Flow Chart for a 1000 MW(e) BWR (Deduced from /70/)

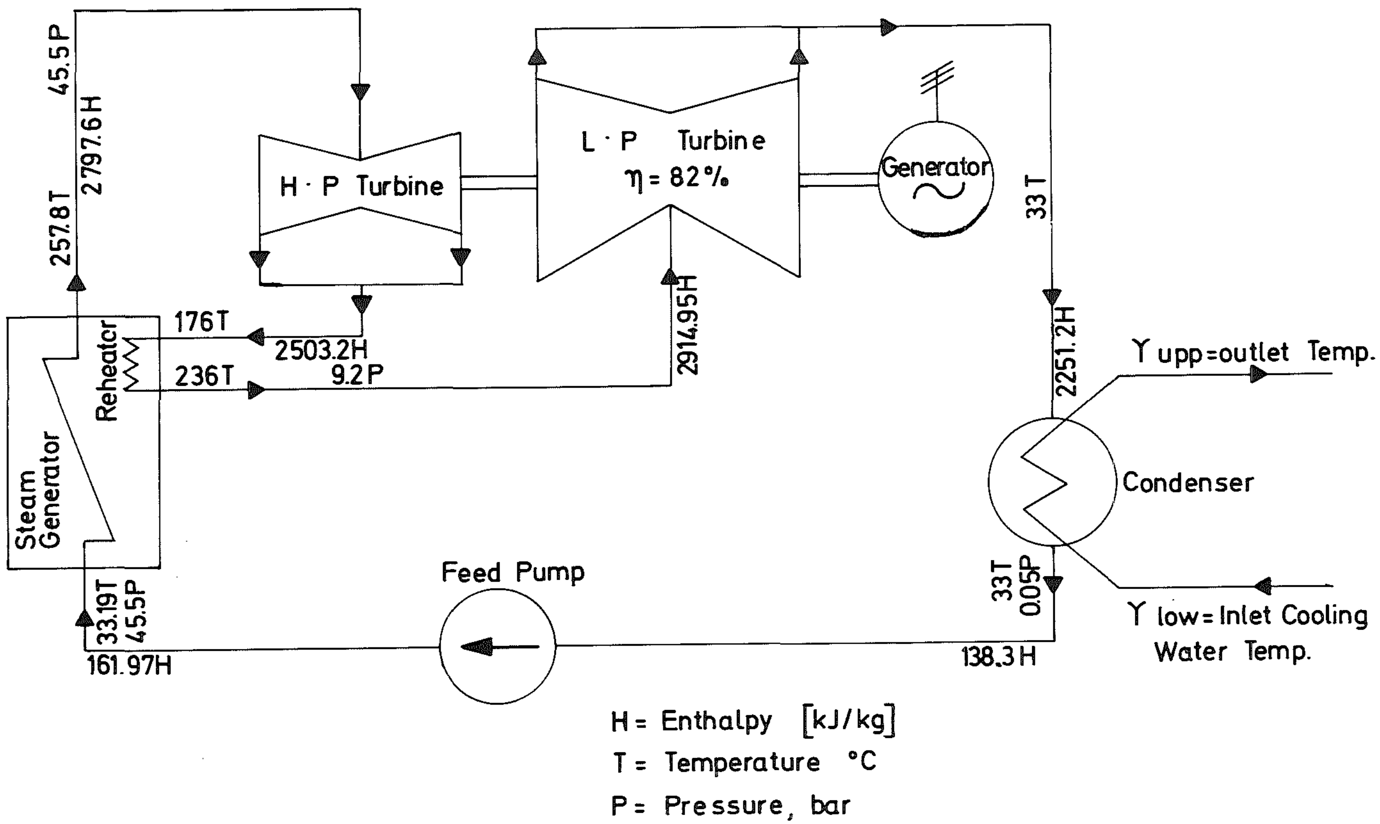


Figure 44: Simplified Flow Chart for a 645 MW(e) Candu-PHWR (Deduced from /71/)

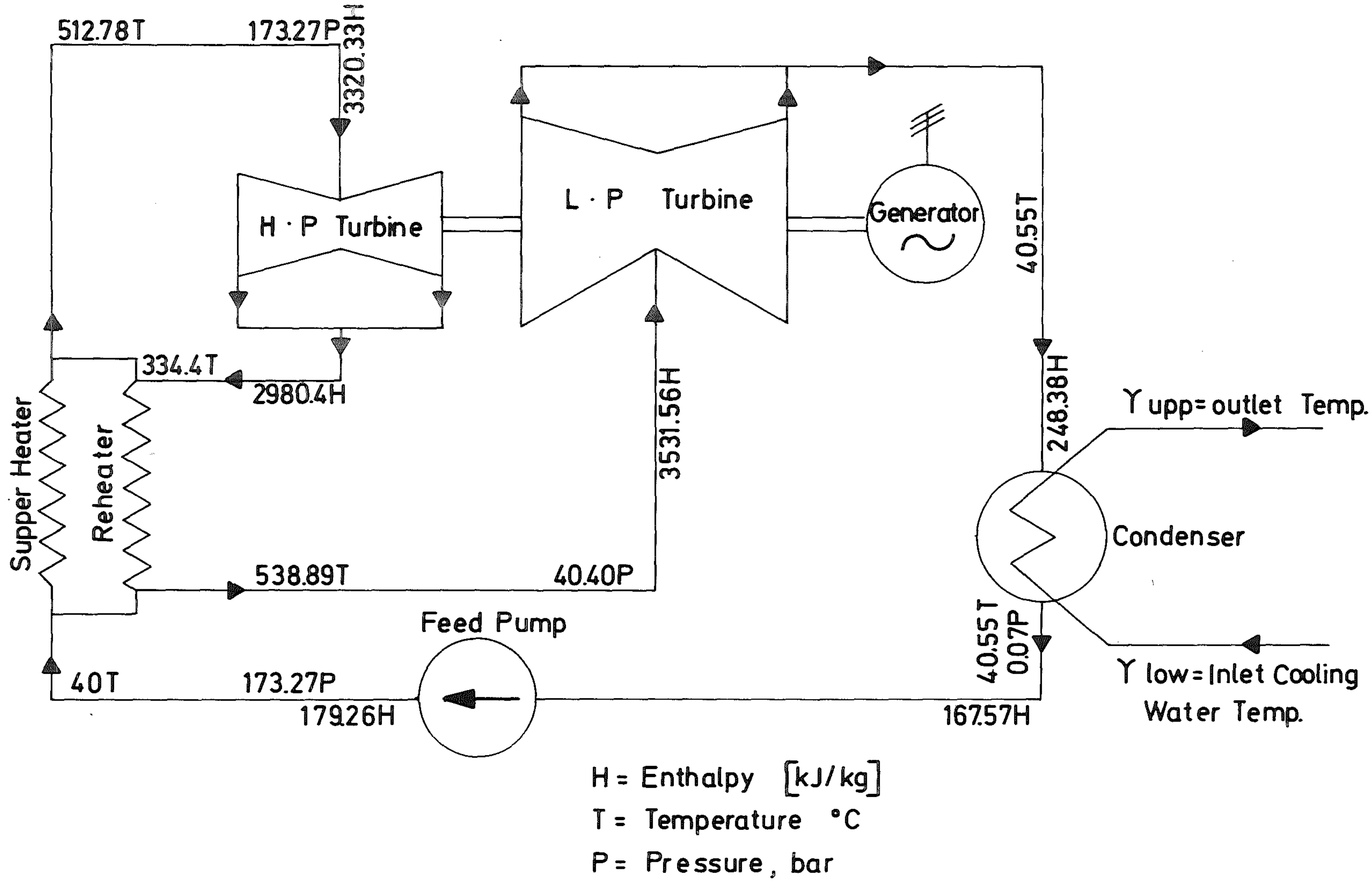


Figure 45: Simplified Flow Chart for a 1160 MW(e) HTGR (Deduced from /72/)

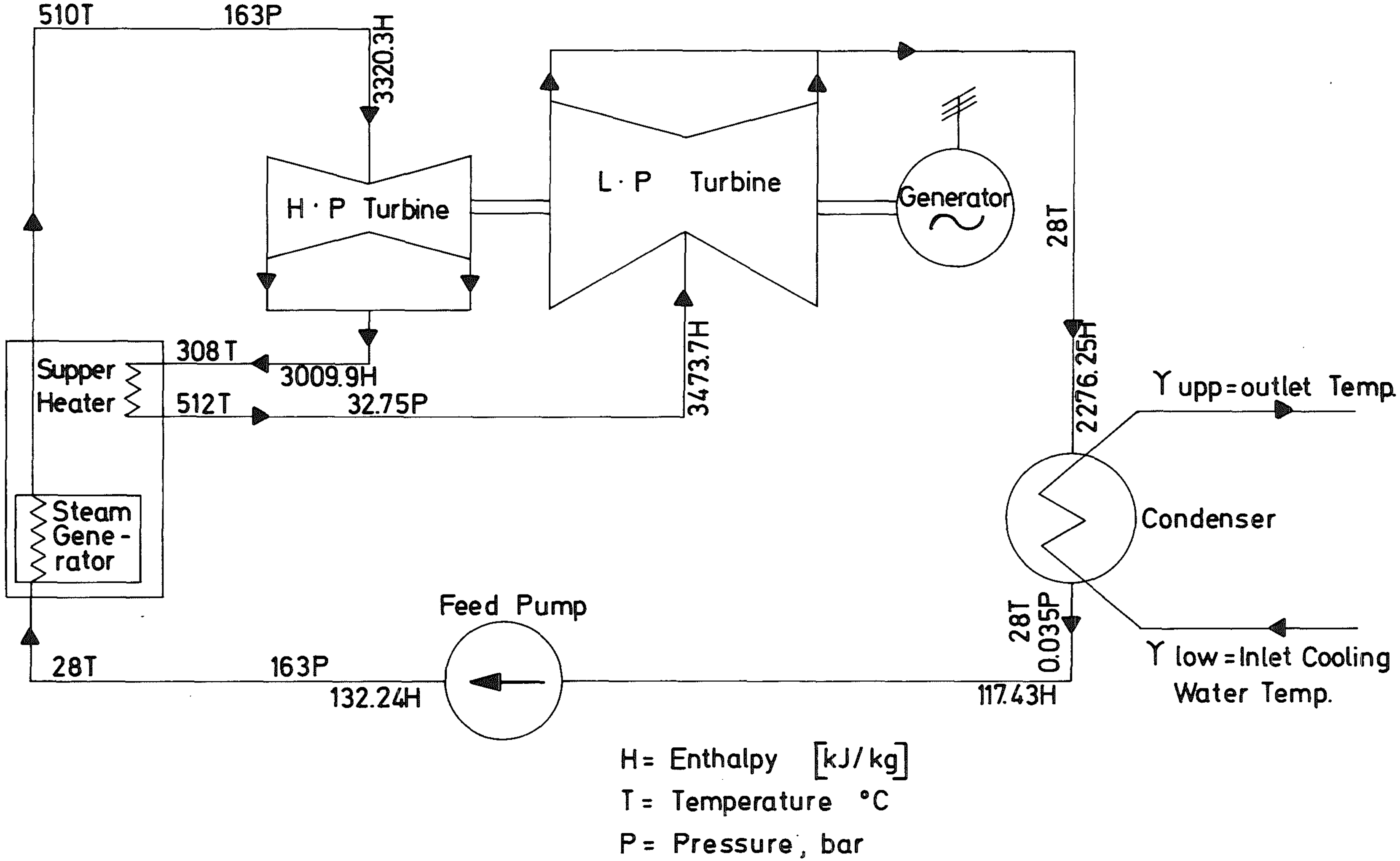


Figure 46: Simplified Flow Chart for a 250 MW(e) FBR (Phenix) (Deduced from /73/)

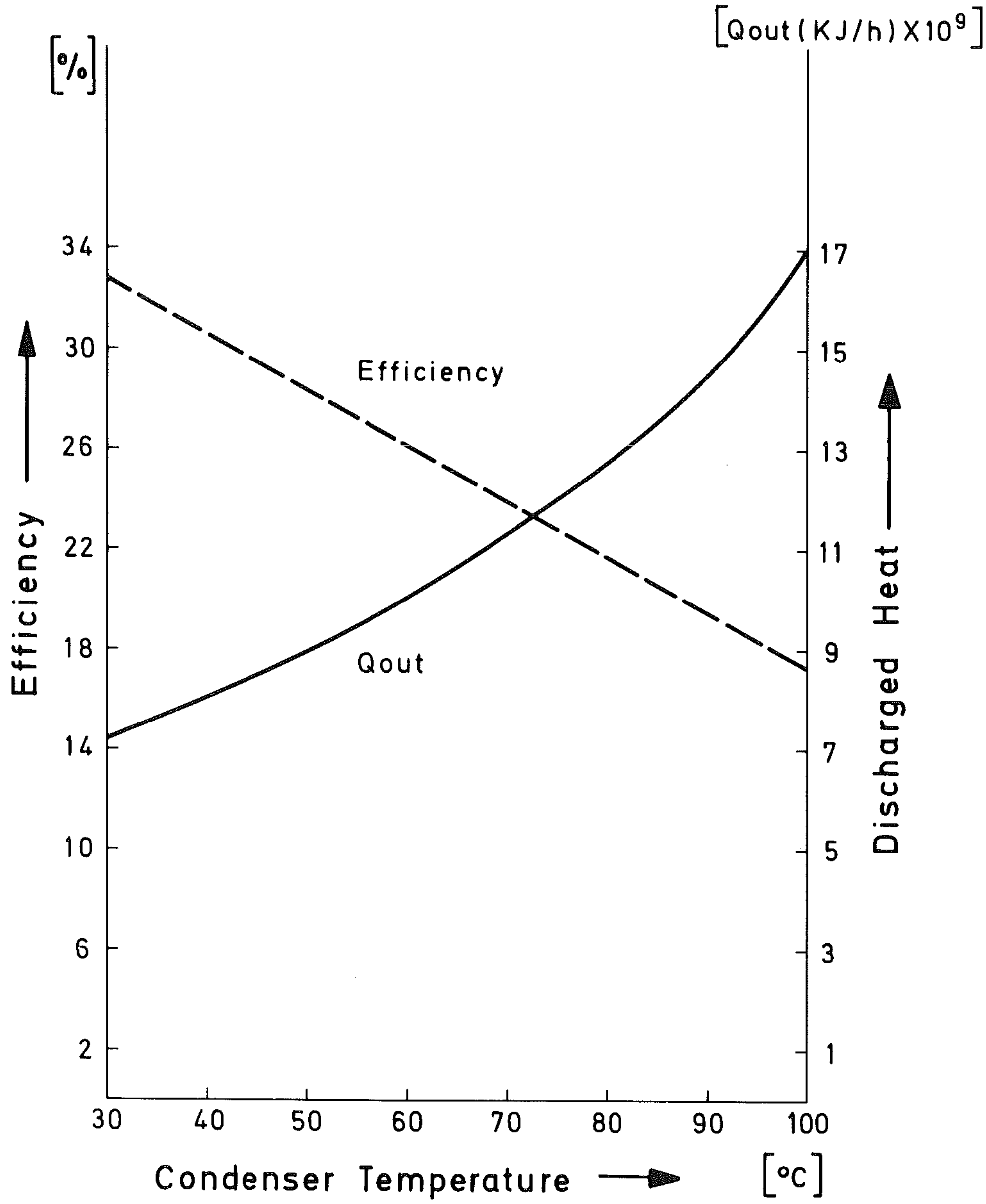
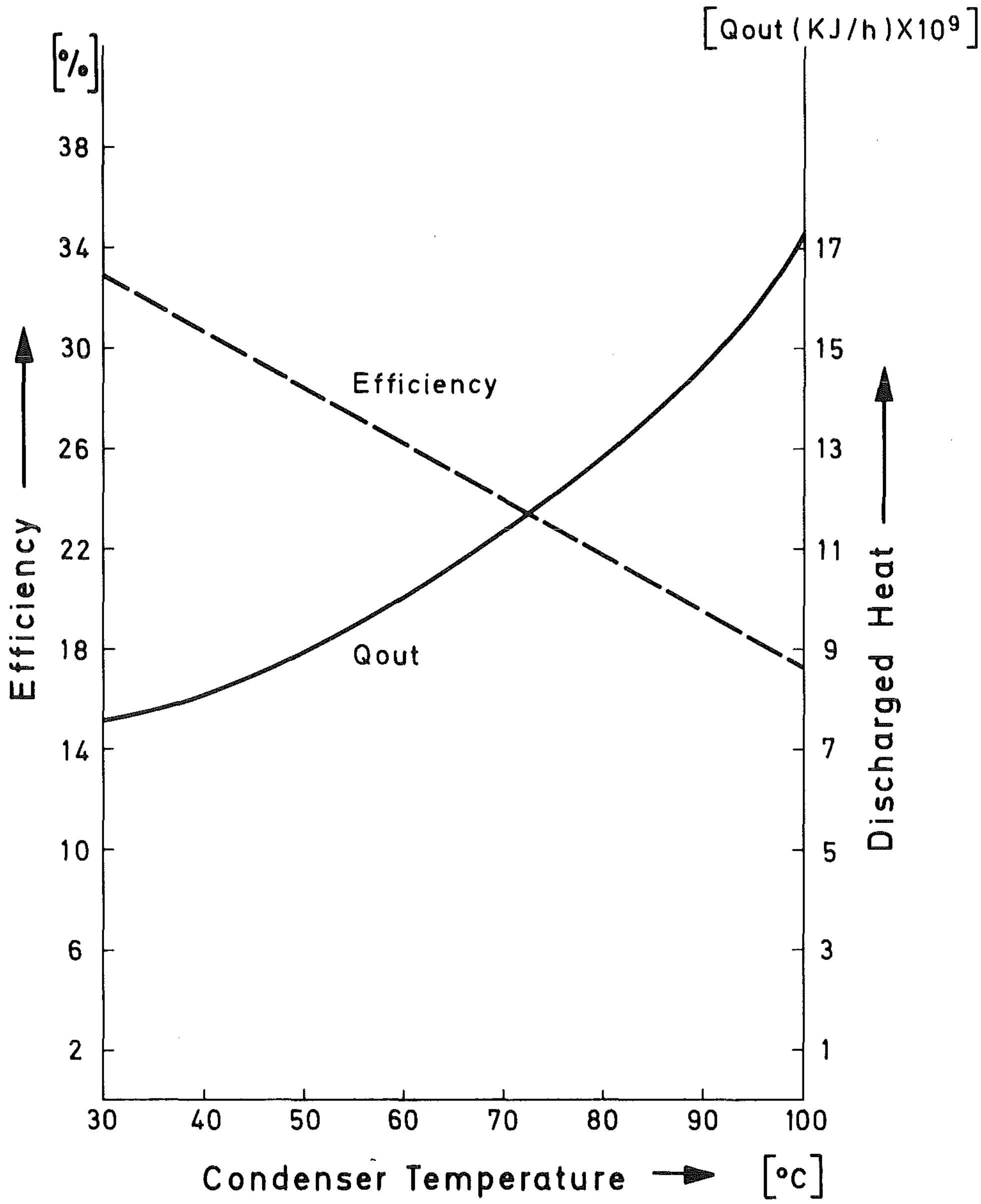


Figure 47: The Impact of the Increase in Condenser Temperature on Plant Thermal Efficiency and Discharged Heat of a 1000 MW(e) PWR



<u>Figure 48:</u> The Impact of the Increase in Condenser Temperature on Plant Thermal Efficiency and Discharged Heat of a <u>1000 MW(e) BWR</u>

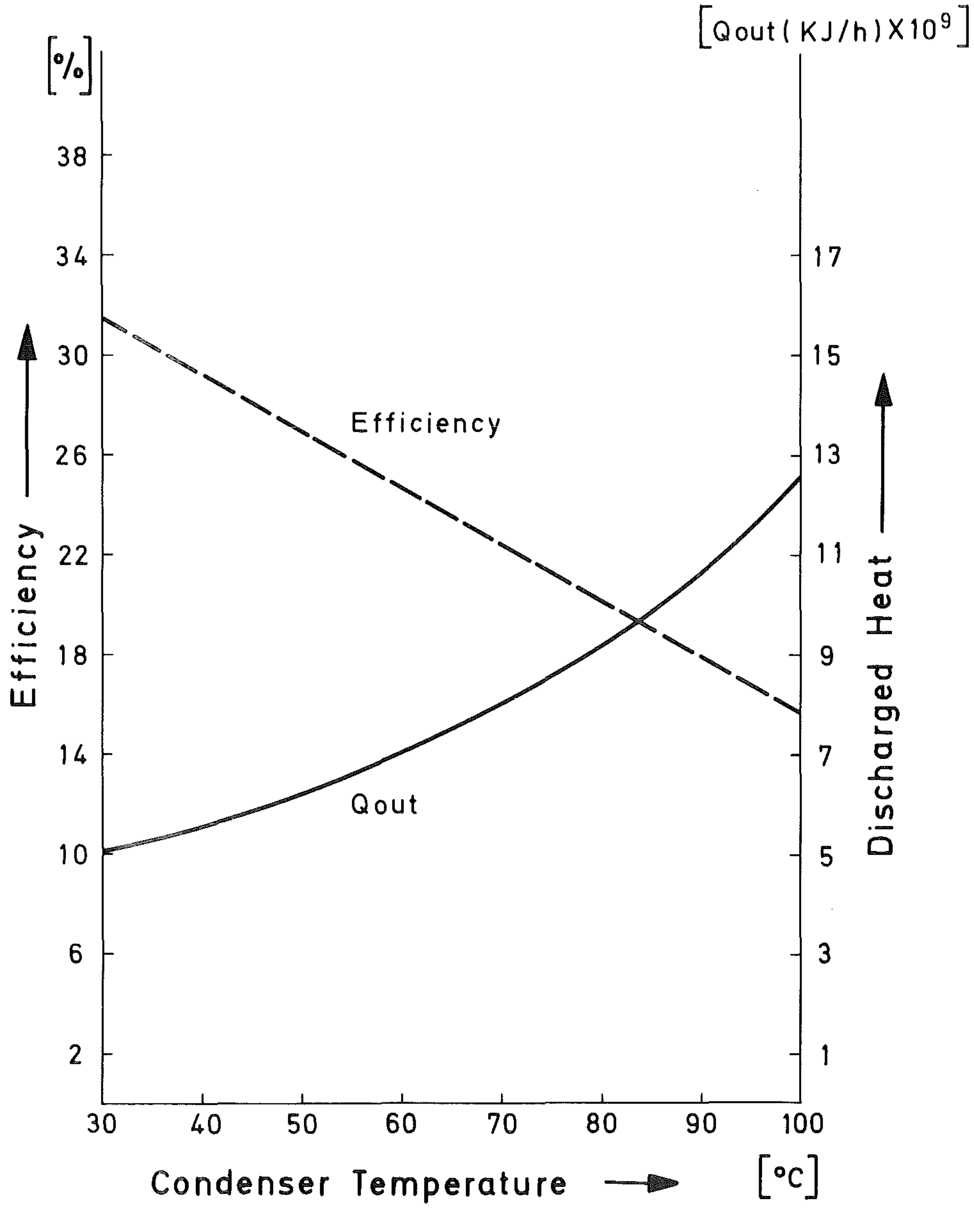


Figure 49: The Impact of the Increase in Condenser Temperature on Plant Thermal Efficiency and Discharged Heat of a 645 MW(e) Candu-PHWR

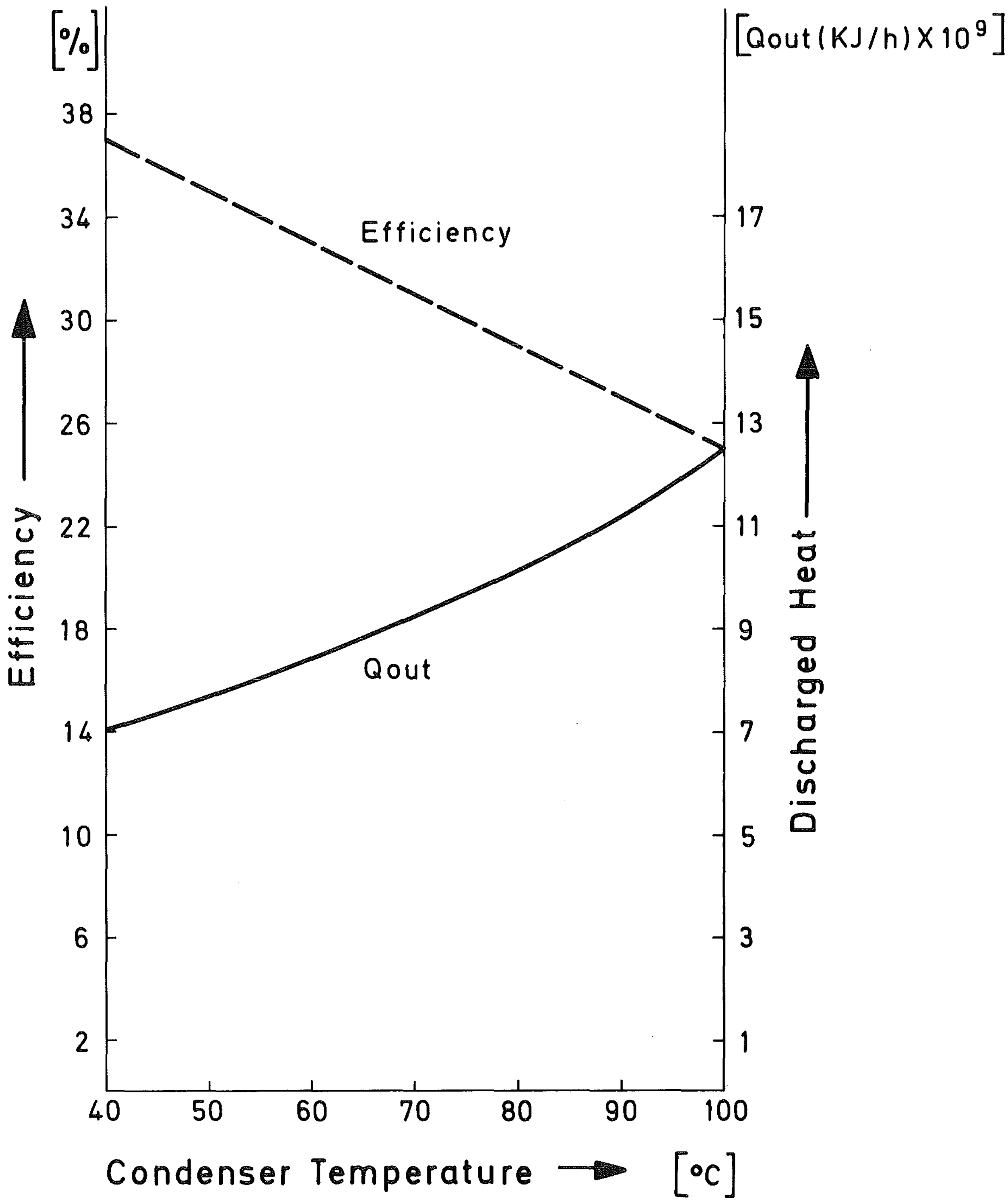


Figure 50: The Impact of the Increase in Condenser Temperature on Plant Thermal Efficiency and Discharged Heat of a 1160 MW(e) HTGR

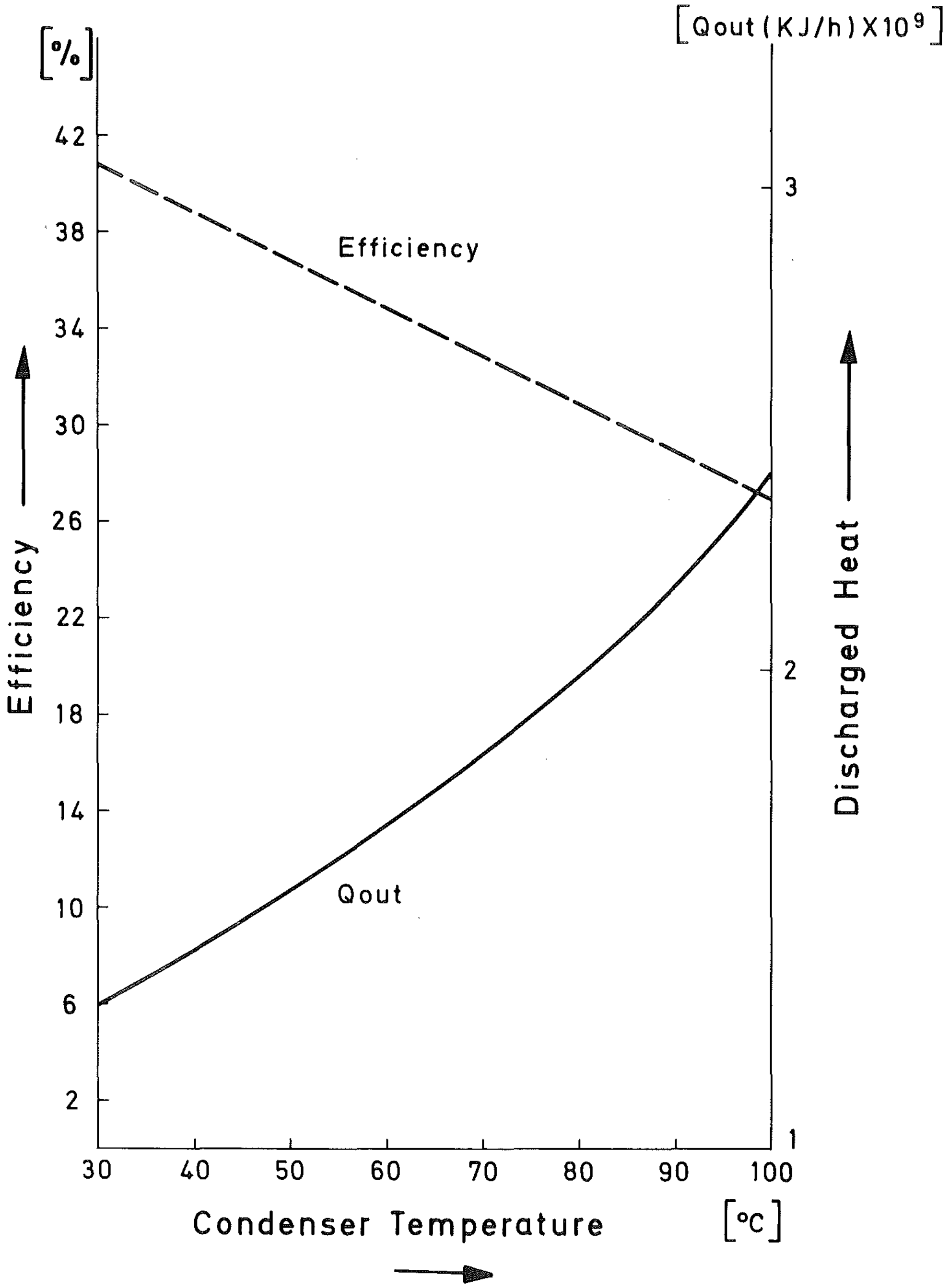


Figure 51: The Impact of the Increase in Condenser Temperature on Plant Thermal Efficiency and Discharged Heat of a 250 MW(e) FBR (Phenix)

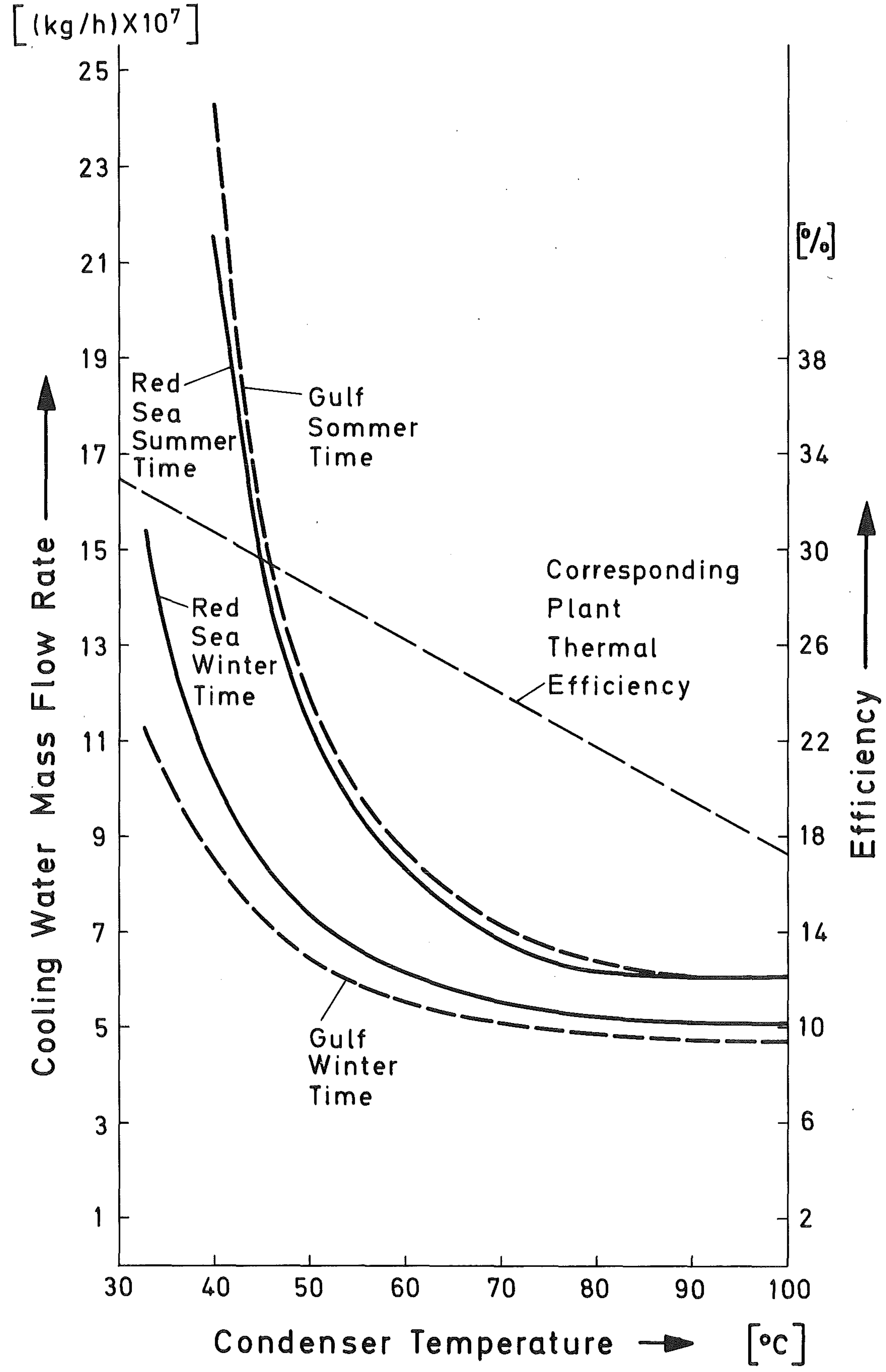


Figure 52: The Impact of the Increase in Condenser Temperature on Cooling Water Mass Flow Rate During the Summer and Winter Times of a 1000 MW(e) PWR

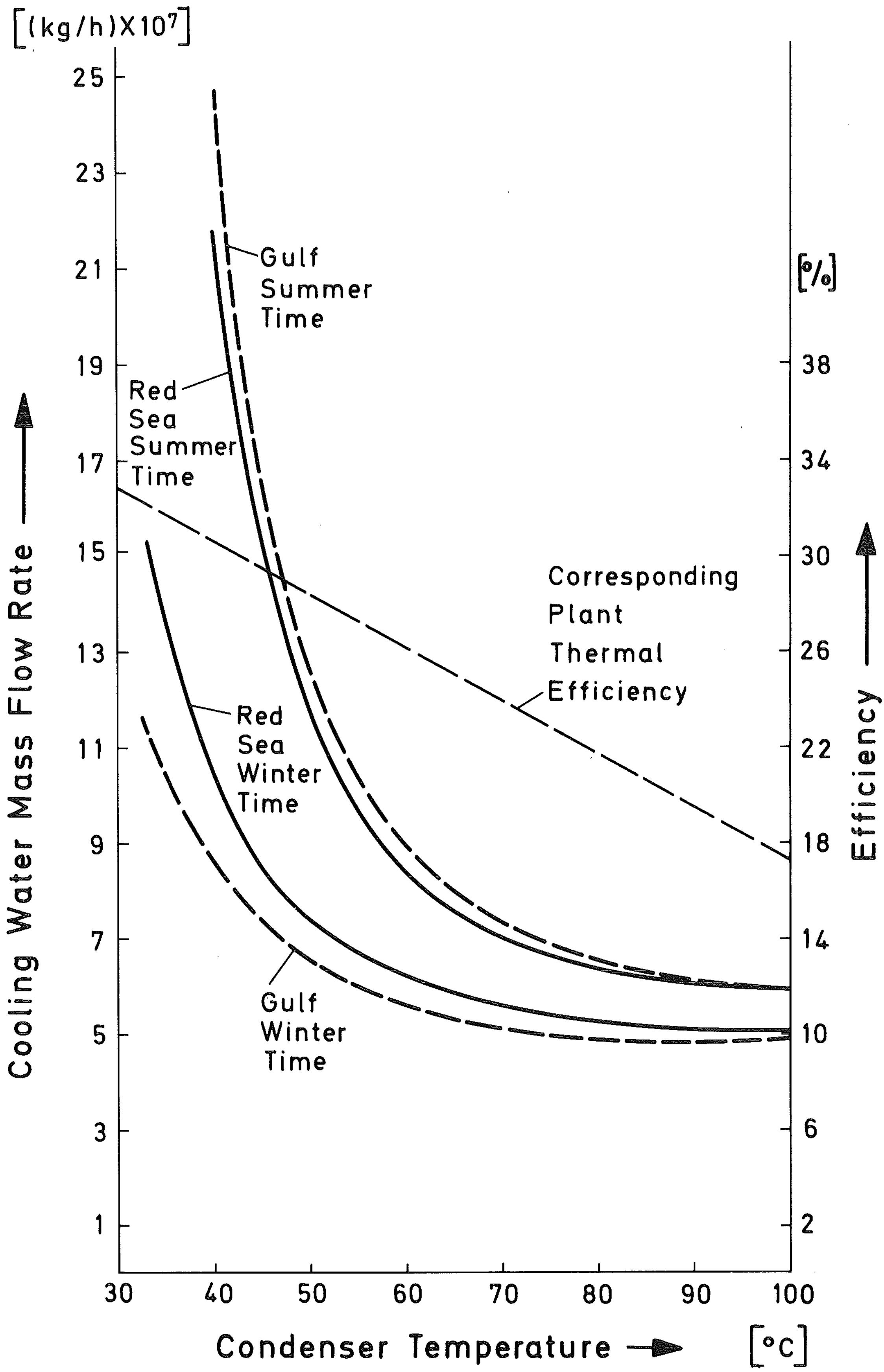


Figure 53: The Impact of the Increase in Condenser Temperature on Cooling Water Mass Flow Rate During the Summer and Winter Times of a 1000 MW(e) BWR

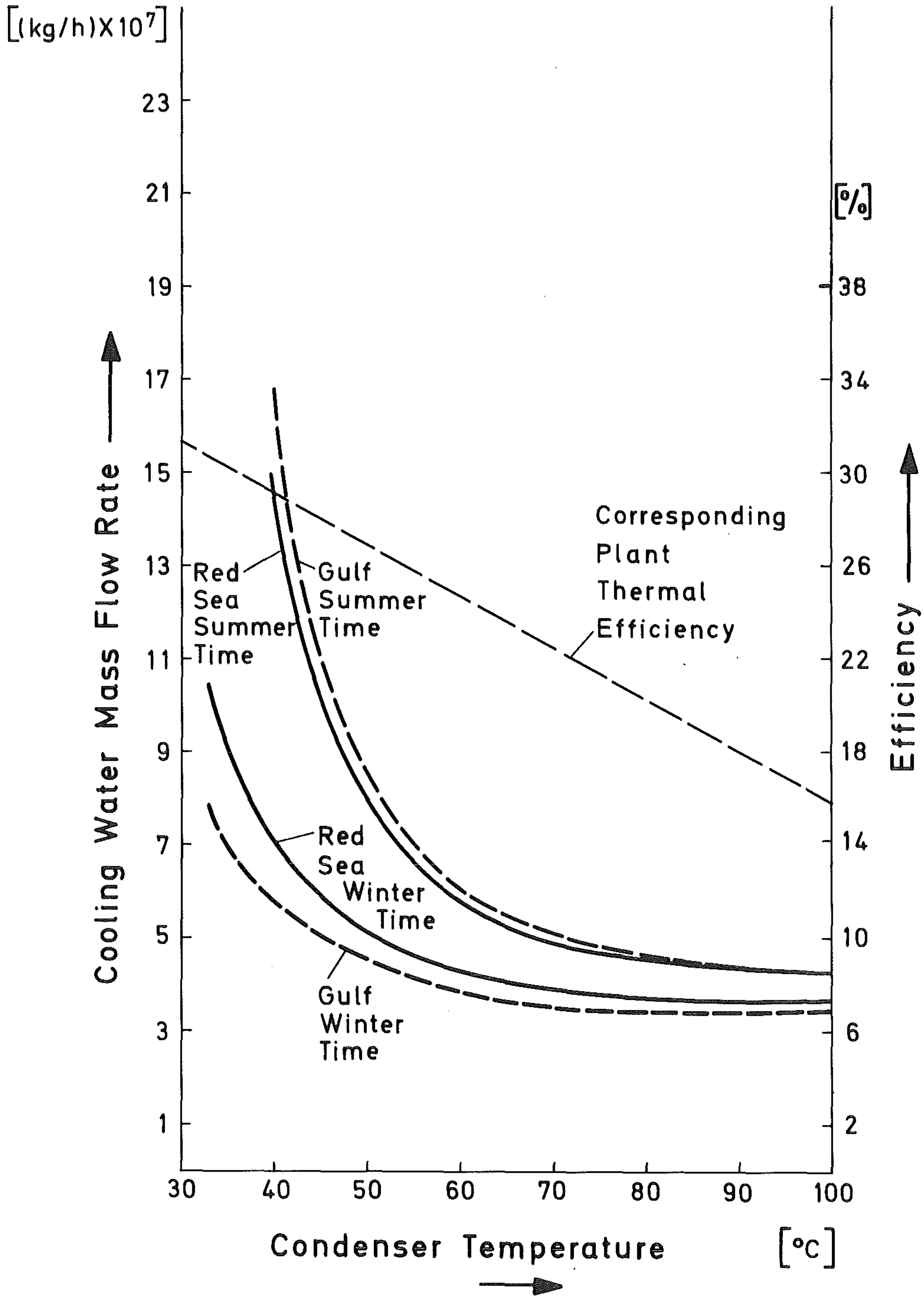


Figure 54: The Impact of the Increase in Condenser Temperature on Cooling Water Mass Flow Rate During the Summer and Winter Times of a 645 MW(e) Candu-PHWR

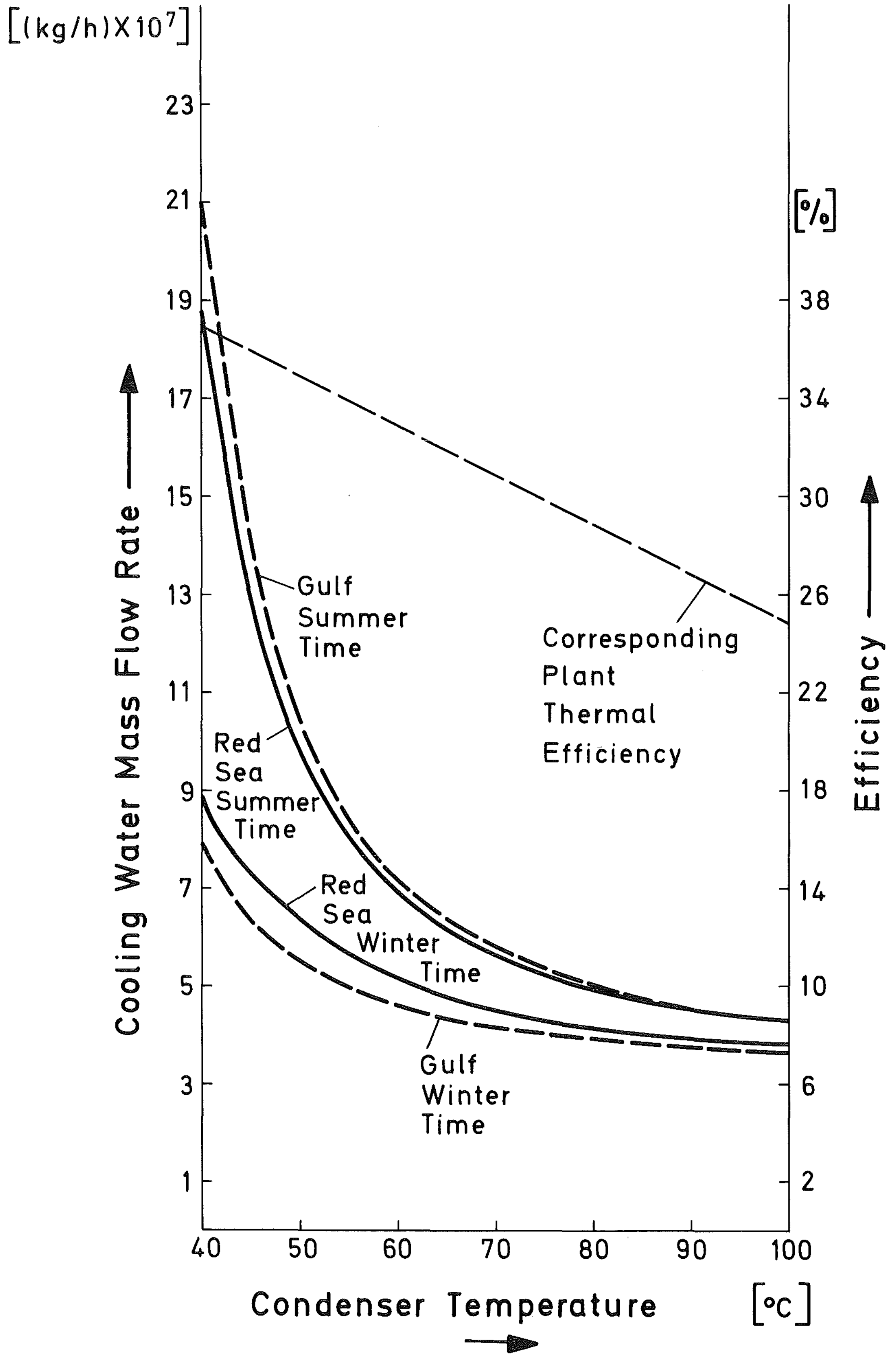


Figure 55: The Impact of the Increase in Condenser Temperature on Cooling Water Mass Flow Rate During the Summer and Winter Times of a 1160 MW(e) HTGR

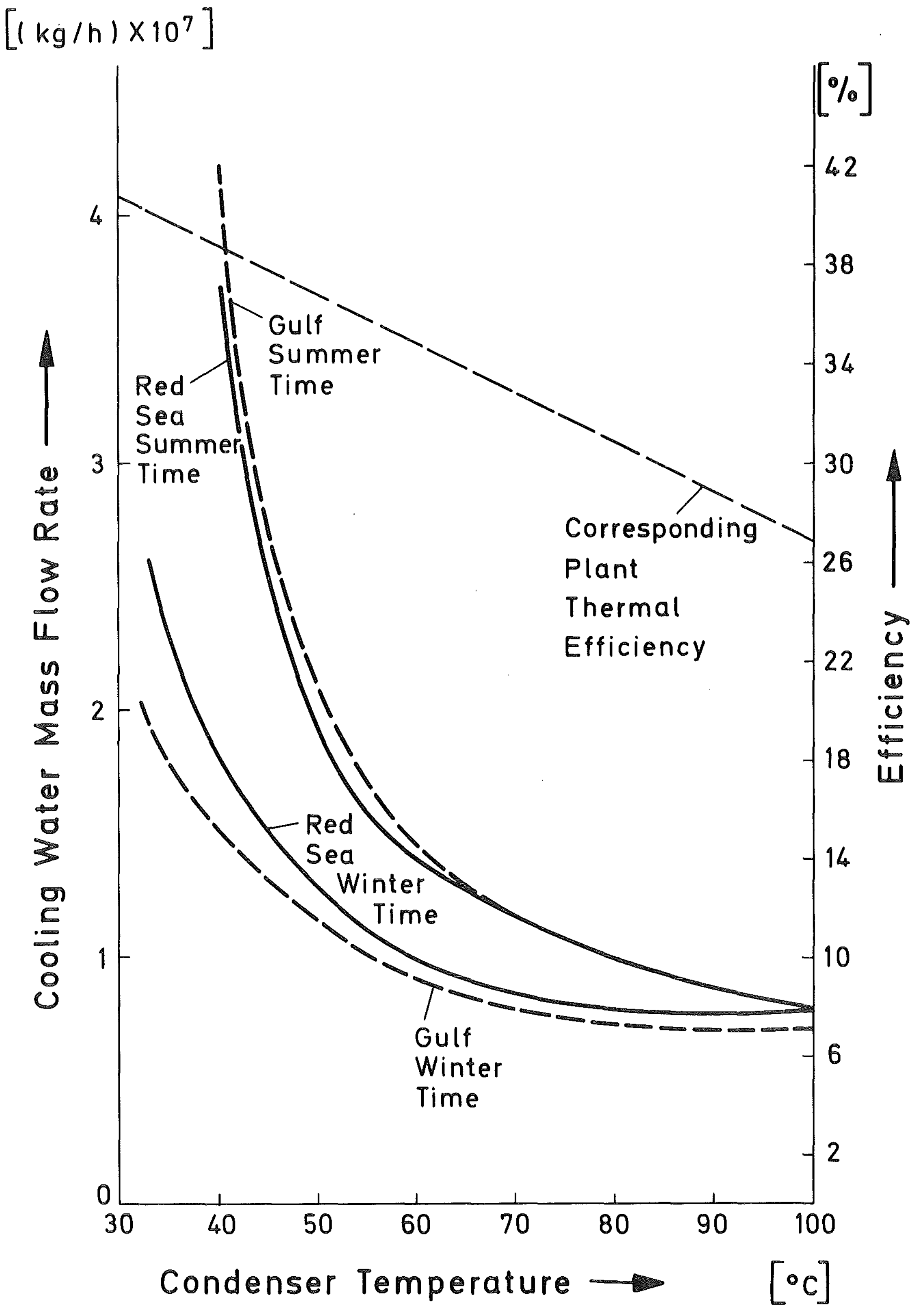


Figure 56: The Impact of the Increase in Condenser Temperature on Cooling Water Mass Flow Rate During the Summer and Winter Times of a 250 MW(e) FBR (Phenix)

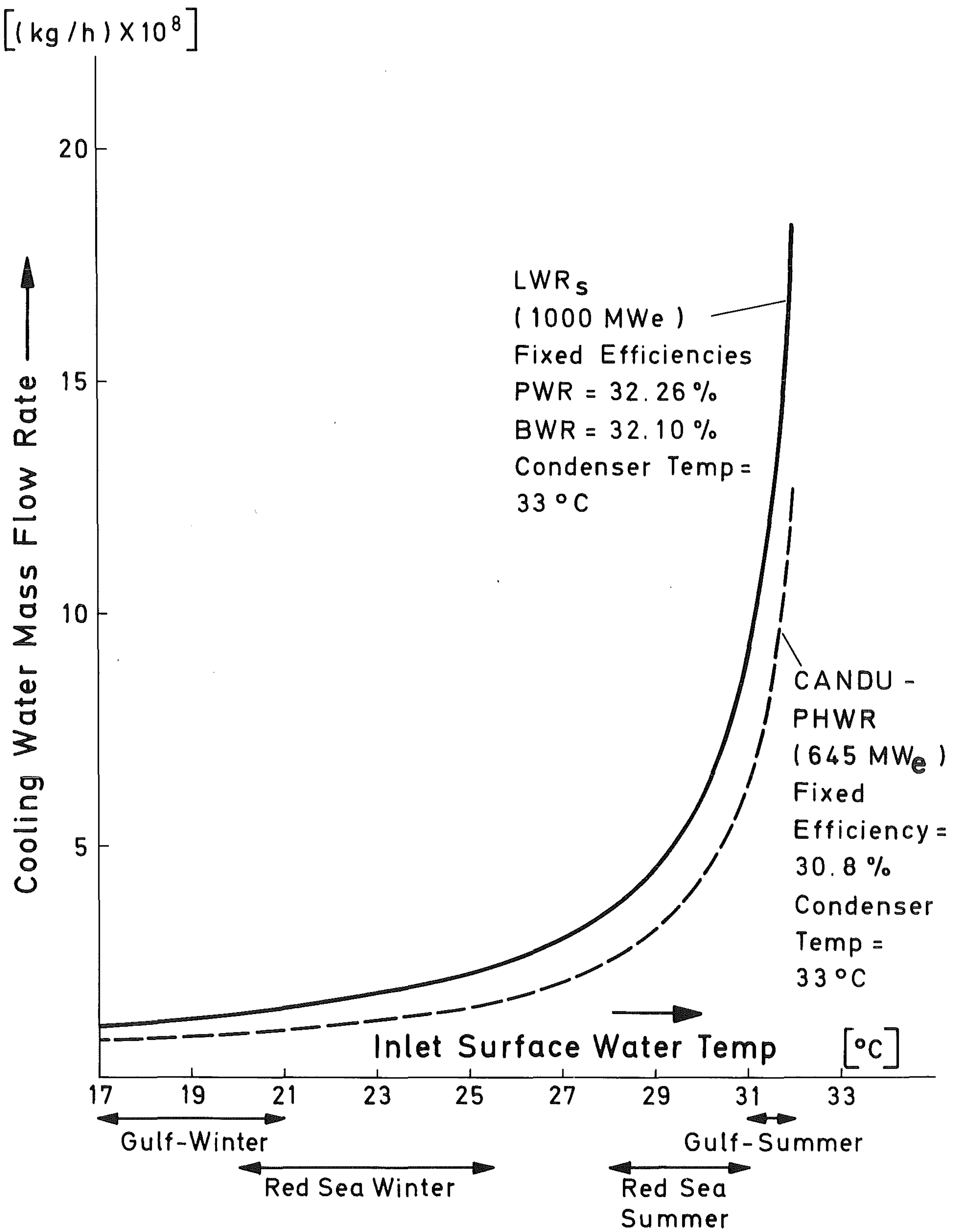


Figure 57: The Impact of the Inlet Cooling Water Temperature on the Cooling Water Mass Flow Rate for Fixed Efficiency of Water Reactors

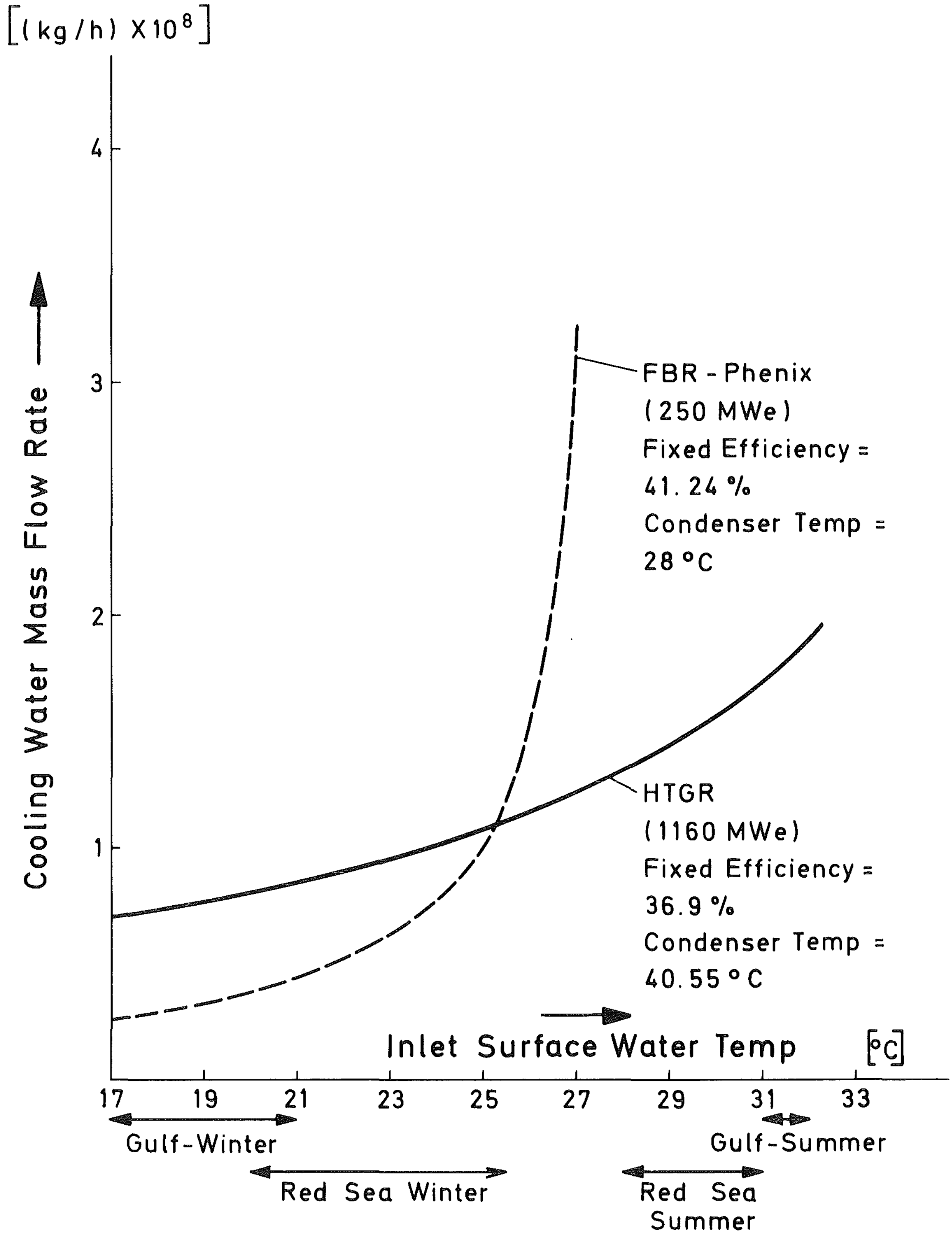


Figure 58: The Impact of the Inlet Cooling Water Temperature on the Cooling Water Mass Flow Rate for Fixed Efficiency of Advanced Reactors

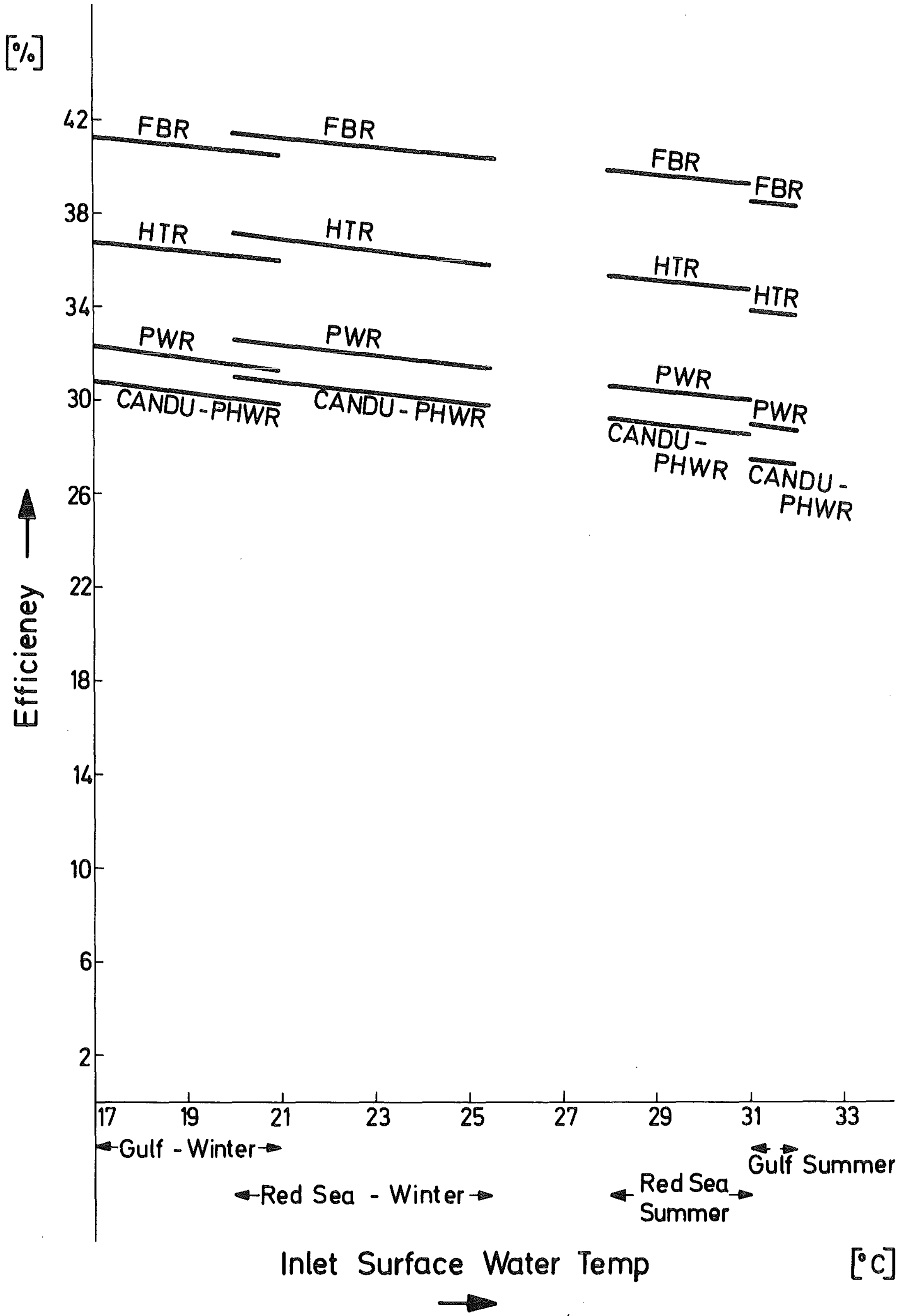


Figure 59: Efficiency Fluctuation with Inlet Cooling Water Temperature for Fixed Outlet Temperature and Mass Flow Rate of: 1000 MW(e) PWR, 645 MW(e) Candu-PHWR, 1160 MW(e) HTGR, 250 MW(e) FBR (Phenix)

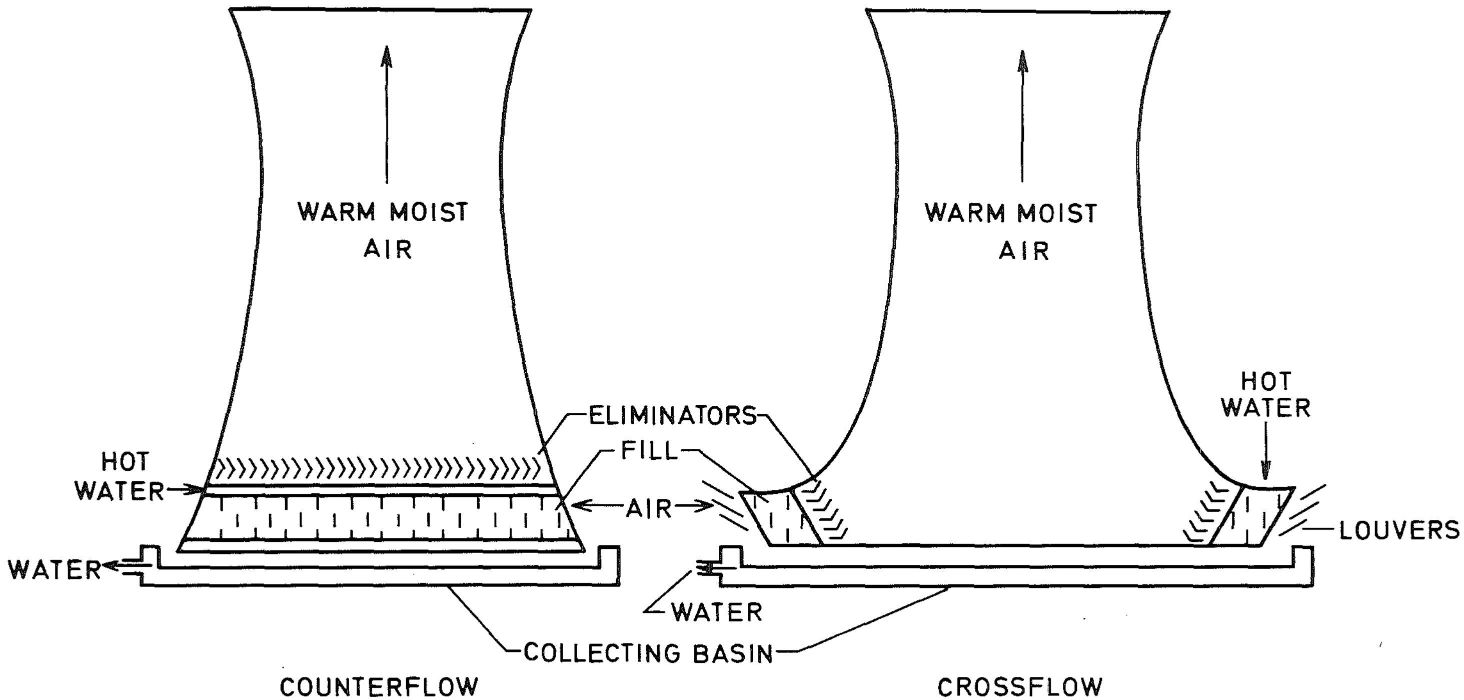


Figure 60: Schematics of the Hyperbolic Natural Draft Cooling Towers

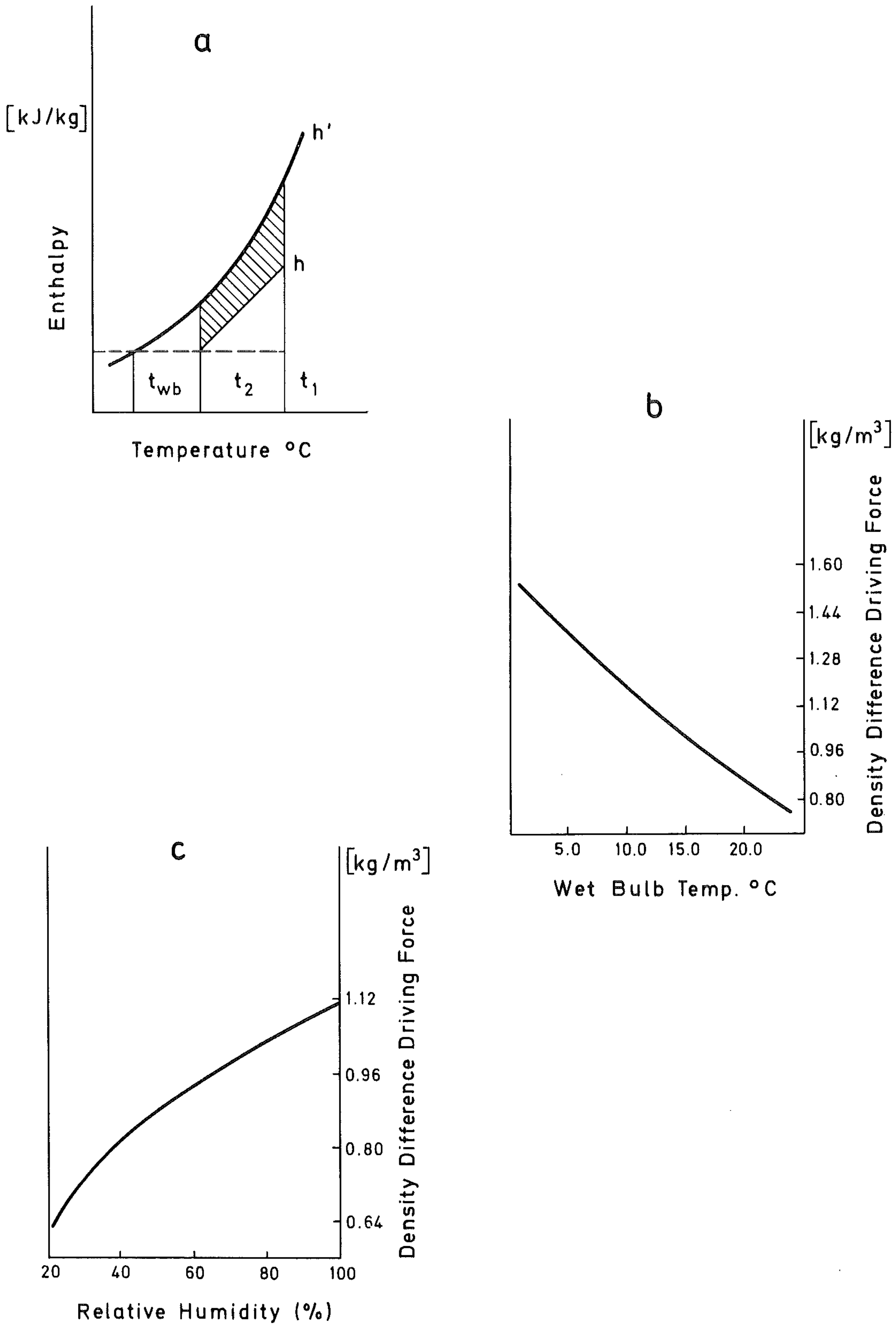


Figure 61: a) Performance Demand Characteristics Curve (Wet Cooling Tower)

b) Effect of Wet Bulb Temperature on Density Difference Driving Force (RH=60%, L/G = 1.5)

c) Effect of Relative Humidity on Density Difference Driving Force (WBT = 18°C, L/G = 1.5)

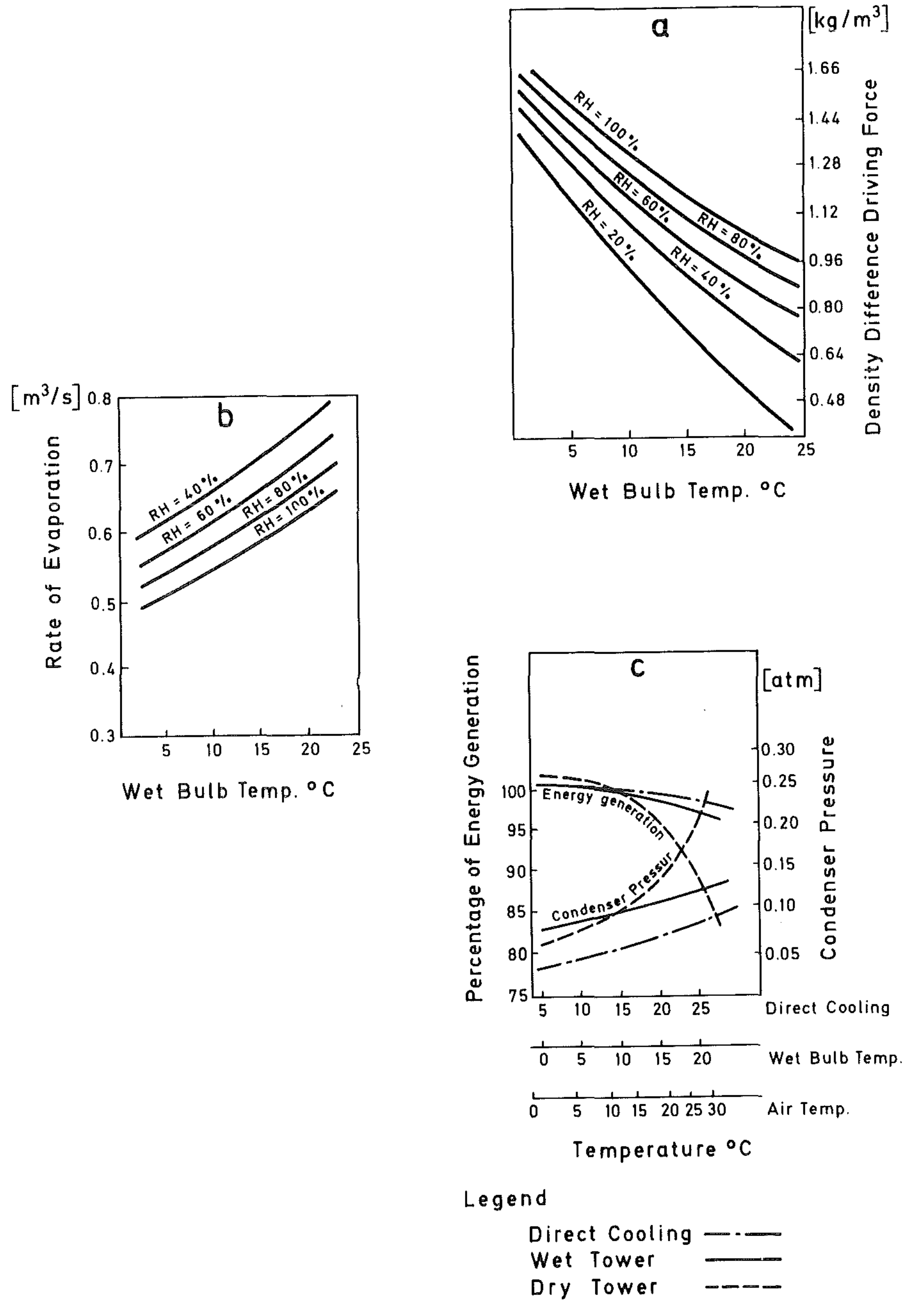


Figure 62: a) Combined Effects of Wet Bulb Temperature and Relative Humidity on Density Difference Driving Force (L/G = 1.5)

b) Combined Effects of Wet Bulb Temperature and Relative Humidity on the Rate of Evaporation (1000 MW(e) LWR)

c) Effect of Cooling Temperature on Plant Efficiency: A Comparison of Direct Cooling, Cooling with Wet Tower, and Cooling with Dry Tower