Committee I
The Nuclear Option in the Past,
Present and in the Future

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SAFETY OF NUCLEAR POWER PLANTS IN BULGARIA

by

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SAFETY OF NUCLEAR POWER PLANTS IN BULGARIA AND EAST - EUROPEAN COUNTRIES

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There are currently world-wide 420 nuclear power plants (NPPs) on operation and 77 under construction. They are operated by 24 countries. China, Cuba and Romania are scheduled to complete their first units in the next several years.

Global nuclear electricity is about 16.6 % of the total electricity generation. The share in different countries varies considerably, reaching some 74.5 % in France, 60 % in Belgium and about 50 % in Hungary and Korea.

An overview by region of NPPs in operation and under construction is presented in Figures 1 and 2. While Western Europe has the largest number of units in operation, Eastern Europe has the largest number under construction.

Soviet-designed reactors of all types make up 11 % of the world's operating reactors and 32 % of those under construction. Of the pressurized water reactors (WWER), which are the only type to have been exported, there are a total of 41 in operation and 31 under construction. In eastern and central Europe there are in addition to

Soviet designed WWER plants, 5 Canadian designed heavy water reactors (HWR) under construction in Romania and also a Westinghouse pressurized-water reactor (PWR) is in operation in Slovenia.

The dependence of Central and Eastern European countries on nuclear electricity is considerable; it is 50 % in Hungary, 35.6 % in Bulgaria, 28.4 % in Czecho-Slovakia and 12.2 % in ex USSR.

There are a number of safety problems which have been identified in WWER Soviet designed PWR plants. They include deficiencies not only in design, but also in operation and in the overall material conditions. However, it is only through a thorough evaluation of these three basic aspects of safety, design adequacy, operational aspects and the overall material condition of the plant, that a thorough picture of safety can be obtained.

At this time there are 10 first generation 440 MW WWER, model 230 reactors in operation. Two units in Armenia and four in the Eastern part of Germany have been shut down (Fig. 3). Four of the operating units are located in Bulgaria, two are in Czecho-Slovakia and four are in Russia. All of these units lack safety design features basis of other pressurized water plants. The weaknesses include lack of containment to enclose the reactor systems, insufficient redundancy and separations of safety equipment, limited emergency core capacity, insufficient fire protection, and insufficient instrumentation and control systems.

These units clearly do not meet current safety requirements. Neverthelesss, there are some positive features, such as the relatively low core power density, and the large water inventory in the primary and secondary circuits, which make these reactors less sensitive to disturbances when compared to more modern plants.

The second generation of 440 MW WWER model 213 reactors have eliminated many of the design deficiencies of the model 230, particularly through the use of sealed chambers to localize accidents and a steam suppression system. Of the 16 units in operation (Fig. 4), the two reactors located in Finland have undergone significant safety improvements - containment structure surrounding the reactor system. At this there are four model 213 units under construction in Czecho-Slovakia. In addition, two WWER model 318 reactors are under construction in Cuba. As with the units in Finland, the Cuban plant incorporates a containment structure as well as a number of additional safety improvements.

The safety concept of the larger and more modern Soviet designed 1000 MW WWER plants is similar to that of none-Soviet PWR plants in operation worldwide and includes a full containment structure. However, some concerns related to design and operational problems remain, even for the more advanced 1000 MW units. Of the 17 units in operation, only two in Bulgaria are outside the Soviet Union. Nineteen other units are under construction in the Soviet Union and two units are under construction in Czecho-Slovakia (Fig. 5).

In the Soviet Union there are also 16 large graphite reactors (RBMK) of the Chernobyl type in operation and 4 under construction, (Fig. 6). In

1990, RBMK plants generated 47.8 % of total nuclear electricity in the Russia. As of the beginning of the 1991, RBMK installed capacity accounted for 45 % of the total nuclear generating capacity in the Russia. Since the Chernobyl accident the safety of these reactors has been a matter of great in international concern.

In response to requests from Member States operating Soviet-designed WWER 440/230 NPP for assistance through IAEA's nuclear safety services, a major international Project was established to evaluate these first generation reactors as a complement to the relevant on-going national, bilateral and multilateral activities.

Thirty-two experts form ten countries and three international organizations together with twenty-five Soviet specialists, examined detailed information prepared by Soviet designers and operators. Use was also made of the results of other studies, including the investigation carried out in Germany for the Greifswald NPP in 1989 and the one performed in the USA.

The original design concept of WWER 440/230 was developed in the late sixties and early seventies in compliance with Russian industrial codes, standards and rules which were effective at the time of design.

The design basis accident (DBA) is a small break of the primary cooling circuit of 32 mm in diameter (8 cm^2, equivalent to the diameter of the flow restrictors installed on the pessurizer spray line of 90 mm). The primary circuit is located in the hermetic zone (compartments) of the reactor building designed to a pressure of 0.1 MPa which may occur in DBA. In case of accidents with breaks greater than 32 mm equivalent, compartment pressure may exceed the design value. In this case dumping devices open and close after steam-air mixture is discharged to the atmosphere and the pressure is reduced. Besides, compartment is also equipped with a sprinkler system to reduce the pressure after the accident.

During DBA reactor vessel water level will always exceed the core water level and water delivered by emergency pumps provides sufficient heat removal eliminating fuel rod failure.

The safety concept further assumes high reliability of essential systems during plant lifetime which permits neglecting accidents beyond those considered in the design. Safety systems are designed based on the single failure criteria, but no consideration is given to common cause failures.

In general, it was found that the degree of redundancy, diversity and segregation was low in some of the reactor systems, therefore making them susceptible to common-cause failures.

Violations of single failure criteria have also been established. Other weakness were also found due to the fact that, at the time of design, specific nuclear standards had not been applied with regard to instrumentation and control and electric power supply.

It was further noted that compared to current practice in the case of most other NPP types, the design basis is very limited and that safety analysis had been performed of only a narrow spectrum of potential accidents. Confinement function was also found to have safety shortcomings.

Another safety concern, specific to the WWER - 440 plant type, is the embrittlement of the reactor vessel wall, caused by the neutron bombardment during plant operation. The same phenomenon is found at all reactor vessels but in the WWER-440 vessels it is more pronounced due to the small distance between the reactor core outer edge and the vessel wall. The embrittlement means that the transition temperature below which the reactor vessel steel loses its toughness and becomes brittle, increases continuously with the vessel age. In a new steel, the transition temperature is usually less than $0^{o}C$, but may have increased in some WWER 440 vessels to values bigger than $150^{o}C$.

On the other hand, the NPP has some positive features. These include:

- The reactor core is small with favorable physical characteristics and practically free from the xenon oscillations.

- The core has a low heat production with respect to the fuel weight. The average fuel temperature in the normal operation is low. The heat flux from the fuel to the coolant is so low that the safely margin to a head transfer crisis is significantly higher than in the other rectors. This feature is important during transients.

- Each cooling loop of the primary circuit is equipped with isolation valves and can be isolated separately from the rest of the circuit. This allows the maintenance of the individual main circulation pumps and the steam generators without decreasing the water level of the reactor coolant.

- A unique safety feature of the WWER 440 is a large volume of cooling water contained in the primary circuit and in the steam generators. The ratio of the total coolant volume to the core power is for the WWER 440 more than twice as much as for a new German PWR. The coolant volume is a valuable buffer that gives time for corrective actions in abnormal events where the balance between heat production and coolant supply has been lost. The large amount of secondary water contained in the SG allows, in comparison with German and French reactors, a relatively long period (more than six hours) to facilitate decay heat removal before the use of the EFW system. This fact saved a WWER 440 plant from a severe accident at least twice (Greifswald 1975, Armenia 1982).

- The tow deaerators and two turbines are a good buffer against disturbances at the turbine plant.

  It also means that one single turbine trip does not necessitate a reactor scram but only a controlled power reduction to 50 % of the nominal power.

- The existence of six cooling loops (instead of two, three of four which are found at other pressurized water reactors) means that transients such as stop of a main coolant pump cause only a small deviation from normal values of the main control parameters.

- The decay heat removal from a shutdown reactor is organized in a manner which makes the heat removal path less vulnerable to operating errors than in the Western type of pressurized water reactors; recent studies in France and USA have suggested that almost half of the total risk of a severe reactor accident comes from loss of decay heat removal during shutdown conditions.

Basic design deficiencies and positive features were confirmed during the IAEA Safety Review Missions, although the value of a number of design strengths and specific plant modifications have also become evident. Moreover, there are major operational shortcomings. There are serious problems with the effectiveness of management in identifying and correcting nuclear safety issues; there are deficiencies in the material conditions of equipment; there are shortcomings in fire protection; vital operating procedures are frequently incomplete and their use is not enforced. Training programmes are insufficient and there is a lack of adequate simulators. Shortcomings in regulatory oversight, particularly with adequate inspection capability and the lack of enforcement authority have been identified.

Of particular safety concern were the findings of the mission to Kozloduy Units 1 - 4 in Bulgaria. On the basis of the findings, the Director General wrote the Bulgarian Prime Minister and urged that he undertakes the vitally needed steps to upgrade conditions to allow operation even to an interim basis. The major shortcomings observed in Bulgaria, particularly those related to the material conditions of equipment, were not evident on visits to the similar type plants in Czecho-Slovakia and in Russia.

The Republic of Bulgaria belongs to the countries which are extremely poorly endowed with energy resources. The organic fuel resources amount to about 200 tons of oil equivalent per capita as compared with average of 2 000 tons in the world. The hydro resources are also scarce. The country has practically no oil and gas.

Nevertheless, from 1970 to 1990 the consumption of fuel and energy resources in the country increased by 70 % reaching 46-47 million tons of oil equivalent (Diagram 7). In 1990 the energy consumption per capita was 4 500 kg of oil equivalent (KOE), close to that in the former West Germany. The development of power generating capacities and energy consumption in the country during the same period has been more intensive and from 19.4 billion kilowatt-hours in 1970 reached 49.2 billion kilowatt- hours in 1989 (Diagram 8). This process is typical for all developed countries and is directly related to the all round economic development of Bulgaria. If we look back again at the international comparisons we will see that with 5 200 kilowatts per year Bulgaria exceeds two times and a half the average in the world (1926 kilowatt-hours) and rates before Hungary (3 255), Poland (3 354), Italy (3 443) and others. Main share in the growth of the energy production falls on the priority use of low-calorific lignite mainly at the "Maritsa-East" plant which now surpassed reasonable limits.

Annually, 1.2 million tons of sulfur dioxide are emitted into the atmosphere, thousands of decares of luxuriant soil in the Thracian lowlands have been destroyed. Under these circumstances the country had only one alternative to provide for normal economic development - to develop nuclear power. It started in 1970 with the construction of the first NPP "Kozloduy" unit. It was put on line in 1974 with the three following on the same side coming on line in 1975, 1980 and 1982. The four WWER 440s are type V-230s.

Unit 5 went on line in 1987, unit 6 is under power tests and the BNSA (Bulgarian Nuclear Safety Authority) has granted a licence for power tests up to 100 %.

Currently, NPP "Kozloduy" accounts for 35.6 % of the country's energy production . For over 17 years of operation 177 terawatt-hours of electric power have been produced. The average load factor per unit over the whole period of their operation is about:

Unit 1	17 years	72.76 %
Unit 2	16 years	75.95 %
Unit 3	11 years	78.89 %
Unit 4	9 years	82.34 %
Unit 5	3 years	44.50 %

The first four Kozloduy units rate among the best in the world according to this indicator (as compared with the world NPPs in operation). In spite of the good operational results we are all aware that the times when the honorary chairman of the IAEA Mr. Zigvard Eklund pointed out Bulgaria among the few countries in the world which give "good example of continuous and successful nuclear programs" have passed for good. Currently, the problems the Bulgarian nuclear power is facing are more numerous than the positive results. The trends in this field are also not positive. Over the last 7 years (1983 - 1990) in the BNSA have been reported 45 safety-significant events. In 1991, 36 events have been reported. The difference is evident and is due not only to the stringent performance of the requirements of the operating utility. The all-round crisis in our society over the last years affects inevitably the nuclear power industry of the country.

According to the preliminary forecast NPP Belene units 1 and 2 should be put in operation by 1995. Currently, the construction works there have been suspended due to the protests of the population of the nearby town of Svishtov notwithstanding the fact that about one billion dollars were invested there. To proceed with construction works on the Belene side in the nearest future is practically impossible.

In this situation and under circumstances of highly limited economic feasibility to import electric energy Bulgaria has no other alternative but to continue operation of the NPP Kozloduy.

In spite of this, irrespective of the difficult consequences for this country's economy and mainly for its population due to the imposed regime of electricity supply in the fall of 1991 Bulgaria shut down the first two units at Kozloduy NPP in order to perform a broad programme for modernization. This was not done neither in the CSFR nor in Russia. Thus, the government of Bulgaria and the regulatory authorities in the country (BNSA) proved in practice the change in the approach and the change in the priorities in its activities. For the first time, the problems of nuclear and radiation safety were placed above the temporary political and economic interests.

The programme for Restoring of Systems and Equipment Design Functional Availability and Upgrading of the Operational Reliability and Safety of Units 1 and 2 - NPP Kozloduy is part of so-called "Special Project" established within WANO (World Association of Nuclear Operators) for assistance from western utilities to operating utilities in Bulgaria, Czecho-Slovakia and the former Soviet Union.

Two WANO working groups, one in the Moscow Center another in the Paris Center, have been cooperating for six months last year within the so-called "Special Project". Their purpose was to define areas where assistance by western utilities to Eastern countries operating WWER 440/230 was suitable for implementing their modernization programme of V 230 NPPs.

To that end they have issued complementary design programmes for a dozen of generic issues to be developed to improve the basic safety of these reactors, both in design and operation. In addition, they have agreed on design review inspections by western experts to assist in evaluating the technical solutions for implementing the measures included in the modernization programmes. Lastly, active twinnings between each V 230 plant and a western plant have been welcomed by operating countries.

Because of the urgent need of assistance and due to the deadlines imposed by local regulatory authorities , it was essential to start this programme very quickly, from July 1991.

Therefore, it was decided to select and define a limited number of urgent tasks to be undertaken over the next six months to assist immediately the operating countries in fulfilling their commitments as regards improvement of safety. The corresponding six months programme is thus the first stage of the whole programme which addresses short-term and medium-term measures.

It is based on the above mentioned WANO MOSCOW/PARIS agreed proposals, with additional details covered the first six months. It includes an evaluation of the corresponding required recourses.

This six months programme is divided into two main parts:

PART A : deals with generic issues which are relevant to all the plants.

PART B: is devoted to the specific and complementary assistance to KOZLODUY.

WANO has been acting like an operator during the past six months. WANO's role has been to assist operating utilities to define the assistance they could be given by western countries to implement their own backfitting programmes and to identify the ways and means for this assistance to be provided, including drafting of applications to the European Community for requesting funding of this work.

Recapitulation of resources requirements to implement this programme over the first next six months shows a few millions ECUs over 1991, out of a programme which should amount approximately to 50 millions ECUs.

For all the generic issues WANO has proposed a consistent approach to all WWER 440/230 operators. Therefore, provisions are made in each proposal for international integrated teams (advisory or coordination) including experts from Russia, Czecho-Slovakia, Bulgaria and western countries.

If is assumed that full assistance will be provided by the eastern partners, in releasing necessary proprietary information with high priority.

Content of the six months programme:

1. It refers to the following generic issues which have been considered as requesting urgent action:

- reactor vessel integrity (complementary programme on vessel embrittlement);
- main pipework integrity (application of leak-before-break criterion);
- review and extension of accident analysis;
- qualification of confinement;
- qualification of sensors, actuators, electrical and mechanical equipment under accident conditions;
- elaboration of revised operating procedures;
- simulator improvement;
- probabilistic safety assessment Level 1 (PSA) for Kozloduy 1/2 units.

2. In addition, design review inspections are proposed.

They are aimed at assisting local design organizations or institutes in evaluating technical solutions proposed to implement short-term measures of the backfitting programmes.

As regards Kozloduy NPP, specific assistance is developed on the request of Bulgarian authorities by EC according to the PHARE programme. EC has given a grant of 11.5 million ECU to support project for increasing Kozloduy safety. The money can be used to pay for the work by the western experts and organizations but not to finance the purchase of hardware.

These works were also coordinated by the World Association of Nuclear Operators (WANO) under the so-called Additional Specific Assistance to Kozloduy NPP.

Content of the Programme for the first six months was:

1. As per PART A the following issues have been considered as requesting urgent actions:

- delivery of Greifswald spare parts (a proposal was sent to Kozloduy by Greifswald Management);
- dispatching of Greifswald control room operators to Kozloduy (still under consideration by the Bulgarian Government);
- training at Novovoronezh's simulator of Kozloduy operators;
- training programme and facilities improvement;
- up-grading of technical documentation for units 1 to 4.

2. "House-keeping", urgent actions requested by IAEA, following their OSART mission in June, are also included in this programme.

3. Assistance in management.

On the other hand, active twinning between Bugey and Kozloduy NPP's and assistance from Greifswald NPP are aimed at helping in managerial problems at the plant.

A protocol was signed in June and cooperation has already started with Bugey.

The aim of these programmes was to improve quickly the material conditions of the plant and to start upgrading of safety culture. Besides the guidance on good management, operations and maintenance practices, the programmes have supported planning of minor hardware improvements which can be implemented by the site organization. The positive results of the programme are already seen in the significant improvement of the order and cleanliness in the plant spaces. Worth mentioning is also that unit 5 had recently been in a ten day long outage, because the safety equipment had not been in a condition which is required for continued power production. Start-up of unit 5 had been permitted only after the safety equipment operability had been restored. Due compliance with the limits and conditions set for safe operation is different from the old habits and indicates new safety attitudes.

Another programme, called sometimes by a common name "Six months programme" is being launched to implement the "Generic 6 month WANO programme". This programme is not going to be completed in six months but will take several years. It involves extensive safety analysis and feasibility studies which in distant future might lead to concrete improvement proposals. Most of the work to be done in the "Six months programme" is similar to the work which is done at the western plants during the plant construction phase with ample time.

Now, at the end of the current bidding process, 4 contracts are signed by the Bulgarian Authorities with the following western companies to deal with generic issues which ar relevant to all the plants:

- Belgatom + IVO
- Siemens + EOF
- Empressa Agrupados
- Westinfhouse + Endesa + Tecnatom + Inetec.

These companies have to start urgently their work because the above two programmes are included in " an outage Assistance programme" which helps to manage and coordinate work during ongoing outages of units 1 and 2. This programme includes measures for restoring initial design conditions of systems and equipment and also measures for up-grading the operational safety of these units. It integrates all the requirements of the BNSA (Bulgarian nuclear safety authority) and of IAEA (following OSART and ASSET missions).

The programme has been handed over to BNSA and a "licensing process" has started: the normal results of such discussions is the issuance by the Safety Authorities of a "licence" to restart the units if the programme is successfully implemented.

Gentlemen,

Nuclear energy development in Bulgaria and the Eastern European countries is in a very difficult and critical stage. Both nuclear power specialists' in these countries and world public's understanding is that we have neither financial nor intellectual potential to solve all problems in our NPPs. On the other hand, a difficult economic situation and threatening power collapse face these countries, and especially Bulgaria, with a very difficult dilemma.

We are sure that only the coordinated mutual efforts of the governments, IAEA and the world nuclear society could help to solve the problems we are facing. That will be of great benefit and importance not only for Bulgaria but also for the development of the world nuclear energy.

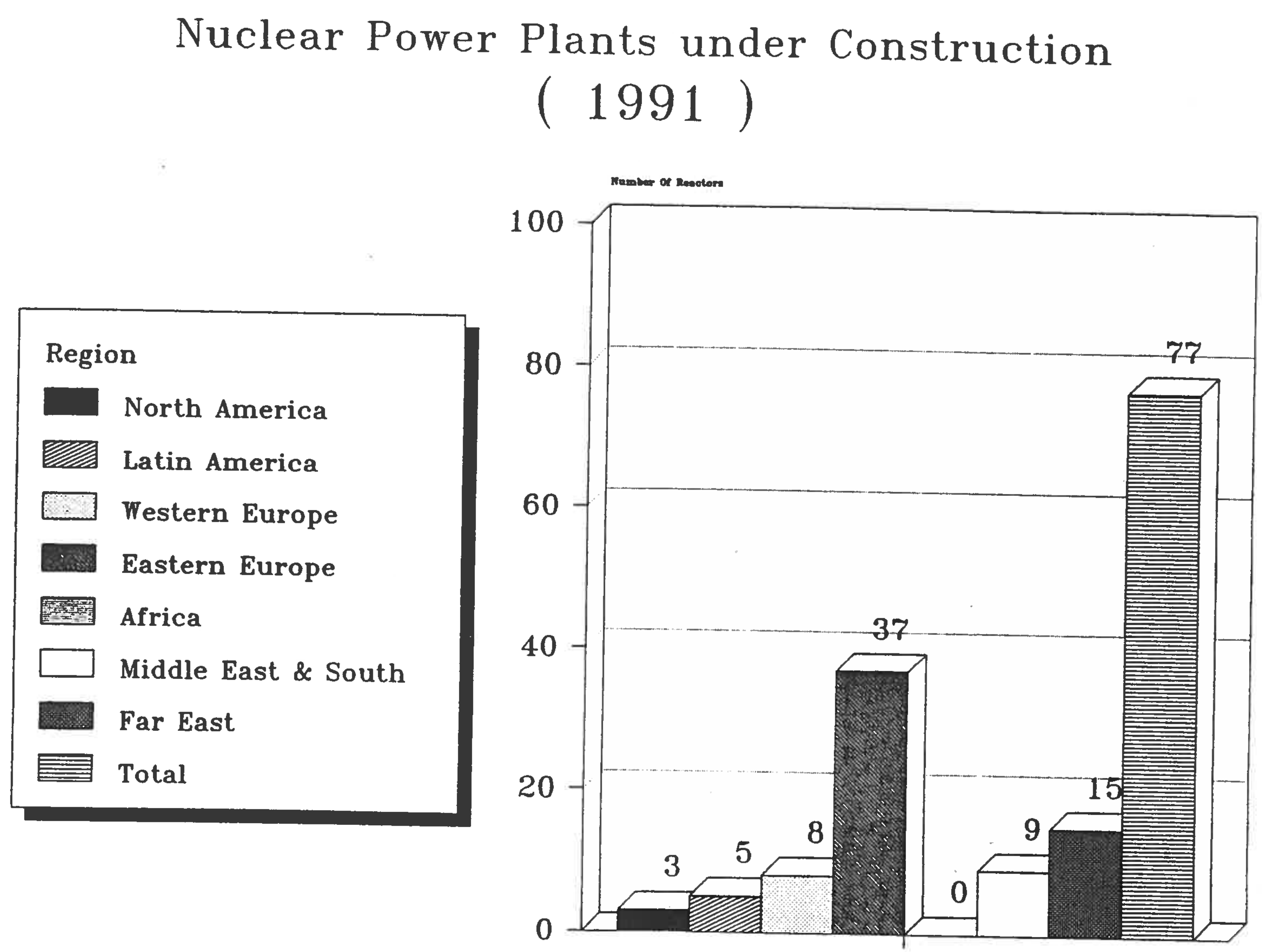
Nuclear Power Plants under Construction
(1991)
Number Of Reactors
100
80
60
40
20
0
3
5
8
37
0
9
15
77
Region
North America
Latin America
Western Europe
Eastern Europe
Africa
Middle East & South
Far East
Total

Figure 2

WWER-440 MODEL 213 REACTORS

USSR	Rovno	Unit 1	1980
		Unit 2	1981
	Kola	Unit 3	1982
		Unit 4	1984
CSFR			
	Bohunice	Unit 3	1984
		Unit 4	1985
	Dukovany		
		Unit 1	1985
		Unit 2	1986
		Unit 3	1986
		Unit 4	1987
		Unit 2	1981
FINLAND			
	Loviisa	Unit 1	1977
		Unit 2	1981
HUNGARY			
	Paks	Unit 1	1983
		Unit 2	1984
		Unit 3	1986
		Unit 4	1987

Figure 4

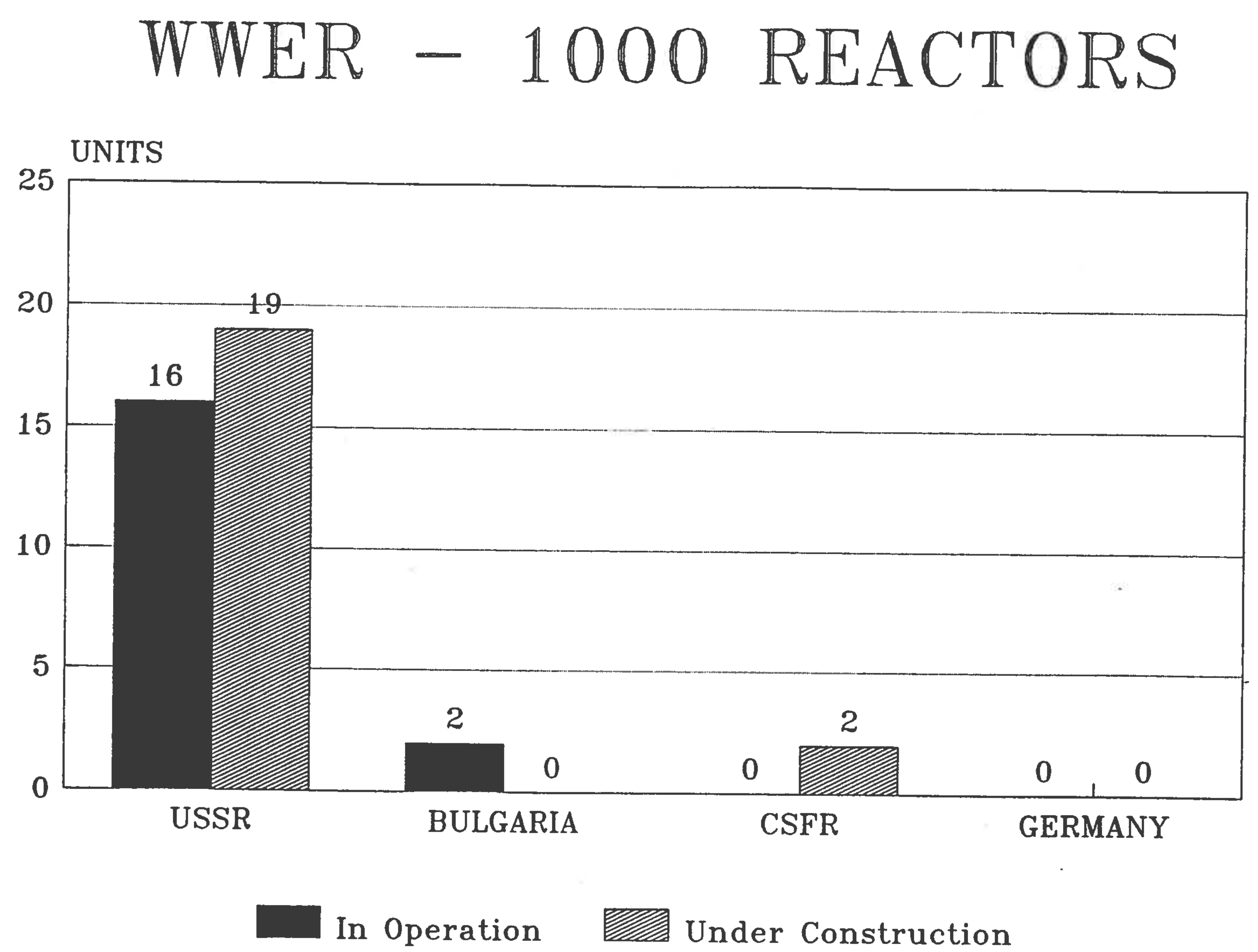
WWER – 1000 REACTORS
UNITS
25
20
15
10
5
0
16
19
2
0
0
2
0
0
USSR
BULGARIA
CSFR
GERMANY
In Operation
Under Construction

Figure 5

RBMK REACTORS

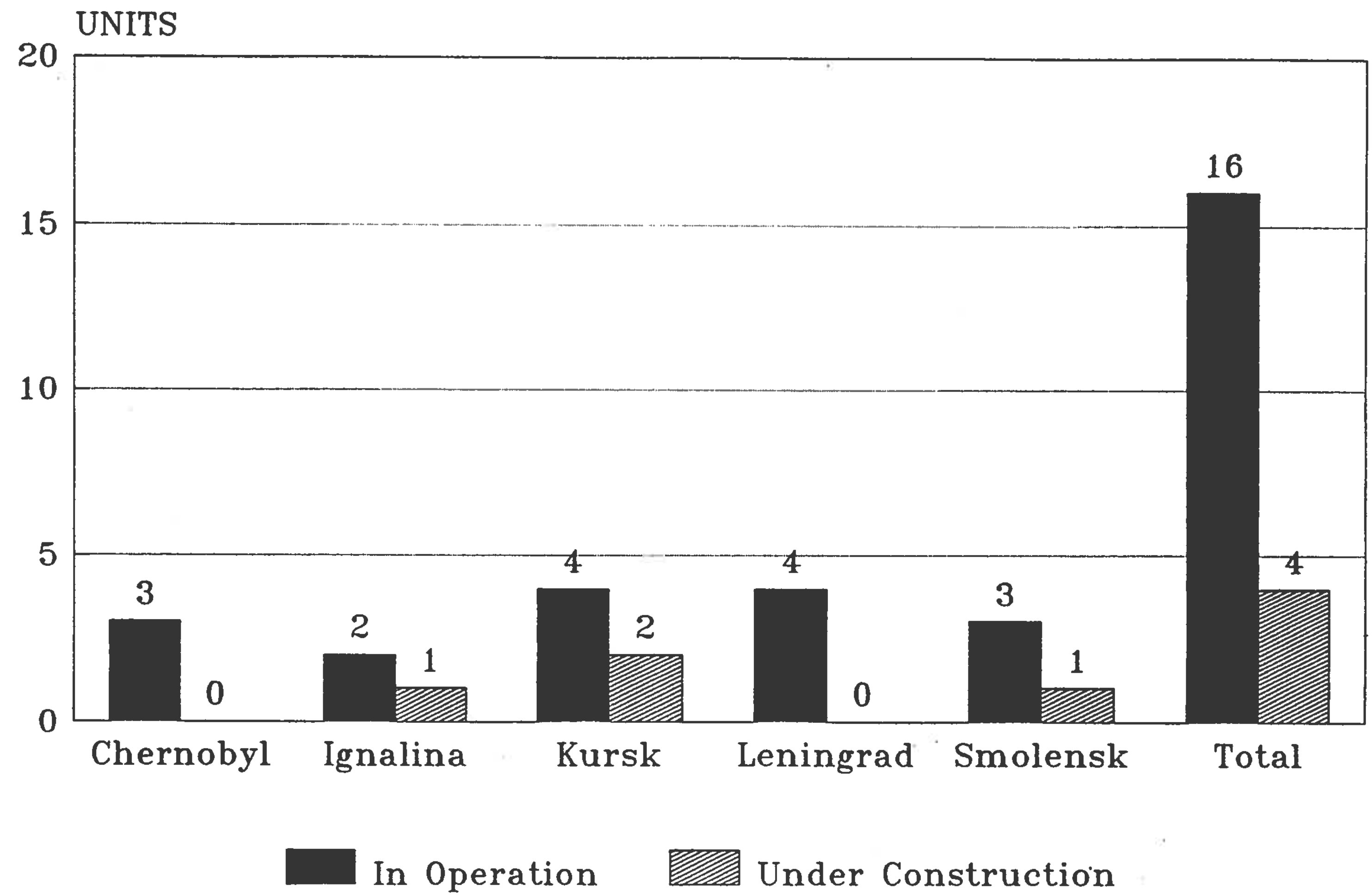

Figure 6

Electrical Energy Consumption
(1960 - 1990)

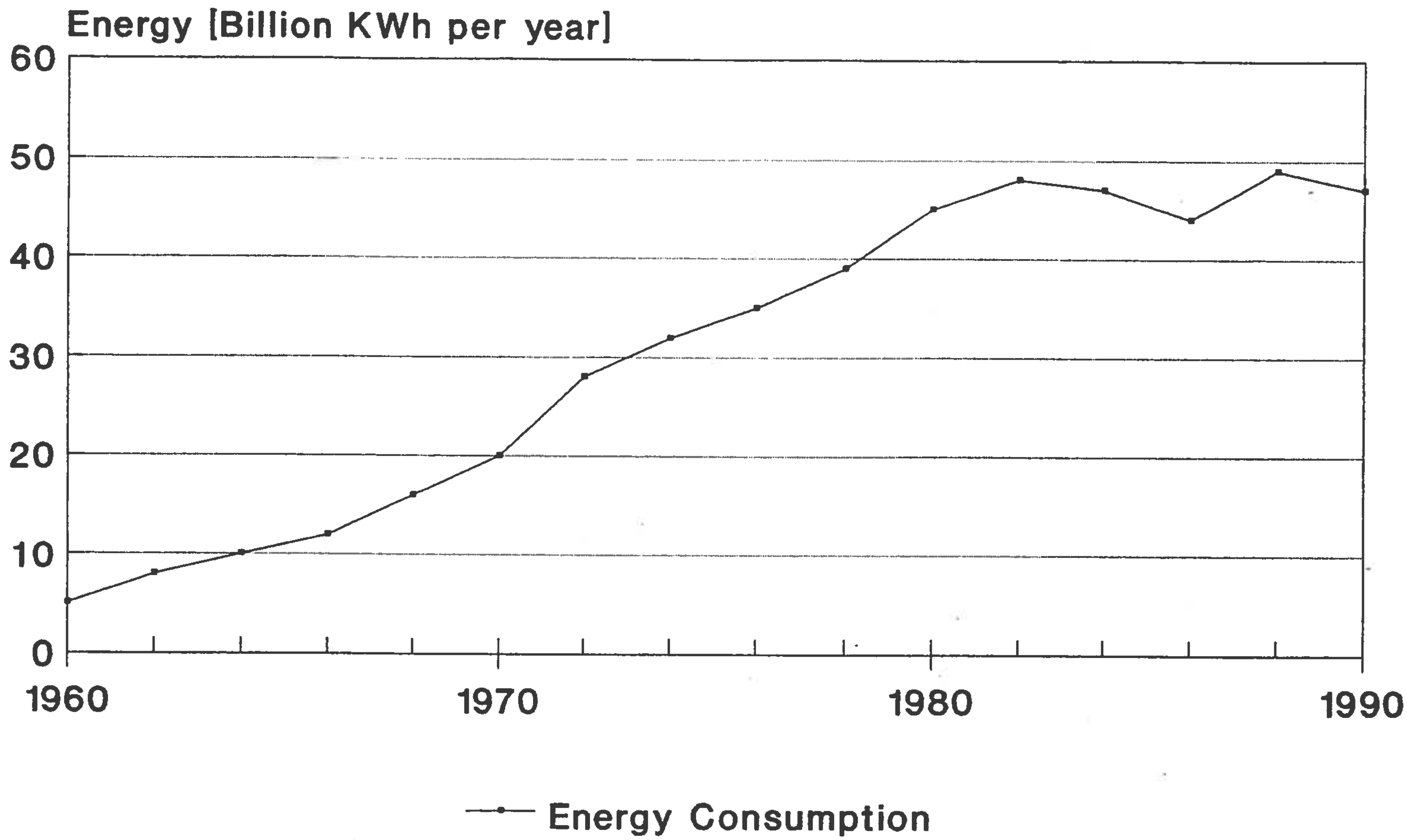

Figure 7

Development of the primary energy resources consumption

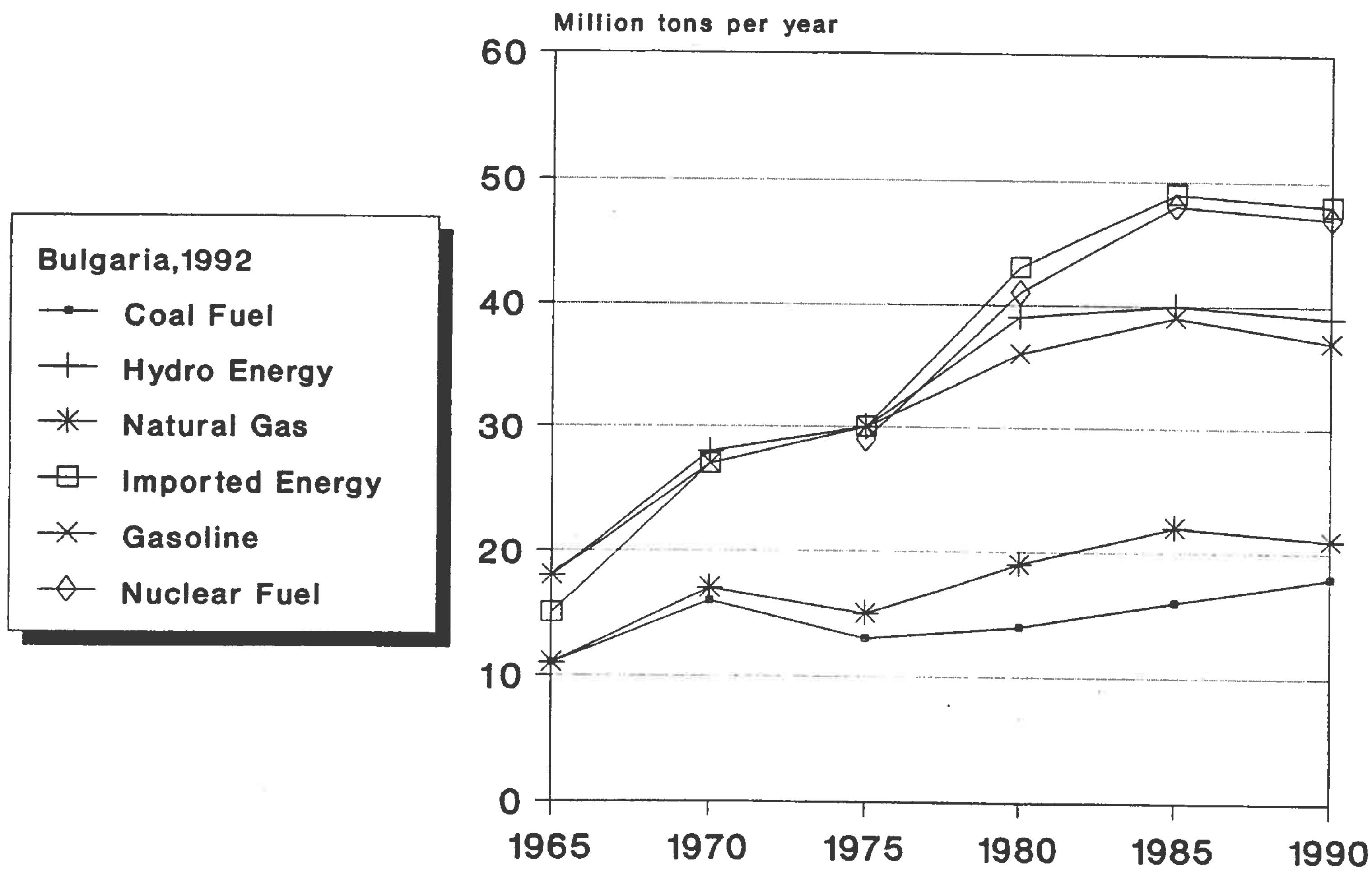

Figure 8