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The Integrated Energy-Economy-Environment Model System has been developed for providing analytical tools for the system analysis and technology assessments in the field of nuclear research and development. This model system consists of the following four model groups. The first model block installs 5 models and can serve to analyze and generate long-term scenarios on economy-energy-environment evolution. The second model block installs 2 models and can serve to analyze the structural transition phenomena in energy-economy-environment interactions. The third model block installs 2 models and can handle power reactor installation strategy problem and long-term fuel cycle analysis. The fourth model block installs 5 models and codes and can treats cost-benefit-risk analysis and assessments.

This report describes mainly the progress and the outlines of application of the model system in these years after the first report on the research and development of the model system (JAERI-M 84-139).

Keywords: E^3 Integrated Model System, Systems Analysis, Technology Assessment, Time-series Analysis, System Dynamics, Linear Programming, Econometrics, Inter Industrial Transaction, Zero Emmission, Economic Assessment

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This report was distributed at IEA/ETSAP Workshop held at Brookhaven National Laboratory on June 24-30, 1987.

エネルギー・経済・環境統合モデルシステム開発に於ける進展

日本原子力研究所動力炉開発・安全性研究管理部
安川　茂・萬金　修一・佐藤　治
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（1987年10月19日受理）

原子力研究開発に係る戦略分析や技術アセスメントを行うためにエネルギー・経済・環境領域にまたがる統合モデルシステムを開発している。当モデルシステムは4モデル群から構成されており，第1モデル群は我が国の長期にわたる社会・経済・エネルギーの発展をダイナミックスに分析し，経済・エネルギー・環境のシナリオ創出を行う事を目的としたモデル群から成っている。第2モデル群はエネルギー・経済・環境の相互関係を構造的に分析する事を目的としたモデル群から成っている。第3モデル群は炉型戦略分析と長期核燃料サイクル分析を目的としたモデル群から成っている。第4モデル群はコスト・ベネフィット・リスクアセスメントを目的としたモデル群から成っている。当モデルシステム開発については第一報を1984年に報告した（JAERI－M　84－139）が，当報告ではその後の進展，適用例の概要に重点を置いて報告する。

本報告書は1987年6月24日，BNL（ブルックヘブン国立研究所）で開催されたIEA/ETSAP（国際エネルギー機関／エネルギー技術システム分析プロジェクト）会議において発表，配布された。

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Since the beginning of the Energy Technology Systems Analysis Project (ETSAP)/Annex II (July 1983 - June 1986), we reported three times to the ETSAP workshop on the development of the Integrated Energy-Economy-Environment Model System [1].

The objectives of developing the model system at JAERI are to provide an analytical tool for the system analysis research field and to apply it to the interdisciplinary problems. In the course of this development, we have learned a lot from the ETSAP working subjects.

As being clear in the successive chapters, the present status of the model system is still in the early stage of application. We may require verification of each tool through application of it to well defined problems. Also, some of tools, such as for decision-analysis, risk assessment, optimization under probabilistic constraints, are still missing.

It is an obvious matter for us that each model concept of our tools has a right to grow up and has a nature of growing-up by itself. However, it is also right that in the course of growing-up they need some stimuli and nutritions. Much broder and complex the system analysis problems become, more concise and fundamental approaches are necessary. The interdisciplinary problem on energy environment matter has such nature so that we are going to make a check & review of our tool and data base at this moment.

2. Model Description

2.1 General Structure

The Integrated Energy-Economy-Environment Model System (Intergrated E^3 Model System), as shown in Fig. 1, consists of the following four model blocks.

The first model block, called as the dynamic scenario generation block, can serve to analyze and construct long-term scenarios on socio-economy evolution with such analytical approaches as system dynamics technique and macro-econometric method. The second model block, as a part for analyzing structural nature of the energy-economy intertaction system, installs the MARKAL model and the input-output model. The third model block handles power reactor installation strategy problem and long-term fuel cycle analysis. The fourth model block treats cost-benefit-risk analysis and various data bases are also included in it.

2.2 Macro Energy-Economy-Environment Model Group

Five macro energy-economy-environment models have been developed for purposes of analyzing, evaluating, projecting,

1. Introduction

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2.2 Macro Energy-Economy-Environment Model Group

Five macro energy-economy-environment models have been developed for purposes of analyzing, evaluating, projecting, and estimating present and future macro energy-economy-environment situations in Japan, and for generating energy-economy-environment scenarios for structural analysis and technical assessments.

They are the macro **E**nergy-**E**conomy-**E**nvironment **M**ulti **V**ariable **A**uto-**R**egressive model EEEMVAR, the macro **ENERGY** **S**ystem **D**ynamics model ENERGYSD, the **L**ong **T**erm **M**acro **E**conometric **MO**del LTMEMO, the model of **TR**ansition in **E**nergy-**E**conomy **PH**enomena TREEPH, and **M**acro **E**conomy-**E**nvironment **MO**del MEEMO. The development of former three models has been already finished, and the final stage of development has been almost attained in the TREEPH model, but the last one is now at the start of development.

EEEMVAR contains energy-economy-environment time series data and algorithms of time-series-analysis and identifications of multi-variable autoregressives type models [1].

ENERGYSD is programmed by DYNAMO language and formed a macro energy demand-supply data base, and it's parameters are obtained by estimation from statistical data, and technical and economic performance data [2].

LTMEMO is composed of almost 70 differencial equations and 40 definitive functions of macro economics in Japan. Parameters in each function are estimated based on national statistic data base [3]. LTMEMO has economic statistic data files and its treatment sub-program and parameter estimation sub-program of various econometric functions. By using these sub-programs, the reference econometric model can be improved and modified easily corresponding to behavioral principles in scenario generations.

TREEPH is constructed by time-invariant non-linear dynamic equations using DYNAMO language and designed to provide the information on structural transition process of energy-economy situation of Japan for longer term than ENERGYSD.

MEEMO are now projecting to be developed to provide projectins of macro environmental indices of Japan based on analysis on the interactions between macro economic activities and environmental effluents of Japan for long term.

2.3 Improvements of MARKAL for Environment Analysis

As describsed in the section 3(2), some simple methodologies were preliminary proposed for the environmental analysis of total energy system by the MARKAL model, at the time when we promoted the international cooperative research program of the study on the role of very high temperature reactor and nuclear process heat utilization in future energy systems [4].

As shown in Table 1, the outlines of those methods are grouped roughly into four categories. The first category is based on case studies in which time series effluent data and cost of each control technology of effluents are changed corresponding to the scenarios on the development of environmental technologies. The second category is mainly dependent on more schematic approach, i.e. some representative control technologies of effluents are selected based on data base and integrated into a reference energy system. The third category is based on addition of new constraint-equations and bounds related to the characteristics of fuels, effluents and cost of energy technologies. The fourth category is based on the performance indices newly added into the objective function of MARKAL and on the trade-off analysis between total system cost and the amounts of effluents.

In the preliminary stage, we found some difficulties in the methods of the 1st and 3rd categories, because the estimates on technical and cost data of control technologies and detailed emission data of energy technologies were not sufficiently available for us. Moreover, the addition and improvements of constraint-equations required complicated program work and are difficult in short term, because MARKAL facilitated in JAERI is written in FORTRAN-IV languages. Therefore, the second and forth approach are adopted for environmental analysis described in section 3(2).

The first improvement is to expand appropriate dimension of variables for the purpose of including not only existing reference energy system but also representative environment control technologies. As the results of the improvement, we build up a large energy-environment system which is composed of 28 CONs, 374 PRCs, 164 DMDs, and 1169 MEMBERs, etc..

The second improvement is to add performance indices of effluents into the objective function after calculating ENV(ENV) in each column coefficient. In replace of SECURITY function, a function composed of summation of ENV(ENV) is programmed. As the result of the improvement, the trade-off analysis between the total system cost including costs of effluent-control technologies and the amounts of environmental effluent are becoming available for us.

2.4 E-I/O(TRANS) Model

The E-I/O(TRANS) model is a multi-sectoral energy-economy interaction model to analyze structurally the long-term evolution of energy-economy systems. The objective of the development is to present the degree of the substitutability and complimentarity among factor inputs under the change of energy technology configuration through quantifying the magnitude of these opposite properties taking into account the technical progress. The model also estimates the impact being brought upon energy technologies from the rest of an economy system. Further, the economic influences of environmental countermeasures in energy systems can be analyzed through changes in cost of energy technologies and pollution control technologies.

The model consists of two sub-models, i.e. TRANS-I/O and E-MATRIX. In the former sub-model, various economic activities and inter-industrial transactions are determined by the input-output method with variable coefficients. While the latter sub-model incorporates the framework of energy matrix analysis to allow combined calculations with MARKAL. Major endogenous functions and/or exogenous variables in the model are the cost share functions representing inter-industrial transaction, consumption functions, investment functions, leisure functions, converters for consumption and for investment, dynamic capital coefficient vectors and operation & maintenance coefficient vectors for energy technologies [1].

Beside the full use of the cost share functions, an option is prepared to reflect to some extent structural changes of an energy system optimized by MARKAL. In this option, input coefficients of energy sectors are generated in E-MATRIX based on the MARKAL solution and then incorporated forcibly into the I/O framework determined by I/O-TRANS. Pilot study of the model for these options is in progress. The results obtained so far indicate relatively large sensitivity within macro economic balances to changes in such quantities as investment price deflator, depreciation rate of capital stock, labor supply, and rate of technical progress in each industry. Two examples of the results are shown in Fig. 2(a) and Fig. 2(b).

A model is now being developed to estimate future demand for useful energy and to serve as a bridge between E-I/O(TRANS) and MARKAL. The model calculates the long-term demand for useful energy in each disaggregated sector of final energy consumption based on the economic activities determined by E-I/O(TRANS). The results can be directly used in MARKAL as its input data.

The model consists of three sub-models each corresponding to the industry, the residential & commercial, and the transportation sector. In the residential & commercial and transportation sub-models, energy demand is calculated based on the characteristics of consumption technologies and their implementation levels in future economic circumstances. While, the industry sub-model has the simplified framework of industry processes. For a given production level of each industry, it calculates useful energy demand for each category of demand devices. The main computer programs are almost completed and technology data are being prepared.

2.5 JALTES Models

The JALTES models have been developed in order to study on long-term reactor strategies and to analyze in detail nuclear fuel cycle systems. The first version was completed in 1976 based on the fuel cycle models developed in JAERI [5]. JALTES-II was then developed to allow more detailed calculation of nuclear fuel balances and fuel cycle activities [6]. This model has been often applied for a variety of subjects associated with future nuclear power development [7]. JALTES-III, the latest version of the JALTES models, has been developed through fundamental modifications on JALTES-II. The brief descriptions of JALTES-II and JALTES-III are given in the following.

JALTES-II is a model to optimize future capacities of nuclear power reactors by the LP technique and to calculate relevant nuclear fuel cycle quantities. The variables for a linear problem are annual additions to capacity of each reactor type. The objective function can be taken as a cumulative consumption of natural uranium, or a total system cost, or others. Constraints can be given to annual electricity generation, installed capacity of each reactor type or total installed capacity, stocks of fissile plutonium, etc.. Inputs to the model are scenario assumptions, reactor and fuel cycle characteristics. Outputs are the information on reactor capacity, materials and fuel cycle services, and system cost.

JALTES-III is also a linear programming model. But it has additional variables representing flows and stocks of materials at each step of a nuclear fuel cycle. Also, it simulates the fuel management which takes place at non-integer yearly time intervals. Moreover it can calculate fuel cycle costs in more detail than JALTES-II. One more feature of JALTES-III is its sofisticated output system. A variety of figures and tables can be produced through full-screen operation of the output control program. Though major part of the model is now completed, it will be improved further through applications to various subjects.

2.6 Cost-Benefit-Risk Assessment Model Group and Data Base

The fourth block in Fig. 1 involves cost-benefit-risk assessment models and data bases. Model group at present consists of five models, i.e. the **S**ingle-**U**nit **P**ower **P**lant **CO**st estimating model SUPPCO, simulation model on **FINANC**ial conditions in **E**nergy industries FINANCE, **RE**gional or **LO**cal **S**ocio-**E**nvironmental impact of energy **P**lants RELOSEP, computer code for **CONCEPT**ual cost estimates for steam-electric power plants CONCEPT, and MARKAL with function of value flow analysis.

i) SUPPCO

Recently, economical assessment of nuclear and fuel cycle technologies becomes important in nuclear R & D fields, because of over-abundant in fossil energy supply and increasing phenomena in R & D cost in advanced nuclear systems. We, therefore, have developed and facilitated some cost assessment models of nuclear power plants.

SUPPCO can produce generating costs of a single unit power plant at a reference year by the levelized cost calculation methods. The model consists of mainly four subprograms, for a) plant capital cost calculation, b) non-fuel working capital calculation, c) nuclear fuel cycle cost calculation, and d) operation and maintenance cost calculation. Especially, the item c) is broken down in detail and has simple and complex methods reflecting non-linearities and stock activities in nuclear material flows in fuel cycle systems.

ii) FINANCE-K/M

The purposes of the financial model of energy industries include to evaluate the situations of financial operations in nuclear industries and to calculate process or production cost in each of nuclear fuel cycle industries. After calculating production or process cost sufficient for given internal reservations (or internal rate of return, or internal rate of return on equity, or dividend rate), the model can provide such financial tables as income statements, cash flow statement, balance sheet, detailed operating and administrations cost table, financial performance indicators, and technical data tables , and can make detailed financial analysis for the energy industries with a single unit energy facility by the K-method or with a number of various facilities by the M-method.

iii) RELOSEP

RELOSEP is a system dynamics model to evaluate quantitatively the impacts of a large scale energy facility to economies and environments in regional societies. It consists of 14 sectors such as population, land use, transportation, industries, public facilities, financial, water resources, energy, environment, etc.. The environmental sector has air pollution, water pollution, and waste subsectors and can take into account not only direct impact on environment by siting and operating of energy facilities, but also indirect impact on environment through the increase of activities in industries caused by siting of energy facilities.

iv) CONCEPT Model

CONCEPT is a model to provide conceptual estimates for capital costs of nuclear-fueled and fossil-fired power plants based on the cost model data and historical cost data on equipments, labor, and materials. Cost estimates can be made as a function of plant type, size, location, and date of initial operation. The original computer programs together with cost data sets have been developed and updated at ORNL in the US.

The source programs and cost data sets of CONCEPT-4, prepared for the IBM machine, were introduced and converted for the use on the FACOM machine in JAERI. Normal operation of converted programs and data files was confirmed through sample calculations. The modification was then given on the output routine to provide additionally the cost breakdown along with the industrial classification in the I/O tables of Japan.

v) MARKAL-Value Flow Program

A computer program has been developed to calculate value flows and benefit/cost ratios of energy technologies in a MARKAL optimum solution. The algorithm of the program is based on the mathematical formulation given by Finnis et al. [8], where the value flow is defined as a multiplication of column activity, dual activity, and matrix coefficient Aij for corresponding column and row, and the benefit/cost ratio is defined as value out divided by the sum of value to sink and value out.

The program is written in FORTRAN, and is independent to the conventional report generator of MARKAL. The input data are a MARKAL class dictionary, MARKAL data tables, a BCDOUT (input to MPS/X), and a optimum solution of MARKAL. Calculation is made only for technologies specified exogenously. The output data include all value flows and benefit/cost ratios for each of selected technologies.

vi) Technology Data

Energy technologies are classified into conversion, process, and end-use technologies as defined in the MARKAL model. As for conversion technologies, electric power, cogeneration, and district heating plants, and electricity storage plants are registered, and as for process technologies, refinery technologies, synthetic fuel production technologies, and nuclear fuel cycle technologies. As for end-use technologies, various heating devices and motors for industry, residential and commercial uses, devices for transportation use are registered.

Technical performances of these energy technologies have been investigated to compile the data along with the items 1.1 - 1.11 and 4.2 in Table 2. Especially for nuclear energy technologies, reactor characteristic data are compiled on such reactor types as conventional LWR, advanced LWR, advanced thermal reactor (ATR), FBR, high conversion light water reactor (HCLWR), and high-temperature gas-cooled reactor (HTGR).

As far as cost data are concerned, items 2.1 - 2.13 in Table 2 are the same as cost data for the ETSAP Energy Technology Characterization, however, the item 2.14 is newly added for energy-economy interaction analysis by TRANS-I/O combined with E-MATRIX, and the item 4.3 is also newly added as cost data of environmental protection technologies. The above-mentioned item 2.14 is to define the input structure from each industry to constitute the total investment and O&M costs for an individual technology.

vii) Environmental Data

As for the environmental data, the main subjects of investigation are to compile emission data of pollutants from energy technologies, and also the information on technologies and equipments for environmental protection against individual pollutants as shown in items 3 and 4 in Table 2.

These pollutants are classified into air pollutants, water pollutants, and wastes as shown in items 3.1 - 3.3 in Table 2, and are measured at the exits of both energy technologies and protection technologies as shown in Fig. 3. The sources of these pollutants are raw materials of non energy kinds and raw materials and/or fuels of energy kinds.

Environmental data for MARKAL consist of environmental coefficients of resource activities, technology capacities, technology investments, and technology activities. In the case of adopting methodologies proposed in the section 2(3), the technical and cost data of emission control technologies are also necessary for analysis.

The data on environmental emissions are categorized into conversion technologies (CON), process technologies (PRC), and demand technologies (DMD) for environmental emissions of sulfur oxides (SOx), nitrogen oxides (NOx), and carbon dioxide (CO_2). The amounts of SOx and NOx emitted by the industry sectors are shown in Fig. 4(a) and Fig. 4(b).

We have collected the data on emission coefficients of energy technologies, and reduction rate and cost of emission control technologies. The data on environmental emissions of energy technologies are compiled taking into account following three points, i.e. a) sulfur content in fuels, b) NOx both from fuels and fuel combustion, c) CO_2 emission coefficents by Edmonds and Reilly for coal, oil and gas [9]. As far as the data on emission control technologies are concerned, some representative technical and cost data have been investigated on the equipments of desulfurization and denitration, because our preliminary approach to environmental analysis by MARKAL have been based on the 2nd method proposed in the section 2(3) and table 1.

viii) Fuel Mix

The process models for energy-intensive industries have been developed, by utilizing the framework of the MARKAL model, in order to analyze in detail the structure of energy consumption and to estimate specific energy consumptions and possible changes in fuel mixes in future. The pulp and paper manufacturing and iron and steel making have been so far selected for the development. Since the process model of the pulp and paper industry has almost completed, its outline is introduced in the following.

The pulp manufacturing process is divided into ten different processes each of which has unit processes for chipping, cooking or grinding, refining, screening, bleaching, and drying. The paper and board manufacturing process is divided into pulp blending and paper-making processes. The latter is further divided into 24 unit processes according to the fabrication methods. These unit processes are treated as "process technologies" in MARKAL.

The pulp and paper industry uses purchased fuels and recovered wastes as energy sources. The formers are treated as "imported energy carriers", while the latter as "energy carriers" produced in manufacturing processes. All materials, semi-products, and finished products are also treated as "energy carriers" in the MARKAL model. Beside the purchase from the outside, electricity is also generated inside this industry. The self-generation of electricity is modelled by using "conversion technologies".

The data on energy efficiency of each unit process have been investigated. Also, the historical data on consumption of fuels and materials, production of pulp and paper products have been collected. The results of preliminary interpolation studies for the years 1977 - 1983 have shown good agreement with actual figures for energy consumption in this time interval.

3. Model Application

3.1 IEA/ETSAP/FEEST

Since the initiation of the IEA energy systems analysis study in 1976, JAERI has been a member of the studying group. Till now, we have been engaged in the MARKAL model development, the energy technology characterization, and the scenario runs. On these works, the working results were documented into books, reports, draft materials, etc. [10].

In regard to the IEA/ETSAP/Annex-III and FEEST, we are now entering into another phase of research work, in which risk evaluation and/or assessment is strongly addressed. This risk evaluation calls us various kinds of attentions. For instances: How much is energy-related investment risk? How much is energy-related environmental risk? What kind of approach and methodology is most appropriate to handle the risk evaluation? Is the Probabilistic Risk Assessment (PRA) applicable in reasonable level now, especially for assessing cost-risk trade-off? Where is interdisciplinary problem area necessary for the PRA approach? Before tackling the research subject of the ETSAP/Annex III program, it seems worthy for us to make clinic on those questions.

3.2 Systems Analysis on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization

Since 1984, JAERI and MIT have been carrying out the cooperative research program on systems analysis. The subject of the program is the study on the role of very high temperature reactor and nuclear process heat utilization in future energy systems in the context of a) effective utilization of energy, b) aiming at zero emission, c) conveniency, d) stable supply, and e) economy. The study consists of four tasks, i.e. a) projection of energy demand and supply, b) energy technology characterization, c) impact analysis of energy technologies on national economy and environment, and d) identifying the path in research and development.

To carry out those tasks analytically, at first stage, we had established behavioral principles and performance indices of energy systems in our studies [11]. The details of analytical approach of studies and working schedule were settled. The reference energy system of future energy systems had been

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The energy-economy-environment related activities of Japan, which cover the time period from the year our national economy recovered to the pre-war level to the year it entered into the reduced economy, have been reviewed [13].

Macro-economic and energy supply scenarios for Japan through the long-term have been generated. The possible region of the socio-economy development till the year 2030 were analyzed by the long-term macro-econometric model LTMEMO, and the possible ranges of long-term energy-supply and demand were analyzed by the energy SD model ENERGYSD [14].

Within these scenario regions, the structural analysis on long-term energy supply-demand and its impact analysis both on national economy and on environment had been carried out. The analyses were made with MARKAL and E-I/O(TRANS) model. An example of the results is shown in Fig. 5 which indicates that nuclear energy and coal should take more important roles in future primary energy supply, and that nuclear energy will contribute not only to electricity supply, but also to non-electric energy supply through applications of high-temperature nuclear heat to such technologies as methane reforming, hydrogen production [15].

The analyses are now being made on the more detailed interaction problems between energy-economy and energy-environment of Japan, e.g. the analysis is being carried out by environment-modified MARKAL using environmental emissions as additional indices in order to investigate the role of the VHTR and its heat utilization systems from the viewpoint "zero emission to the environment". The results of these analysis will be presented at the ICIES/IIASA meeting in Vienna on July 1987.

The task d) of the study, i.e. identifying the path in R&D, has been also proceeded with a special attention to key technologies involved in our technological frame. There exist four fundamental processes behind this. The first one is a reforming process decomposing hydrocarbon material into CO and H_2, and the various impurities, such as sulphur, nitrogen, heavy metals, are removed from the products at the same time. The second is a synthetic process producing SNG and/or synthetic oil from separated gases. The third is a gas separation process, for instances, air separation, flue-gas separation. The fourth is a gas-turbine combined cycle which can be expected to have high thermal efficiency. Moreover heat pumps and cogeneration serve for effective utilization of energy.

Hydrogen becomes one of key energy carriers connecting the conversion technologies with end-use technologies. The production of hydrogen needs a large amount of energy. High temperature process heat from VHTR can be considered to be one of the most promising candidates as an energy supplier to it.

The systems analysis has been carried out in order to elucidate the concept of the IES. The results obtained at present are followings: a) The steam reforming process has been evaluated to be suitable for the conversion of carbonic resources to fuel oil and gas. b) The thermochemical hydrogen production process (UT-3 cycle consisting of Br, Ca and Fe compounds) is very atractive and has a great potential to become one of competitive hydrogen production processes. The energy balance of UT-3 cycle utilizing the process heat from VHTR is shown in Fig. 6. c) The CO reheat gas turbine combined power plant can be expected to realize a high level of cost-effectiveness when integrated effectively into an overall heat and power system.

3.3 HCLWR & Long-Term Fuel Cycle Analysis

The role of HCLWR was studied by using the JALTES-II model from the viewpoint of long-term nuclear fuel requirements. The reactor types considered were LWR with enriched UO_2 fuels and/or MOX fuels, advanced LWR, FBR, and HCLWR. The installed capacity of each reactor type was optimized over the time horizon 1970 - 2100 by minimizing cumulative natural uranium consumption under the condition that the sum of installed capacity meet the demand for nuclear power capacity given exogenously. Here a constraint was given on the stock of plutonium to keep non-negative values throughout the time horizon.

The date of commercialization was assumed as the year 2000 for HCLWR, and as either the year 2030 or 2050 for FBR. the recycling time period, i.e. time length from dis-loading of fuel materials to re-loading of them, was assumed as either 6 years or 4 years. Another important assumption was that fuels of HCLWR can be flexibly switched from PuO_2-depleted UO_2 to enriched UO_2 to keep plutonium balances after FBR commercialization.

The main results obtained are: a) HCLWR will be introduced by substituting a part of LWR, i.e. without impeding introduction of FBR. b) Cumulative consumption of natural uranium can be reduced by 18% compared with the case of no HCLWR. Also, plutonium stock outside the reactors can be suppressed significantly for the period before FBR commercialization. c) Even when FBR commercialization delays for 20 years, the increase in natural uranium consumption will be almost prevented through introduction of HCLWR. d) Reduction in a recycling time will improve plutonium balances substantially and expand the possible advantage of HCLWR introduction. A comparison of results on cumulative consumption of natural uranium and fissile plutonium stock is given in Fig. 7.

3.4 SMPR Technology Assessments

We project technical assessments on the small and medium power reactors for the purpose of extracting the R & D subjects beyond the task force in systems analysis and technical assessments on the VHTR described in 3(2). That is to say, we are now starting to do a series of technical assessments for the purpose of extracting value criteria for nuclear reactors not only from supply sides but also from demand sides: e.g. safety (inherent safety), economy (cost, life-time, O&M), constructions (QC, QA, factory fabrication), standards and criteria (reactor grade, non reactor grade), resources (fuel cycle, materials, labor), adaptabilities for energy demand (forms, load following, activities), investments (modularization), efficiencies (co-generation, utilization system), public acceptance (benefit/risk, environment impacts), fuel selection (uranium/thorium), etc..

Preliminary assessments on SMPR have been done to obtain economic perspectives of SMPR in the future energy market of Japan. The marginal values of the investment cost were analyzed for each of five types of SMPRs to penetrate into the future energy system, by using the MARKAL model. While, the economic conditions for SMPR to be adopted by electric utilities were analyzed through comparison of financial performances of a Japan's typical electric utility in two cases with SMPR and without SMPR by using the FINANCE-M model. The results of those analysis are submitted to the Seminar on SMSNR in Lausanne on 26th August 1987 [17].

While, the transitions in the concepts and design details of BWR and PWR in past have been also investigated under the contract with fabricators for the purpose of reflecting the results on the technical and economic assessment of SMPRs as next generation reactors.

3.5 New Integration in Future Energy System

A joint study program on the New Integration in Future Energy System has initiated in May 1987. This study program is supported by the Ministry of Education and is led by Professor Yoichi Kaya, the University of Tokyo. The study group consists of seven universities and JAERI.

Objectives of the study are to visualize a future energy system which is adaptable to Japan from view points of long-term environment imapcts, economical efficiency, robustness against various external disturbances, and also to extract holonic paths which are most effectively reachable to the ultimate energy system.

The research subjects in the programme are (a) ways of integration of sub-systems, (b) heat and electricity load management in urban area, (c) potential evaluation for small scale dispersed type energy systems such as solar heating and cooling, munucipal electric power generation by garbage burning, and co-generation, (d) new traffic system and appliances to mitigate environmental pollutions, (e) investigation of scaling law and benefit of moduralization, (f) inherent safety approaches and their implications, (g) decision analysis under uncertainty, etc.. JAERI will share the subject (a), (c), (f).

4. Conclusion

As described in the previous chapters, we can say that the development of the Integrated Energy-Economy-Environment Model System is devoted mainly to the systems analysis on nuclear energy system. Even if we limit its application within this research field, we do not yet accommodate such parts as risk and consequence analyses to the model system.

Utilizing technical resources inside JAERI and available from outsides, we are going to make our efforts on those subjects also. For realization of these, we must proceed to the most difficult problem, i.e. the preparations of data base from which such functions as a probabilistic confidence frequency function for energy facilities as well as dose-risk response functions for various pollutants could be selected and/or identified.

Compilation of application experiences of the Integrated E^3 Model System is also an important job for us, and through the experiences we will improve our model system. The IEA/ETSAP/ ANNEX III programme will be one of occasions for such expriences.

References

1) Yasukawa S., Mankin S., Sato O., and Yonese H.: "Development of Integrated Models for Energy-Economy System Analysis at JAERI", JAERI-M 84-139 (1984).

Yasukawa S., Mankin S., Sato O., Yamaguchi K., and Ueno S.: "Recent Progress in Energy Technology Systems Analysis at JAERI", dist. paper at the ETSAP workshop held at KFA (1985).

Yasukawa S., Mankin S., Sato O., Yamaguchi K., and Ueno S.: "Integrated Energy-Economy Model and Its Application in JAERI", prepared for the final report of the ETSAP/Annex II (1986).

2) Mankin S.: "Macro-Economic and Energy Scenarios for Japan through the Long-Term", JAERI-M 86-054 (1986).

3) Mankin S., Yamazaki S.: "Development of a Long Term Macro Econometric Model for Strategic Analysis and Cost Assessments in Nuclear R & D Fields", JAERI-M 85-186 (1985).

4) Mankin S.: "Primitive Methodologies and the Subject of Environmental Analysis on Total Energy System by MARKAL", MIT Project Meeting in JAERI, internal memo 39-1 (1986) [in Japanese].

5) Yasukawa S., Furuhashi A.: "Fuel-Demand II Code for the Use of Long-Term Fuel Cycle Analyses", JAERI-internal memo (1970) [in Japanese].

6) Sato O., Yasukawa S.: "JALTES-II: A Systems Analysis Model for Long-Term Strategy on Nuclear Power Development", JAERI-M 85-129 (1985) [in Japanese].

7) Sato O., Yasukawa S.: "Evaluation of Long-Term Nuclear Fuel Cycle Requirements", JAERI-internal memo (1978) [in Japanese].

Sato O., Yasukawa S.: "The Study on Japan's Long-Term Reactor Strategy - Roles of ATR and LWR with MOX Fuels", JAERI-internal memo (1980) [in Japanese].

Sato O., Yasukawa S.: "The Study on Japan's Long-Term Reactor Strategy - Strategies on Plutonium Utilization", JAERI-internal memo (1981) [in Japanese].

Sato O., Yasukawa S.: "Future Prospects of Nuclear Fuel Cycle Requirements in the Pacific Basin Region", JAERI-internal memo (1985) [in Japanese].

8) Finnis M.W., Gundermann J., and Tosato G.: "Value Flows in a Linear Economic Model", HL 84/2535 (1984).

9) Edmonds J. and Reilly J.: "A Long Term, Global, Energy, Economic Model of Carbon Dioxide Release from Fossil Fuel

Use", Energy Economics Vol.5, No.74, (1983).

10) (Phase-I Report)

BNL & KFA: "An Initial Multi-National Study of Future Energy Systems and Impacts of Some Evolving Technologies", BNL-50641 & Jul-1406 (1977).

(Phase-II Report)

OECD/IEA: "A Group Strategy for Energy Research, Development, and Demonstration", OECD, Paris (1980).

Sailor V.L. (Editor): "Technology Review Report", BNL 27074 (1979)

Japan Ad-Hoc Group on IEA/SA: "Energy Scenario Report for Japan", a country report of Phase II (1979).

(Phase-III Report)

Tosato G., Brady J., Essam P., Finnis M., Giesen G., Rath-Nagel S., Vos H., and Wilde D. (Editors): "Energy after the Eighties, A Cooperative Study by Countries of the IEA", Elsivier Science Publishers (1984).

Fishbone L.G., Giesen G., Goldstein G., Hymmen H.A., Stocks K.J., Vos H., Wilde D., Zoelcher R., Balzer C., and Abilock H.: "User's Guide for MARKAL (BNL/KFA Version 2.0)", (1982).

Mueller M., Maher K.J.: "Summary Report on Technology Characterizations IEA, Energy Technology Systems Analysis Project", Jul-Spez-185 (1982).

Yasukawa S., Mankin S., and Sato O.: "IEA Energy Technology Systems Analysis Project, Task 2: Technology Characterization for Nuclear Energy Technologies", dist. paper at the ETSAP workshop held at KFA (1981).

Yasukawa S., Sato O.: "IEA Energy Technology Systems Analysis Project, Base Task: Pilot Study for the Improvement of MARKAL Programme", dist. paper at the ETSAP workshop held at KFA (1981).

ETL & JAERI: "Results of Phase-B Scenario Runs for Japan", dist. paper at the ETSAP workshop held at Dublin (1983).

ETL & JAERI: "Revised Draft of Scenario Analysis on Japan's Energy System", a country report of Phase III (1983).

(Phase-IV Report)

OECD/IEA: "Energy Technology Systems Analysis Project, Annex II (July 1983 - June 1986) (Draft)", (1987).

11) Hara M., Yasukawa S., Tadokoro Y., Mankin S., Sato O., and Yamaguchi K.: "Work Plan for the Study on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization in Future Energy Systems", presented at the Consortium Meeting for the IES Study held at Washington D.C. (1984).

12) Hara M., Yasukawa S., Mankin S., Sato O., and Yamaguchi K.: "The Study on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization in Future Energy Systems -Progress Report No.1-", presented at the Consortium Meeting for the IES Study held at IIASA (1985).

13) Yasukawa S., Mankin S., Sato O., Yamaguchi K., Ueno S., and Hara M.: "The Study on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization in Future Energy Systems - Review of Energy-Economy-Environment System in Past and Present Years -", presented at the Consortium Meeting for the IES Study held at Taipei (1986) and JAERI-M 86-073 (1986) [in Japanese].

14) Mankin S., Yasukawa S., Sato O., Yamaguchi K., Ueno S., and Hara M.: "The Study on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization in Future Energy Systems - Macro-Economic and Energy Supply Scenarios for Japan through the long-term -", presented at the Consortium Meeting for the IES Study held at Taipei (1986).

15) Yasukawa S., Mankin S., Tadokoro Y., Sato O., Yamaguchi K., and Ueno S.: "The Study on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization in Future Energy Systems - Impact Analysis of Future Energy Technologies in Long-Term Energy Supply-Demand, National Economy, and Environment -", presented at the Consortium Meeting for the IES Study held at Sweden on Sep. 1986 and JAERI-M 86-165 (1986).

16) Yasukawa S., Mankin S., Sato O., Tadokoro Y., Nakano Y., Nagano T., Yamaguchi K., Ueno S.: "The Study on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization in Future Energy Systems - Implication in Energy, Economy, and Environment of Japan -", to be presented at the ICIES/IIASA Meeting at Vienna on July 1987.

17) Mankin S., Sato O., Yasukawa S., Hayashi T.: "Economic Perspectives of SMSNRs in the Energy Market of Japan", to be presented at Seminar on Small and Medium Sized Nuclear Reactors held on Aug. 24-26, 1987 at Lausanne, Switzerland (1987).

Table 1 Preliminary Approach to Environmental Analysis by MARKAL Modification

Methods: Categolies	Item No.	Outlines of methods	Objects of analysis	Specific characteristics: Program modification	Reference energy system	Input-data Acquisition	Calculation case	Status of progress
Parametric survey based on input-data change	1-a	Change of emission data of each energy technologies in time series	Estimation of total amount of emissions in cost or security minimum problem	Input-data change sub-programme	N.M.	Effluent scenario & detail data	Various scenario case study or Parametric survey by detail data	in progress
	1-b	Change of cost data of emission control technologies in time series and in detail	Optimization of total energy system in cost minimum included emission control cost	same as 1-a		Cost scenario & detail data		in progress
	1-c	(1-a).AND.(1-b)	Trade off between total cost and and amounts of emissions	same as 1-a		same as 1-a, 1-b		in progress
Integration into reference energy system	2-a	Setting representative emission control technologies in each kind of effluent and cost categories	Trade off between total cost and amounts of effluent	TCH PRC MEMBER etc. Dimension expansion	Addition of control technologies in reference energy system	Grouping of technologies based on fuel, effluent, control technologies	Not much	completed
	2-b	Setting various representative control technologies in each effluent/size/consentration	Trade off between total cost and amounts of effluent					completed
Addition of constrain equations or bounds	3-a	Addition of constrains equations on effluents	Cost minimum optimization under effluents constrain	Large programming work Difficult in short time	N.M.	Steady state aquisition	Case study	N.A.
	3-b	Addition of constrains equations on total cost of emission control technologies	Scenario analysis on total cost of control of effluents					
	3-c	(3-a).AND.(3-c).OR. Bounds set	C/S minimum optimization under effluents constrains					
Modification of object function	4-a	Addition $\sum_{T}\sum_{ENV}$ ENV(ENV) in objective functions	Minimization of total amounts of effluents	Easy Replace security element by ENV(ENV)	N.M.	Depends on the quality of analysis	Reference cases	Completed
	4-b	Trade off analysis between PRICE and $\sum_{T}\sum_{ENV}$ ENV(ENV)	Trade off between effluent and cost				Trade-off Case study	Completed
	4-c	PRICE/SECURITY/ $\sum\sum$ENV(ENV) trade off analysis	Paret optimization in three dimensions	Not available in short term				N.A.

N.M.: Not necessary to be modified
N.A.: Not available at present

Table 2 List of Data Items for Technology Characterization

1. Technical Data 1.1 Design Capacity 1.2 First Commercial Service Year 1.3 Energy Inputs Per Year (Full Load) 1.4 Energy Outputs Per Year (Full Load) 1.5 Maximum Annual Availability 1.6 Capacity Factor 1.7 Overall Efficiency (Full Load) 1.8 Overall Efficiency (Average Load) 1.9 Design and Licensing Time 1.10 Construction Time 1.11 Technical Lifetime	3.2 Effluents to the Water Water contaminations, Radioactivities, Heat, Others 3.3 Wastes Industrial Wastes, Radioactive Wastes Wastes at Deconstruction of Facilities Others
2. Cost Data 2.1 Construction Cost 2.2 Owner's Cost 2.3 Interest During Construction 2.4 Decommissioning Cost Discounted Decommissioning Cost 2.5 Total Capital Cost 2.6 Economic Lifetime 2.7 Annualized Capital Cost 2.8 Fixed O & M Cost 2.9 Variable O & M Cost 2.10 Grid Connection Cost 2.11 R & D Cost 2.12 Input Fuel Cost 2.13 Total Production Cost 2.14 Disaggregated Investment and O & M cost for Use in I/O (TRANS)	4. Measures for Environmental Protection 4.1 Measures for Each of Effluents or Wastes 4.2 Technical Data of Equipments (in addition to items listed left) Effluent or Waste Inputs Per Year Effuent or Waste Outputs Per Year Operation Experience (Years) Loss of Energy Efficiency Number of Operators, Operation Mode 4.3 Cost Data of Equipments (in addition to items listed left) Credit of Outputs 5. Material Data 5.1 Freshwater Use 5.2 Land Use 5.3 Material Requirements 5.4 Employed Persons 6. Technology Implementation 6.1 Maximum Feasible Capacity during 1980 and 2020 6.2 Factors Limiting the Implementation
3. Environmental Data 3.1 Effluents to the Atomosphere SOx, NOx, CO and CO_2, Particulates Special Materials, Radioactivities, Heat, Others	

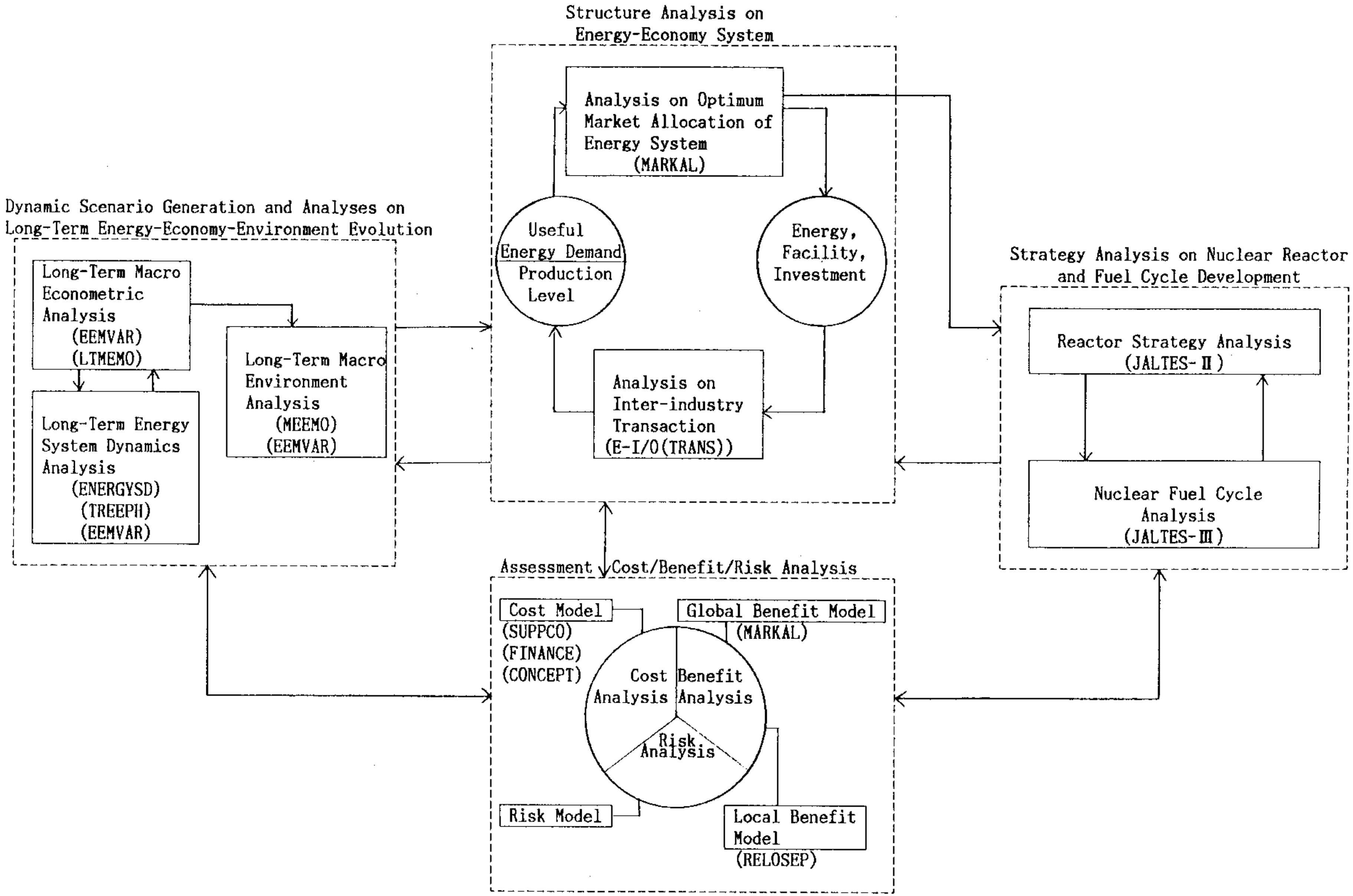


Fig. 1 Integrated Energy-Economy-Environment Model System

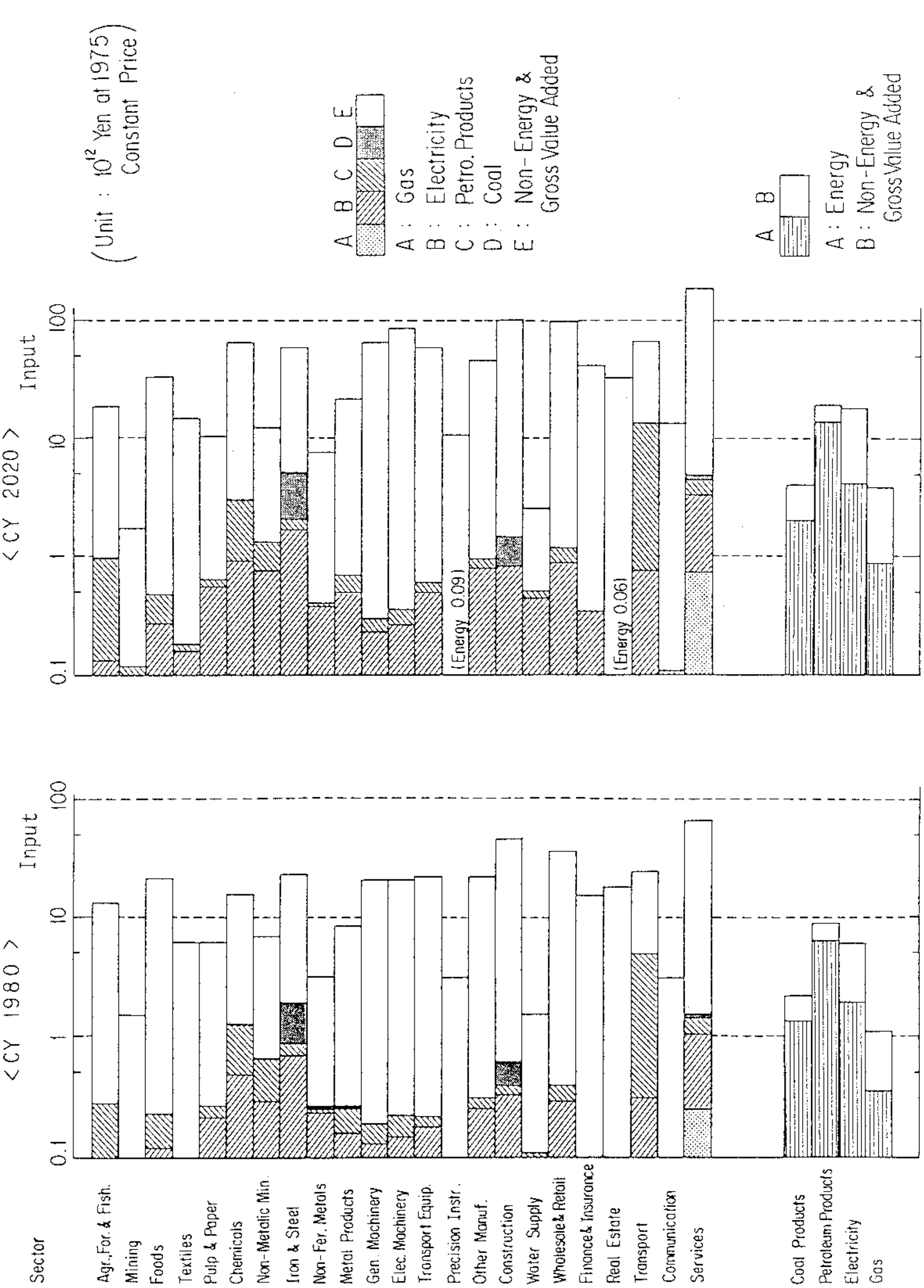


Fig. 2(a) Input Structures of Industry in CY 1980 and CY 2020

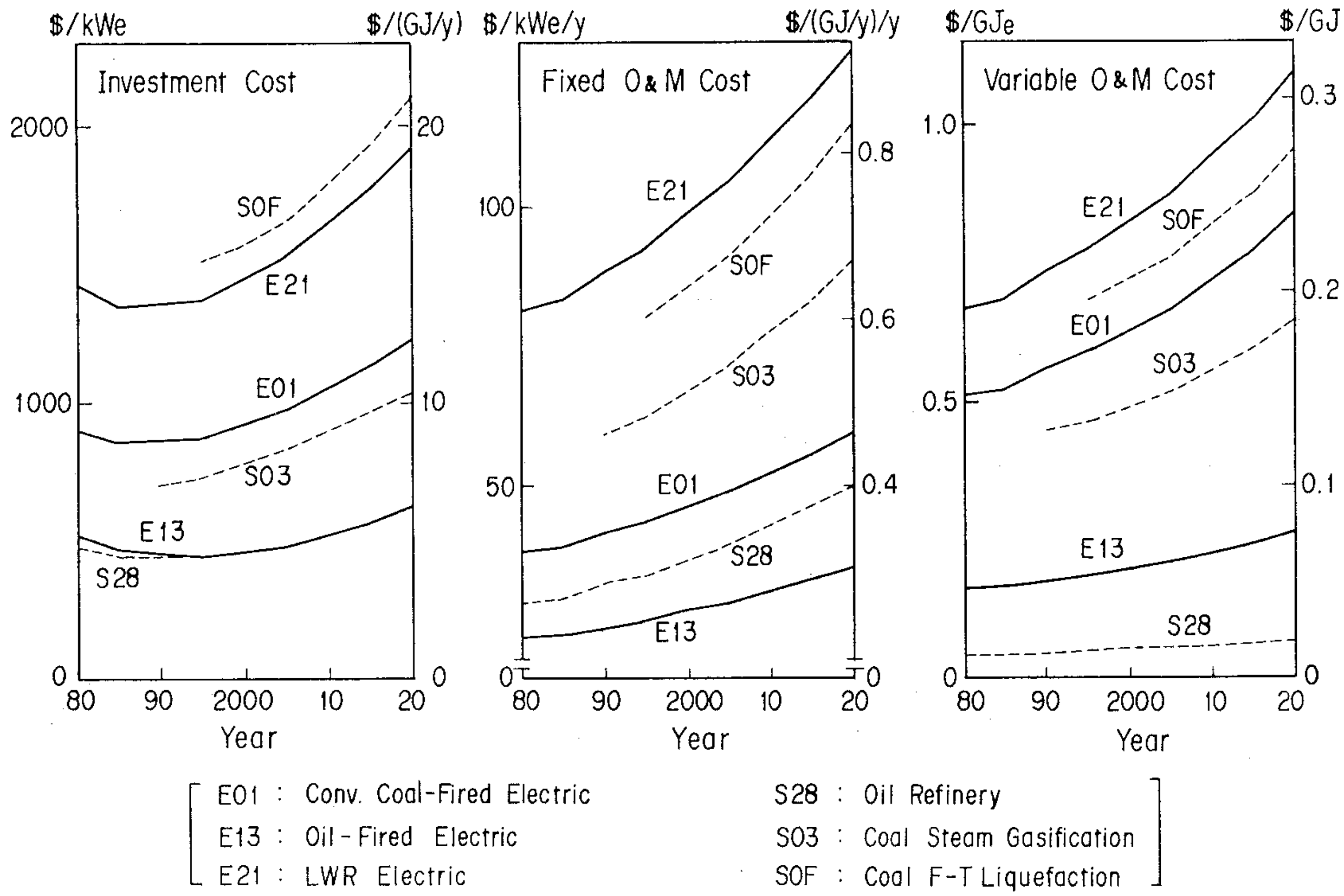
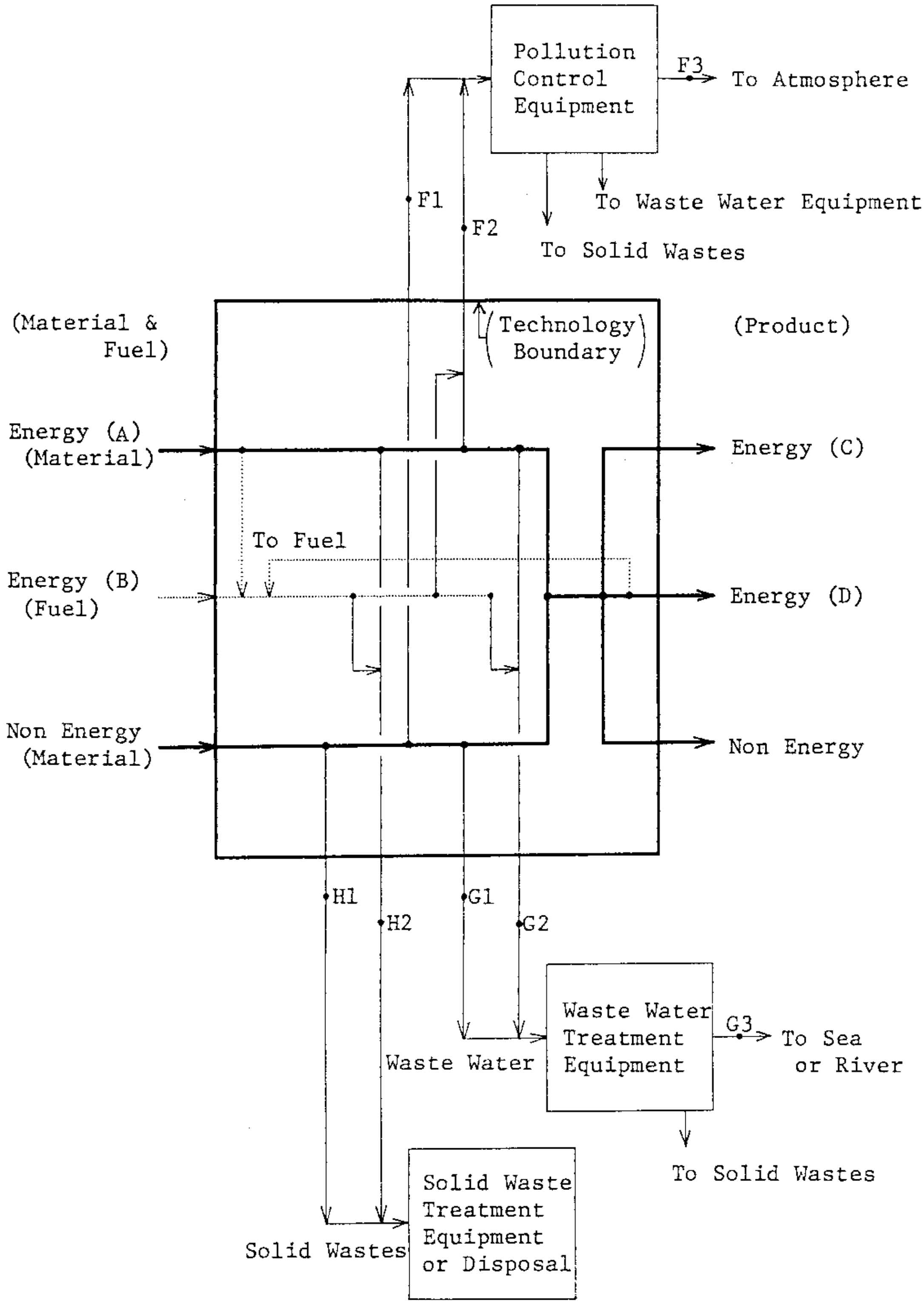
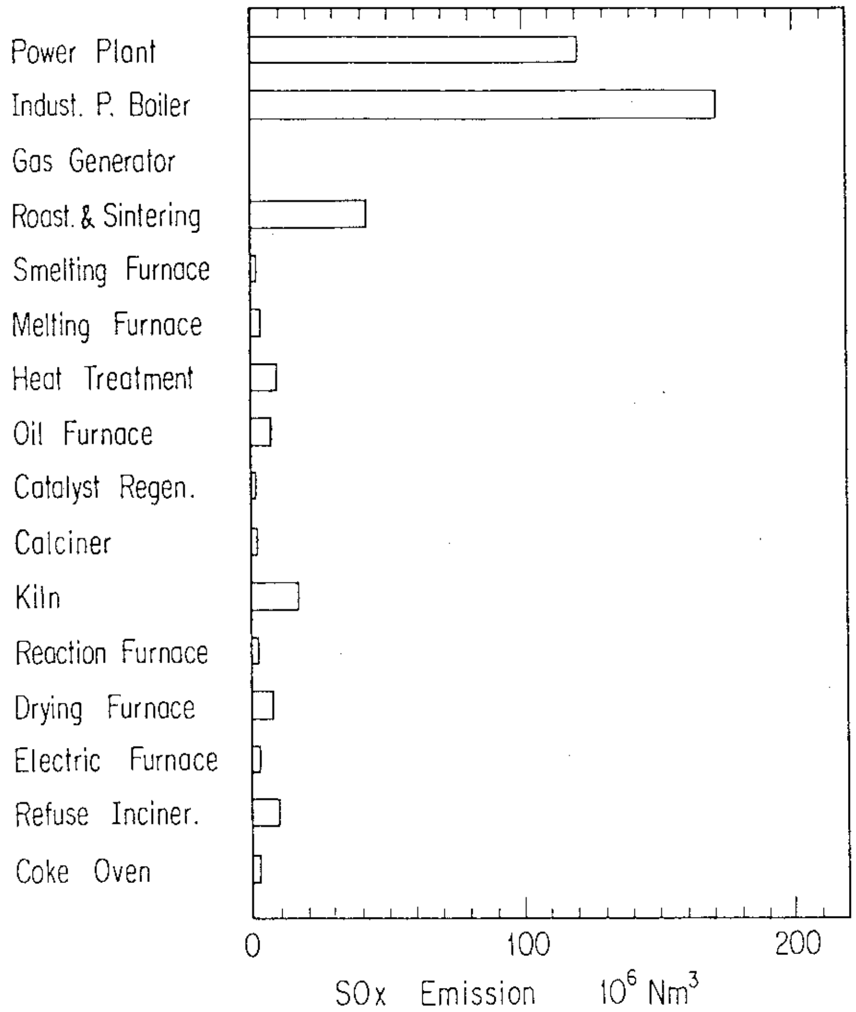


Fig. 2(b) Evolution of Technology Costs at Current Prices under Long-Term Structural Change in Economy



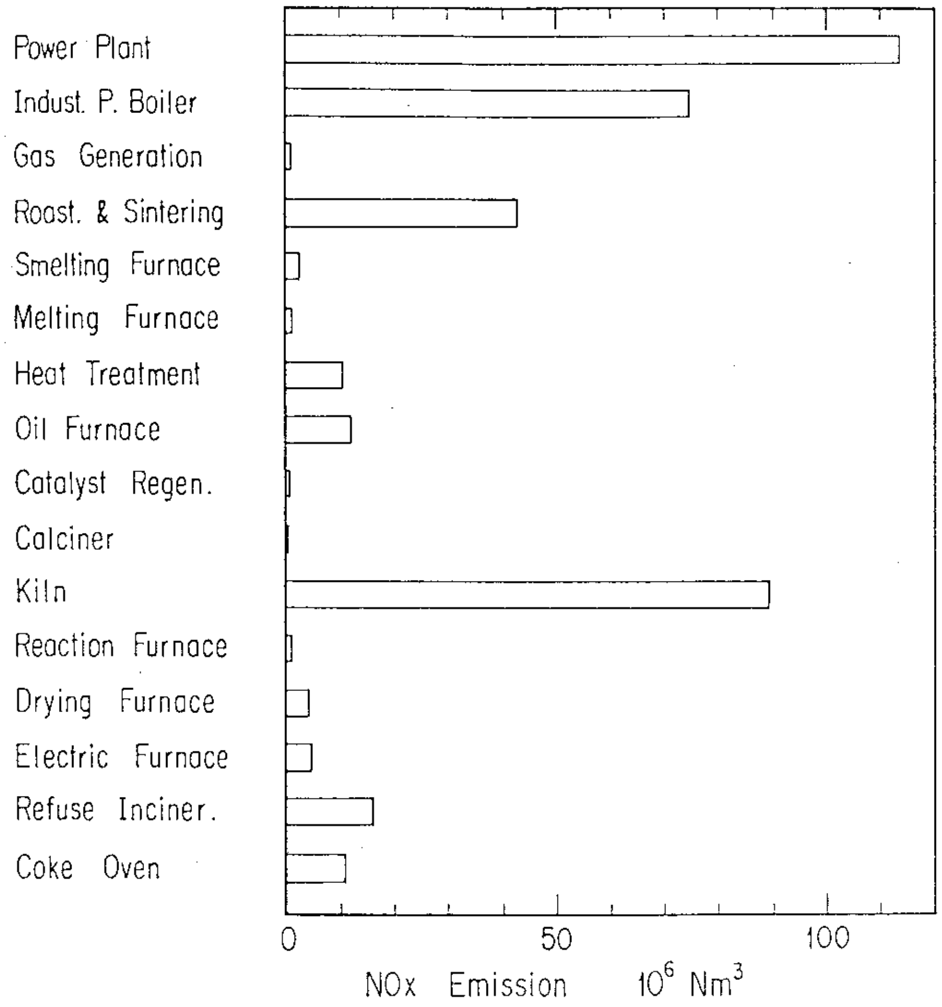
Measuring Points
F1,G1,H1 ; effluents from non energy
F2,G2,H2 ; effluents from energy
F3,G3 ; effluents released after control

Fig. 3 Measuring Concept of Environmental Effluents



(Source : MRI Report prepared for JAERI)

Fig. 4(a) SOx Emission by Industrial Heat Facilities in FY 1980



(Source : MRI Report prepared for JAERI)

Fig. 4(b) NOx Emission by Industrial Heat Facilities in FY 1980

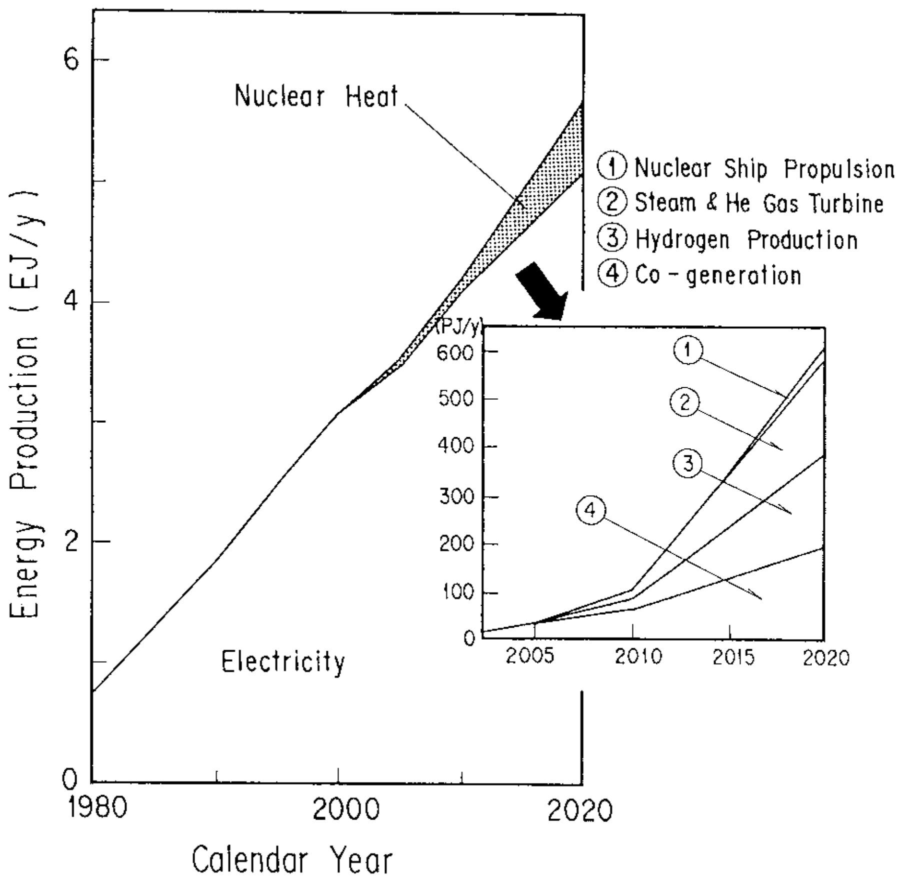


Fig. 5 Low, Intermediate, and High Temperature Nuclear Heat Production and Their Utilization

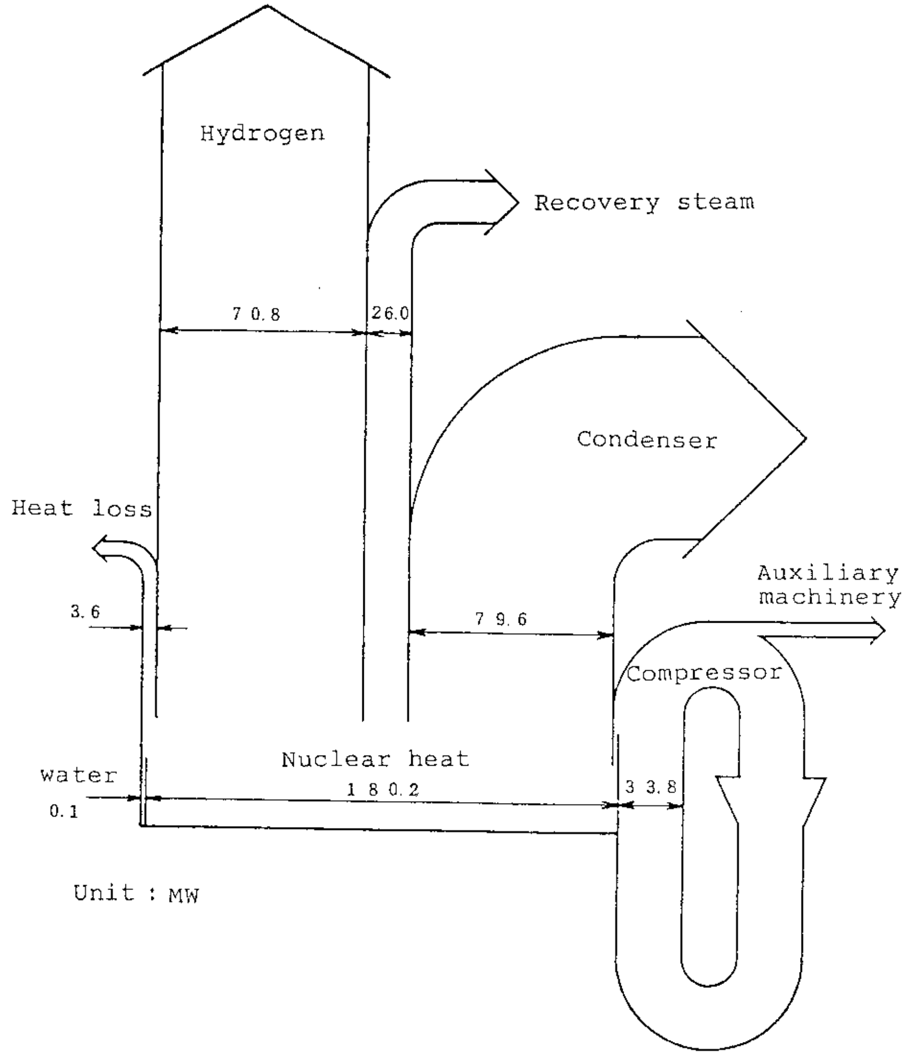
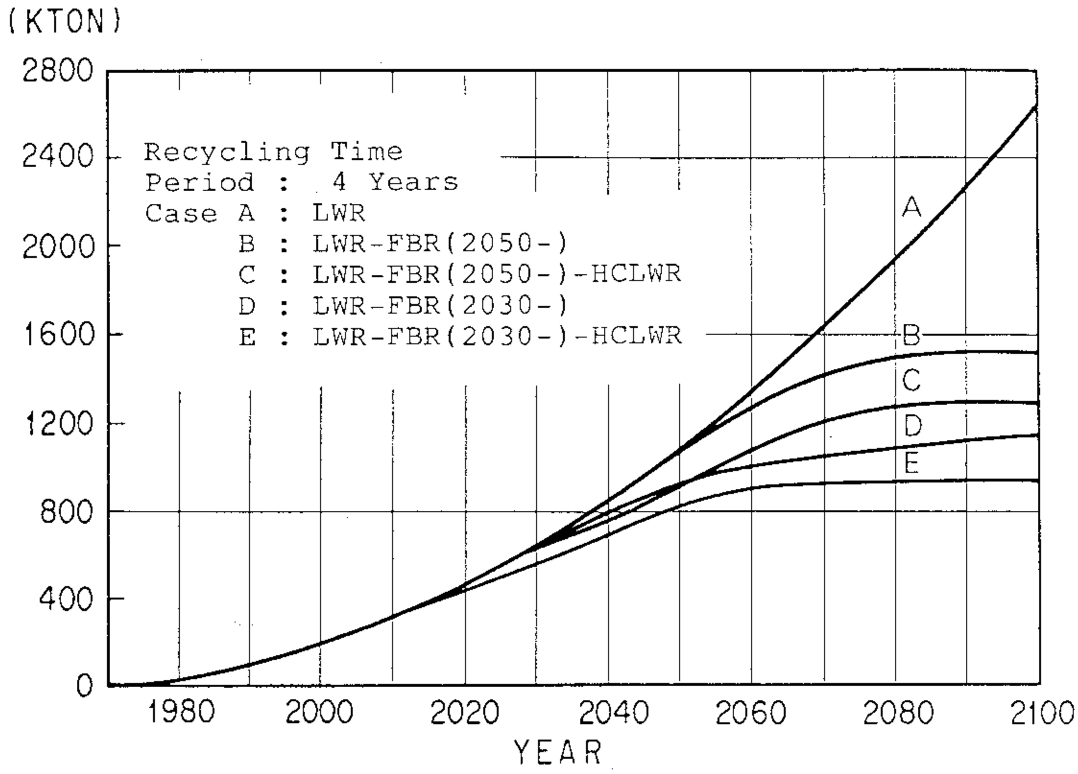
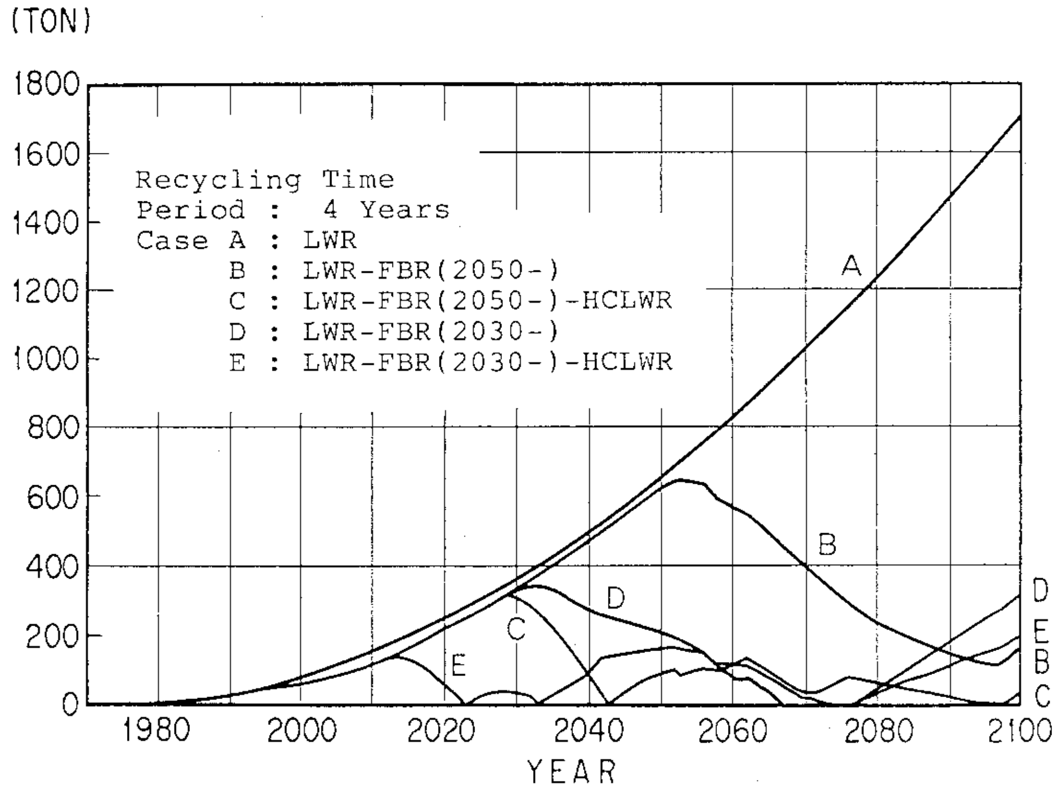


Fig. 6 Enerav Balance of UT—3 Cycle Utilizing the Process Heat from VHTR



(a) Cumulative Consumption of Natural Uranium



(b) Stock of Fissile Plutonium

Fig. 7 Examples of Results in HCLWR & Long-Term Fuel Cycle Analysis