WORKING PAPER

INTERACTIVE INFORMATION SYSTEM
FOR TECHNOLOGY ASSESSMENTS

A.K. Alabyan
A.P. Golovine
V.R. Okorokov
V. Ponomarev

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IIASA
International Institute
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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

Foreword

Evaluation and assessment of new technologies is a rather complicated task due to the involvement of groups of experts, multiple criteria characterizing several alternatives as well as incomplete information about these alternatives. Expert analysis of new technologies by different aspects can be one of the ways of estimating the advantages and shortcomings of each of them and of forecasting their development and usage.

Due to the character of the assessment procedure, especially in the group expert situation, large amounts of information must be processed and analyzed in order to find the final conclusion. Additionally, several factors reflecting the quality of the results, quality of experts opinions, etc. must be calculated during the assessment process. Therefore, this task should be supported by some computer based tools. The paper presents such an information management system supporting the process of technology assessment. The system performs such functions like information collection and storage, interaction with experts and analysts, aggregation of information, graphic presentation of data and results as well as computes several statistical factors necessary to analyze the data submitted by experts. The system, being the first step towards development of more advanced decision support systems has been applied at IIASA for analysis of several technologies for energy production.

Alexander B. Kurzhanski
Chairman
System and Decision Sciences Program

Content

INTERACTIVE INFORMATION SYSTEM FOR TECHNOLOGY ASSESSMENTS

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1. INTRODUCTION

There are several ways to deal with the problems of technology assessments. The traditional ones use different sorts of economic analysis and are well known. The traditional approach is useful for well-defined technologies, for which the reliability of the input data is highly verified. When we deal with some new technologies it is no longer the case. There are many issues beyond the economic factors such as safety, R&D problems, environmental and social impacts and others that are of great importance but sometimes cannot be evaluated numerically with economic calculations. While assessing the future development of new technologies, it is possible to reduce uncertainties relying on the opinions of experts. Expert analysis of new technologies by different aspects can be one of the ways of estimating the advantages and shortcomings of each of them and of forecasting their future development and usage.

The method of an expert computerized analysis of technologies developed at IIASA and described here is based on a questionnaire (an example of the questionnaire to be filled out by one of the experts is presented in Appendix 1), summerizing all necessary information taken from the experts and an interactive computer system that makes all calculations, data processing, and representations.

This first version of technology assessments (TAS) describes an information system for the policy makers as a tool for the full-scale analysis of different technologies.

Before describing the proposed procedure of technology assessments some preliminary considerations should be made concerning the problem of the human possibilities to make estimates. Some assumptions concerning the models of human information processing and decision making could be found in the works devoted to sociological research and in modern trends in expert systems design (see, for example [1, 2, 3]).

Researchers engaged in measurement and mathematical modelling of human phenomena meet the problem to subject human behaviour to numerical analysis. There is strong criticism now that essential individual characteristics are swallowed up in the sameness of quantity. Indeed to a certain extent a sameness is asserted when applying measurment to human phenomena. However, two points should be recalled. First, measuring certain properties connected with human activities need not imply that two cases, when these properties are identical, cannot differ in many other respects. Indeed once these similarities are known it may be easier to concentrate on the differences between individuals. Second, some scales of measurement are more restrictive than others. The identification of objects by categories into which they fit, or by ranks, captures some qualitative similarities. At the same time fewer presumptions are made about their sameness, as is the case when they possess identical values on a metric scale. Notwithstanding this criticism pointing to the limitations of measurment, however, there is an increasing recognition that a qualitative approach need not eschew measurment.

In recent years social scientists have been more and more concerned with measuring qualities in order to grapple with complex configurations and uncertainties inherent in human perception and behaviour. The difficulties assosiated with measuring and numerical analysis of human activities remain immense. Techniques of qualitative data analysis are essential in any effort to incorporate non-numerical information extracted from humans. But it is necessary sometimes to achieve even more: to get some numerical characteristics as to human estimations of some processes or systems performance.

A major factor which can affect the ease with which people use an expert system is the ability of the system to tailor its behaviour to the specific features and needs of an individual user. This is most desirable where one particular system is to be used by people with substantially differing backgrounds. To be effective, systems should know who their users are and the context in which they are trying to work. There are several ways in which a system can tailor its behaviour towards different users. The most simple is where the user is asked to classify himself at the beginning of interaction as belonging to a certain category. In more sophisticated approachs a cluster analysis is used. There are various types of user information which should be included into the system. These generally include knowledge about a user's level of competence, his interests, values, aptitudes, goals, expectations and assumptions and even knowledge about the user's model of how the system works. In the real decision process each expert certainly has his own understanding of the strategy that influences his assignments. Besides individual capabilities, even his present motivations are of importance. To achieve positive results it is necessary not only to verify the initial assignments but also to divide the experts into national, professional and other groups because their opinions could differ.

While analysing such a problem as technology assessements, it becomes clear that the main problem is not only to choose correctly the set of alternatives, criteria and the measurement scale but also to arrange the procedure for accurate verification of the outputs of experts activities that could be provided with mistakes. Moreover an expert can change his mind while analyzing the answers of other experts. The verification procedure should include possibilities to reconsider the initial assumptions concerning alternatives, criteria and certainly numerical and qualitative assignments taken from experts.

The first problem that arises is how to choose the best scale to get expert information. It is well known [1, 2] that to recieve reliable estimations, it is necessary to present the scale that is formulated in a habitual for experts manner. Usually an expert is asked to determine quantitatively the level of quality of alternatives. And the expert should assign the accordance between the quantative estimation and this level. It is clear that this accordance is determined differently by different experts. Such results obtained in this manner can have valuable mistakes. It is better if the scale is verbal (for example "good", "fair", "bad") but again this estimation can be differently connected with the numerical merits. The scale should be flexible enough to try the different accordance between verbal conclusions and these merits.

Another problem is providing noncontradictory and transitive assignments. (Noncontradictory assignments give the same estimations in the same conditions. Transitive assignments are subjected to the condition: if a > b and b > c than a > c). Before formulating the decision rule one must be sure that at least 80 - 90% of the assignments fulfill this requirements.

These preliminary considerations relate strongly to the problems of decision making in the framework of multicriteria ill-structured problems. Human factors influence strongly the success of the assessment procedure of problems, systems and situations. For these problems in which qualitative, ill-defined factors are dominant, the chosen set of evaluation criteria is often subjective and ratings assigned by experts to the given alternatives by each criterion can be quite different.

It is also well known that experts can deal with no more than five to seven criteria if we would like to have reliable results of the assessment procedure. At the same time the initial number of criteria is often much greater. The possible solution can be to reduce their number on the basis of the preliminary analysis of their sameness and to group them.

Some human factors related to the decision process are summerized in Table 1.

Methods of multicriteria decision making differ by the modes of forming the generalized estimates for each alternative on the basis of data extracted from experts. Let's describe some of them keeping in mind their potential usefulness for the problem of technology assessment.

Direct Methods

In these methods the relation between generalized estimates (utility functions) and estimates by separate criteria is predefined. In most cases generalized criterion presents a linear weighed combination of separate criteria. These methods are described elsewhere (see, for example [4]. More sophisticated methods use aspiration levels and take into account disagreement factors [5].

Pairwise Comparison Methods

In these methods DM chooses between selected pairs of alternatives [6]. These methods give as a rule rather reliable solutions but are time consuming. They are mostly used for the small-scale problems with few alternatives and criteria.

Compensation Methods

In these methods [7] estimates for one alternative are tried to be compensated by estimates for another one in order to choose the better one. These methods are considered to be the most user-friendly as at one time an expert deals only with pairs of alternatives. All shortcomings and advantages for both alternatives are analysed and crossed out by pairs to see what is left at the end of this procedure.

Table 1. Human factors related to the decision process.

1.	Human capacities in information processing are rather limited but flexibility of humans, their adaptability and experience make it possible to rely on their expert estimations.
2.	Human capabilities depend on the type of the problem and on the way of obtaining the relevant information from people.
3.	Short-term memory capacity is limited. It can process only several structural data units.
4.	Man either adapts to a complex problem or tries to adapt it to his own capabilities.
5.	Humans are usually able to learn from previous actions (mostly by try-and-see technique).
6.	Solving unique problems often leads to conflicting and differing answers during the decision process.
7.	Human capacities during the decision process depend strongly on the way the problem is formulated.
8.	More adequate are methods of eliciting information from humans that use habitual qualitative scales but not numerical ones.
9.	The complexity of the decision problem increases with the number of criteria, quantity of estimates on the criterion scale and with the number of the resulting quality classes.
10.	Personal, professional, national and other individual motivations influence strongly the assignments of experts.
11.	Interinfluence of opinions of experts engaged in one problem can lead to changes in their initial assignments.
12.	Humans make errors during the decision process due to inadequate understanding of the particular problems, carelessness or other factors.
13.	Human estimates can be contradictory and non-transitive.
14.	Humans prefer the information to be represented more in images, graphs than by tables with numbers.

Axiomatic Methods

In these methods [4] some characteristic features of the utility function are postulated reflecting the preferences of DM. During the assessment procedure these preferences are verified and adjusted.

Interactive Methods

They are used effectively if the partial model of the system is known and preferences and relations between different criteria are analysed and interactively modified [8, 9, 10].

It should be noted that practical application of most of the above described methods for ill-structured problems has rather not been hopeful. One of the reason is that experts cannot assign reliable numerical estimates (ratings) for alternatives by a lot of criteria at once without analysing the opinions of other experts and without some discussions.

Summerizing the brief overview of the existing methods, having in mind to choose the best for the problem of technology assessments, it is clear that to obtain reliable results for a reasonable period of time it is necessary to combine advantages of different methods into one procedure.

In our approach we combined some elements of the direct method of constructing the generalized utility function as a combination of weighed ratings by each criterion for all alternatives with interactive computerized verification procedure. During this procedure, initial assignments of experts are averaged. A special measure - Mean Square Deviation - is inserted to clarify the disagreements between experts. Pairwise comparison is used for the verification of the initial expert assignments.

In this paper we present the initial principles (Section 2), assessment procedure (Section 3) and structure of the system (Section 4). Some programming aspects are described in Section 5. TAS now is being implemented for the assessment of energy technologies. Here we present Interactive Information System for Technology Assessments as a tool for providing full-scale information to the policy maker to analyze the international experience in energy systems. It should be pointed out that this first version of TAS does not claim to provide him with the decision rule to choose the particular technology for his purposes but more to stimulate his decision process on the basis of varying opinions, including national and personal motivations, disagreement features and some averages. It is up to the policy maker to make a decision after analyzing the full set of information stored in TAS.

Based on the experience of the case study on energy technology assessments, it is planned, as a second step, to turn to formulating decision algorithms.

Refering to the above mentioned difficulties to formulate the decision rule based on expert opinions concerning the final choice of technologies for a particular user, it becomes clear that the problem should be divided at least into two stages.

The first version of the technology assessments system can be constructed taking into account human factors of decision making and some preliminary assumptions about the process of calculating the output merits.

2. MAIN PRINCIPLES OF TAS

The main principles of TAS are presented in Table 2.

Table 2. Main principles of TAS.

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1. Openess
TAS is constructed of several universal modules with a standard interface. It allows to add and modify the system for other applications of the same kind.

2. Flexibility
It is rather simple to reformulate the main problem, list of technologies and criteria, to change weights of criteria and their scale, to reform the output calculations, forms of information representation, etc.

3. User-friendliness
After the preliminary professional adjustments the system can be used by a non-professional programming user. It includes an hierarchical HELP-system.

4. Data processing
The data processor consists of a number of small BASIC programs that can be easily edited for the particular user.

5. Graphics
A special graphics subsystem is provided to show any kind of data stored in Introductory, Resultant and Verification Data Bases.

6. Modes of interpretation of the output figures
The criteria scale consists of several answers levels (L): 0 - none, 1 - bad, 2 - poor, 3 - fair, 4 - good, 5 - excellent. They can be interpreted in two modes.
A) Numerical in which each level is assigned a rating (R): $R = N * L$, where N is a scale coefficient which can be varied during the analysis of the results.
B) Non-numerical in which percentage of all answer levels in the output data is calculated.

7. Verification of assignments
A special susbsystem is developed to verify the assignments of experts by the pairwise comparison of those of a given expert, other experts and averages.

8. Disagreements analysis
A disagreement factor is introduced as a mean square deviation of assignments from averages to characterize the difference in opinions.

9. Modification of criteria
A special procedure is suggested to reconsider the list of criteria and to reduce their number on the basis of the analysis of the initial assignments and resultant

data analysis.

10. Experts group analysis
In order to take into account the differences between motivations of various expert groups a special filtering subsystem can select and show the asignments of different expert groups (country, specialization, etc.).

11. Criteria group analysis
All criteria are grouped and averaged output parameters are calculated for each group relying more on the enlarged estimates than on detailed analysis of a large number of criteria.

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3. ASSESSMENT PROCEDURE

Taking into account the above said, the assessment procedure can be divided into different stages.

Choice of Alternatives

In most cases altenatives to be assessed are specified by the group of customers and DM who initiate the assessment procedure. Alternatives - energy technologies to be assessed are listed in Table 3. Their illustrative definition is presented in Appendix 2.

Table 3. List of technologies

---

1. Lurgi Pressure Coal Gasification
2. Hydropyrolysis for coal conversion
3. Coal conversion by supercritical extraction
4. Combined cycle power station with integrated coal gasification
5. High temperature gas cooled reactors
6. Gas turbines
7. "SASOL"-type coal liquifaction plant
8. Low pressure natural gas to methanol conversion
9. Geothermal energy
10. Electrothermal hydrogen
11. High efficiency membrane complex methane production
12. Super heat pump energy accumulation
13. Fuel cell power plant
14. Gasification in molten iron bath

It should be pointed out that the above mentioned technologies and energy systems based on their use have already showed good operating qualities (like the SASOL plant, Lurgi Pressure Coal Gasification). So their main capabilities and features are rather to be assessed by experts. At the same time some of their performance impacts cannot be easily estimated by quantative methods. Another factor that influences their choice for the assessment is their increasing usage in different countries, each having its own experience, traditions and conditions. And the main aim of the assessment procedure is to clarify the potential preferences for each of the teachnologies in different countries. IIASA seems the proper place for such an international analysis of energy technologies.

Choice of the Set of Criteria

As a rule the set of criteria for the expert analysis is choosen on the basis of the experiance of DM engaged in this activities and works of scientists in the field. It is natural that DM who launched the assessment procedure first would like to have much more criteria than necessary - not to forget any of the aspects of the problem. It often leads to a rather big set of criteria which cannot be handled properly by human experts. Special procedures are arranged to decrease the initial number of criteria to make the results more reliable and useful.

In our case 23 criteria were initially chosen (see Table 4).

Table 4. List of criteria.

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1. R&D Time Requirement
2. Costs of R&D
3. Probability of R&D Success
4. Capability of Industrial Manufacturer
5. Availability of Material and Resources
6. Institutional Barriers
7. Social Acceptability
8. Level of Pollution
9. Flexibility of Siting
10. Waste Handling and Disposal
11. Availability of Cleaning
12. Consequences of Accident
13. Safety Characteristics
14. Adaptability to Types and Sources of Fuel
15. Outage Rate
16. Risk of High Damage
17. Capital Cost
18. Construction Period
19. Efficiency of Energy and Resources Utilization
20. Multiproducts Availability

21. O & M Requirements
22. Commercial Acceptability of Product
23. Availability and Prices of Natural Resources

These criteria characterize the possibilities for the successful development of energy technologies, its economic properties and factors related to safety, flexibility and environmental consequences. Their list claims on comprising all sorts of parameters necessary to estimate their development.

The questionnaire consists of a number of tables, each of them having different questions concerning various aspects of all technologies under consideration, weights of the evaluation criteria, and ratings for each technology and criterion.

As mentioned above, the traditional economic approach is useful for well-developed technologies, where the quality of input data is good. For new technologies, especially at the stage of research development, there are many issues beyond the question of capital and operating costs. Among them are social acceptability, level of pollution, availability of necessary materials and resources, cost and time required for R&D, and many others.

In order to have better measurements for the assessment of new energy technologies at IIASA, a method, based on the expert's analysis of the many criteria, was developed by many authors of various countries. Two very similar approaches were developed by the Western IES Consortium [11] and by Russian scientists [12, 13]. A set of evaluation criteria was proposed, including 23 variables concerned with major factors of technology development and implementation. All criteria are divided into four groups (Figure 1):

Group I	contains criteria to assess possibilities of the successful development of a technology up to the stage of a pilot industrial plant. Among the criteria are two more general than the others in the group. They apply to applications of the technology of scale.
Group II	includes environmental consequences of the technology assessed and possibilities of management of the environmental effect.
Group III	is dealing with matters of safety, reliability and technological flexibility of a technology.
Group IV	includes characteristics which are needed to assess economic properties of a technology and the expected economical situation when the technology is implemented.

Assignment of Criteria Weights

The weights for the given criteria can be obtained from the experts or by means of special mathematical procedures [1,2]. We consider the weights for the criteria equal for all technologies because they are dependent mainly on political, social, economic, and other conditions and not on the particular type of technology.

Assignment of Ratings

Several technologies are usually selected and briefed in the questionnaire together with the criteria chosen. First, each expert must estimate the weights of the criteria and then put down the ratings for each technology by each criterion. These ratings are divided into five levels. Each level can be represented in two different forms: verbal conclusions (for example, excellent, good, fair, poor, bad) and numerical values (for example: 5, 4, 3, 2, 1 – five being the highest ranking). All the ratings are multiplied by corresponding values of weighing coefficients to form a score for each technology by each criterion and the total (sum) score of each technology. For different purposes the decision maker can have either the resultant percentage of various levels of verbal conclusions or numerical estimations of means and other statistical values of resultant parameters for each technology.

Output Figures

Each technology j is evaluated by expert k with criterion C_i, where $j = 1,...m$, $k = 1,...L$, $i = 1,...n$. Each criterion has its own weight coefficient W_i assigned by each expert. On the basis of these estimations some characteristic output values are calculated.

Score S_{ijk} is calculated as

$$S_{ijk} = W_{ik} \cdot R_{ijk} \quad ,$$

where R_{ijk} is the rating for j^{th} technology and i^{th} criterion assigned by k^{th} expert

.

Average weight coefficients for criterion:

$$AW_i = \frac{\sum\limits_k W_{ik}}{L} \quad ,$$

and mean square deviations of weight coefficients:

$$MSDA_l = \frac{\sqrt{\sum_k [W_{kl} - AW_l]^2}}{L} \quad .$$

The average score and mean square deviation are calculated for each technology and each criterion:

$$AS_{jl} = \frac{\sum_k S_{jlk}}{L} \quad ,$$

$$MSDS_{jl} = \frac{\sqrt{\sum_k [S_{jlk} - AS_{jl}]^2}}{L} \quad .$$

A separate table presents the total scores for each technology evaluated by each expert:

$$T_{jk} = \sum_i S_{ijk} \quad .$$

A final table contains integrated estimates of all the technologies I_j by averaging the total scores for each technology assigned by each expert:

$$I_j = \frac{\sum_k T_{jk}}{L} \quad .$$

Deviation of experts opinions are estimated by :

$$MSDI_j = \frac{\sqrt{\sum_k [T_{jk} - I_j]^2}}{L} \quad .$$

Denote r - the index of a criteria group: r = 1,..s, where s - number of groups (in our case s = 4).

The average score and MSD are calculated for each expert and each technology for each criteria group

$$AGrkj = \sum Si_g jk / i_g \quad ,$$

$$MSDGkj = \sqrt{\sum [Si_g jk - AGrkjj]^2 / i_g},$$

where i_g is a number of criteria in each group ($\sum i_g = i$).

All the output parameters described above form the Numerical Data Base as a number of tables.

Verification Procedure

Based on the results of initial expert assignments this procedure includes the detailed analysis of all criteria divided into different groups - to clerify their contradictiveness and sameness. This will make it possible to decrease their number and to leave those that are most important for the concrete assessment procedure. Afterwards all experts can observe the obtained results and compare their estimates with average values taking into account the disagreement factors (MSD). It will allow to modify their initial assignments or - if they do not agree with other opinions - to comment their decisions.

At the final stage all information beginning with the initial output data to the verified one is presented for all participants with all comments and graphical images. It will allow not only to have avaraged abstractive results but to describe differences in opinions based on national, professional and other factors. In this case the results of the assessment procedure can be used by different national and social groups and all forecasts will be more reliable.

Criteria Modification

It is well known that if an expert is to deal with a lot of criteria his estimations are not reliable (see Table 1). That's why a special procedure is implemented to reduce their initial number by grouping them.

For this purpose all calculated scores for criteria groups (based on assignments for the full set of criteria) are compared with the assignments made for the criteria groups (see Appendix 1). Verifying these two results will make it possible to use only group criteria assignments in the future.

4. GENERAL STRUCTURE OF TAS

The general structure of TAS is shown in Figure 2. It consists of the *Introductory Data Base*, which stores all the information taken by the questionnaire from the experts, the *Import* program, which brings this information to the Data Processor, The *Data Processor*, including different filters and analyzers to make all data transformations representing it in the most convenient way, and the *Export* program, which puts the processed data into the *Resultant Data Base.*

TAS has a hierarchical menu system. When the user enters TAS he watches the Main Menu on the screen (Figure 3) with all necessary positions beginning with the introduction of experts and the choice of the criteria up to some editing positions - to adjust TAS packages for the needs of the particular user.

First position of the Main Menu is to enter Experts Data Base (Figure 4) - to introduce or change all the information about the experts of the assessment procedure. The next step is to assign weights for the given criteria. When one enters the appropriate position of the Main Menu he finds the Submenu that allows to formulate the list of criteria. Afterwards a special window appears in which each expert can manipulate the values of the criteria weights while their normalization (by the rule that their sum is equal to 100) is being done automatically.

Special export procedure introduces information about experts and chosen values of the criteria weights to the Introductory Data Base (IDB) (Figure 5). After the analysis of the questionnaire ratings for each expert, technology and criterion are introduced to IDB to serve as a basis for further calculations. Or it can be done directly in IDB.

The next two positions of the Main Menu allow to process all introductory data and to export the output data to the Resultant Data Bases (Numerical and Non-numerical).

When the user enters the Numerical Resultant Data Base he can see the NRDB Submenu and can observe all the output figures on the screen as tables or graphs of different kinds and can have them printed out (Figures 6-13). This base includes a separate frame for Averages and MSD of weights and scores for each technology, a frame with calculated scores for groups of criteria and a frame with integrated results for each of the experts and technologies integrated estimates averaged by all experts.

The Non-numerical Resultant Data Base consists of a number of frames. Each frame represents the percentage of different answer levels for each technology (Figure 14).

Entering the 'Verification' position of the Main Menu after pointing the technology-number and expert-number for the comparison of averaged output merits, all the appropriate information is taken from IDB and NRDB and introduced to the Verification Data Base 1 (VDB1) (Figure 15).

Taking into account the problems of the use of a big ammount criteria that contradicts sometimes with human expert factors another verification procedure was suggested to deal with the outputs connected with the criteria groups. To check the reliability of the initial assignments with each of 23 criteria, a separate position is provided in the questionnaire in which the experts are to assign weights and ratings for each technology by the four mentioned criteria groups. This information is compared with output group scores calculated on the basis of initial scores for the 23 criteria (in VDB2).

5. SOME PROGRAMMING ASPECTS

TAS is based on different main modules that were integrated to solve technology assessment problems. Some of the modules were worked out in the Computing Centre of the USSR Academy of Sciences. They include SPECTR - a data oriented base system by which all mentioned data bases were built; SPOUT and SPIN - programs for importing and exporting files from/to data bases to/from calculation and analysing programs; programs that are integrated in Data Processor and serve as means for the appropriate data transformation; FILTERS - to make national and professional samples from all frames of the Resultant Data Base; and LEXICON - files editor. Some additional packages (DG and CHART) are used to represent information on the screen (as graphics and plots) and to have it printed. All menus of TAS were built using module DLG that provides easy modification of menu positions and is based on the call of DOS executable packages (position Dialogue Scenario in the Main Menu calls editor in which all menus can be changed if necessary). File TAS.DOC contains the full description of TAS. One can also get some instructions for using TAS by means of HELP facilities and file TAS.CTL.

Programs for Data Processor are written on BASIC. Therefore, they can be easily modified by the user for his own purposes and for the given structures of the Resultant Data Bases. Separate position of the Main Menu allows to enter GWBASIC editor.

TAS is based on the use of IBM-type personal computers with the hard disk colour display and RAM no less than 512k. It is provided with developed HELP facilities and can be used even by non-specialists in computer programming.

In case of necessary modifications of the forms of data bases, filters, or some other supplementary programs in TAS, consultations of professional programmers will probably be needed to help the user while the normal operation of TAS is a rather simple procedure.

Supplied with the installation procedure TAS requires no less than 3Mbt of the hard disk space.

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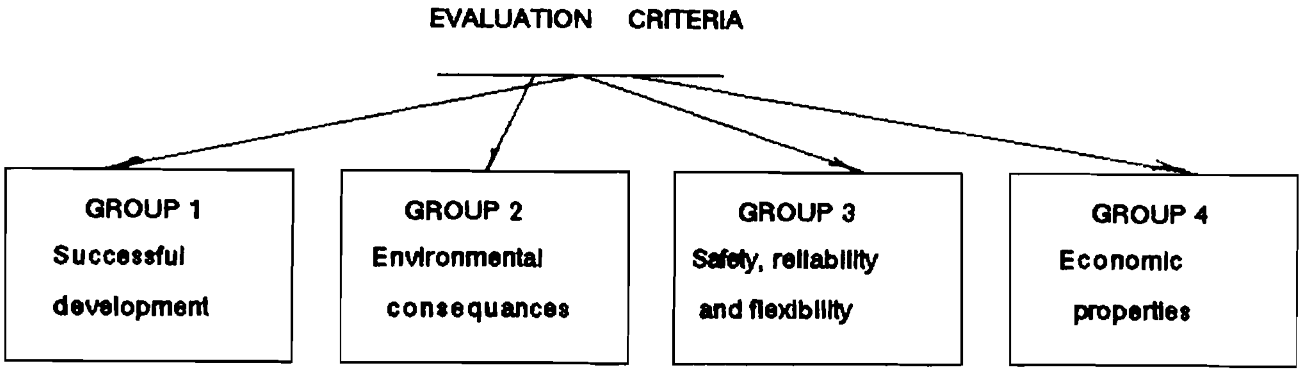


Figure 1. Groups of Criteria.

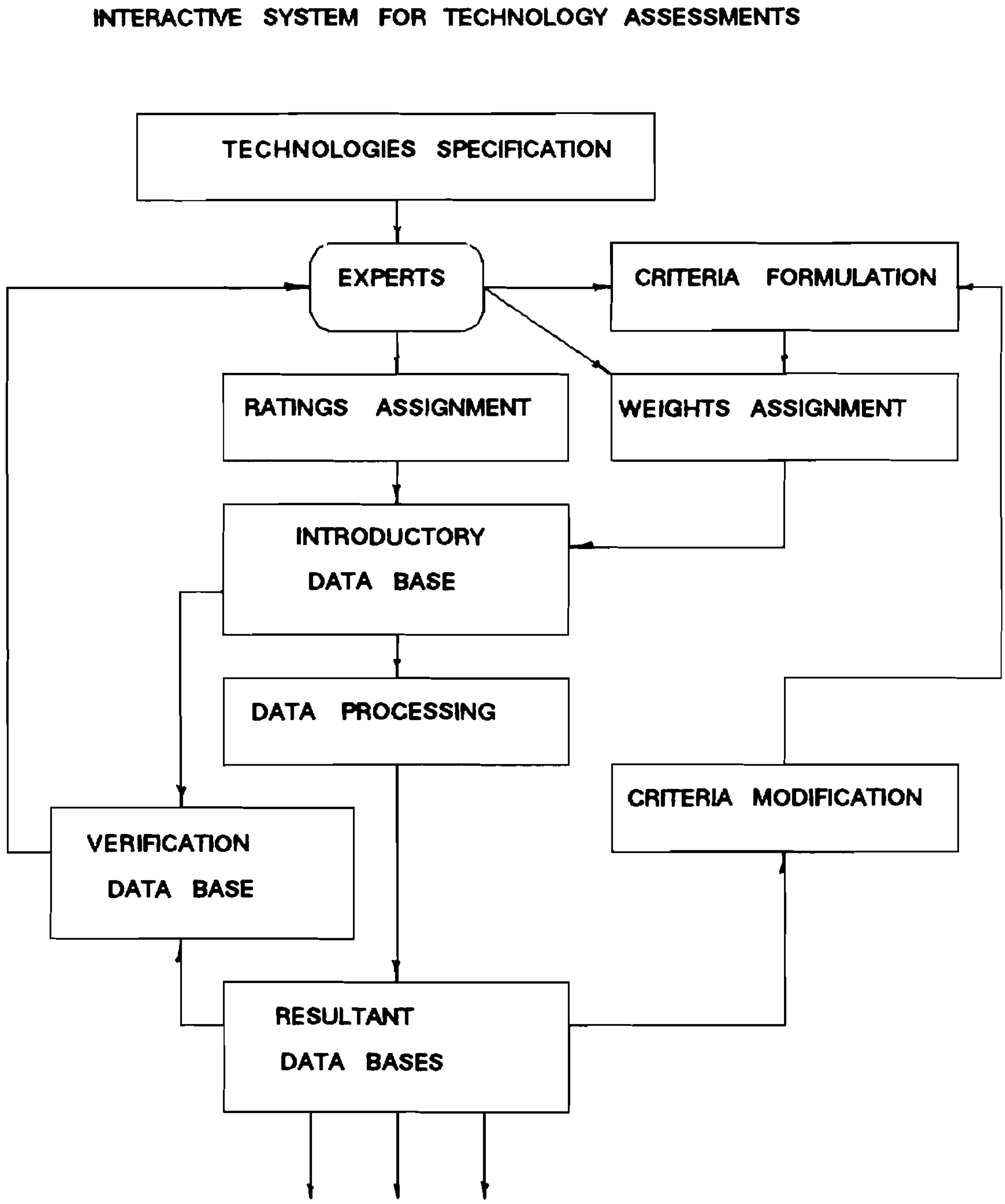


Figure 2. Structure of TAS.

```
|EXPERTS INTRODUCTION                          |
|WEIGHTS ASSIGNMENT                            |
|INTRODUCTORY DATA BASE (IDB)                  |
|NUMERICAL DATA PROCESSING                     |
|NON-NUMERICAL DATA PROCESSING                 |
|RESULTANT DATA BASE (Numerical)               |
|RESULTANT DATA BASE (Non-numerical)           |
|VERIFICATION                                  |
|DIALOGUE SCENARIO                             |
|DATA PROCESSOR EDITING                        |
|                                              |
```

Figure 3. Main Menu.

Experts

N	Name	Country	City	Place of work	Specialization
1	Okorokov V.	USSR	Leningrad	IIASA	GEN
2	Rejewski P.	Poland	Warshava	Chemic.Research Inst	CHEM
3	Fedyaev A.	USSR	Irkutsk	Sib.Energy Inst.	HEAT
4	Filippov S.	USSR	Irkutsk	Sib.Energy Inst.	HEAT
5	Belyaev L.	USSR	Irkutsk	Sib.Energy Inst.	ELECTR
6	Tabors R.D.	USA	Cambridge	MIT	GEN
7	Gilli P.V.	Austria	Graz	Technical Univ.	COAL
8	Spinrad B.I.	USA		Iowa State Univ.	NUCL
9	Heikkila Matti	Finland		Imatran Voima Oy	ELECTR
10	Golovin A.P.	USSR	Irkutsk	IIASA	GEN

Figure 4. Experts Data Base.

T1-T7

N	Criteria	W87	W00	T1		T2		T3		T4		T5		T6		T7	
1	R&D Time Requirement	3	1	1	2	4	5	3	4	3	4	1	4	4	5	3	4
2	Costs of R&D	2	3	1	2	3	3	2	4	4	5	1	4	4	4	2	4
3	Probability of R&D Su	3	4	2	4	4	4	3	5	3	4	2	4	4	5	3	4
4	Capability of Ind.Man	2	2	7	4	4	5	3	4	4	5	1	2	4	5	4	5
5	Availability of Mater	3	4	7	4	4	4	4	4	4	4	2	3	4	4	4	4
6	Institutional Barrier	3	2	1	3	2	3	2	5	1	4	2	3	4	4	3	4
7	Social Acceptability	4	6	1	3	2	3	4	5	4	5	1	2	4	4	4	4
8	Level of Pollution	7	9	5	1	3	4	4	4	4	5	3	4	3	3	3	4
9	Flexibility of Siting	2	5	1	4	4	4	4	4	4	5	4	4	5	5	3	3
10	Waste Handling and Di	6	3	4	4	4	5	4	5	3	4	1	3	5	5	4	4
11	Availability of Clean	2	2	1	4	4	4	4	4	4	5	4	4	4	4	3	4
12	Consequences of Accid	5	6	4	3	3	4	3	4	3	4	1	2	5	5	3	4
13	Safety Characteristic	10	12	4	4	3	4	3	4	3	4	2	4	4	5	3	4
14	Adaptability to Types	4	3	4	4	4	4	4	4	3	4	2	3	4	4	3	4
15	Outage Rate	2	1	3	3	3	3	3	4	2	3	4	4	3	4	2	2
16	Risk of High Damage	7	8	4	2	3	3	3	4	4	5	1	3	4	5	3	3
17	Capital Cost	6	4	15	2	3	4	3	4	4	5	2	3	4	5	3	4
18	Construction Period	3	2	3	2	4	4	3	4	3	4	2	4	4	5	3	4

Figure 5. Sample from IDB (expert 1).

TECHNOLOGY 1

N	Criteria	Average 1987	Average 2000	MSD 1987	MSD 2000
5	Availability of Mater.&Res.	20.444	22.333	3.366	3.962
6	Institutional Barriers	8.875	6.5	1.94	1.677
7	Social Acceptability	9.5	12.5	1.479	2.193
8	Level of Pollution	18.375	19.25	3.171	3.096
9	Flexibility of Siting	5.444	10.444	1.633	2.331
10	Waste Handling and Disposal	11.75	11.	2.51	2.038
11	Availability of Cleaning	9.571	10.428	2.193	2.248
12	Consequences of Accident	20.	20.	3.522	3.681
13	Safety Characteristics	18.625	23.875	3.413	5.449
14	Adaptability to Types and Sources of Fuel	7.142	9.	1.504	1.049
15	Outage Rate	8.25	6.75	0.879	1.026
16	Risk of High Damage	17.428	16.714	3.148	2.292
17	Capital Cost	31.555	21.111	8.751	4.484
18	Construction Period	9.222	12.666	1.585	4.773
19	Efficiency of Energy and Resources Utilizatio	30.125	24.375	12.557	4.275
20	Multiproducts Availability	15.25	17.	4.414	3.94
21	O & M Requirements	9.	9.	2.338	2.371
22	Commercial Acceptability of Product	15.25	16.625	2.454	3.122

Figure 6. Sample from NRDB (technology 1, average scores and MSD).

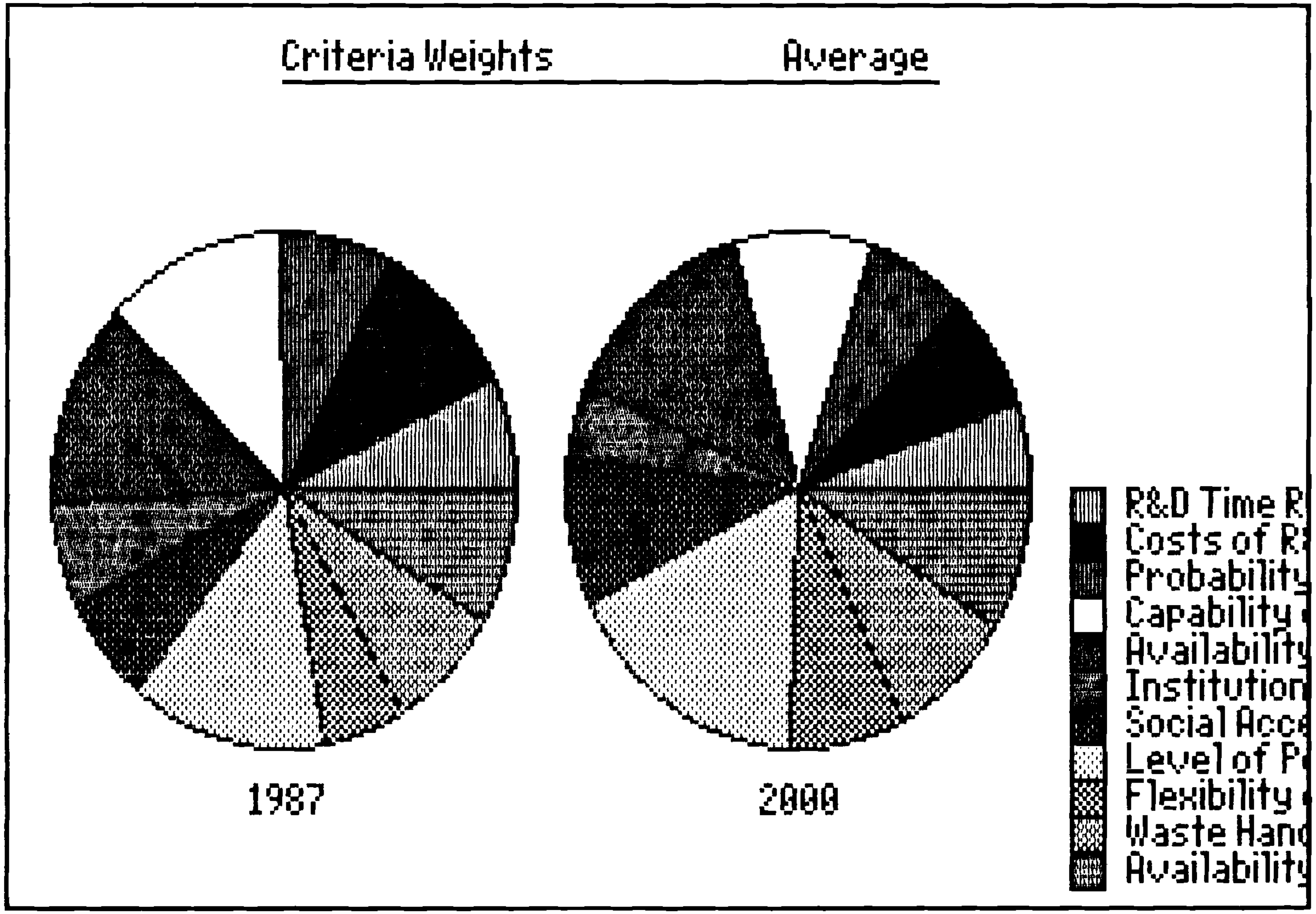


Figure 7. Sample from NRDB (average weights, pie graph).

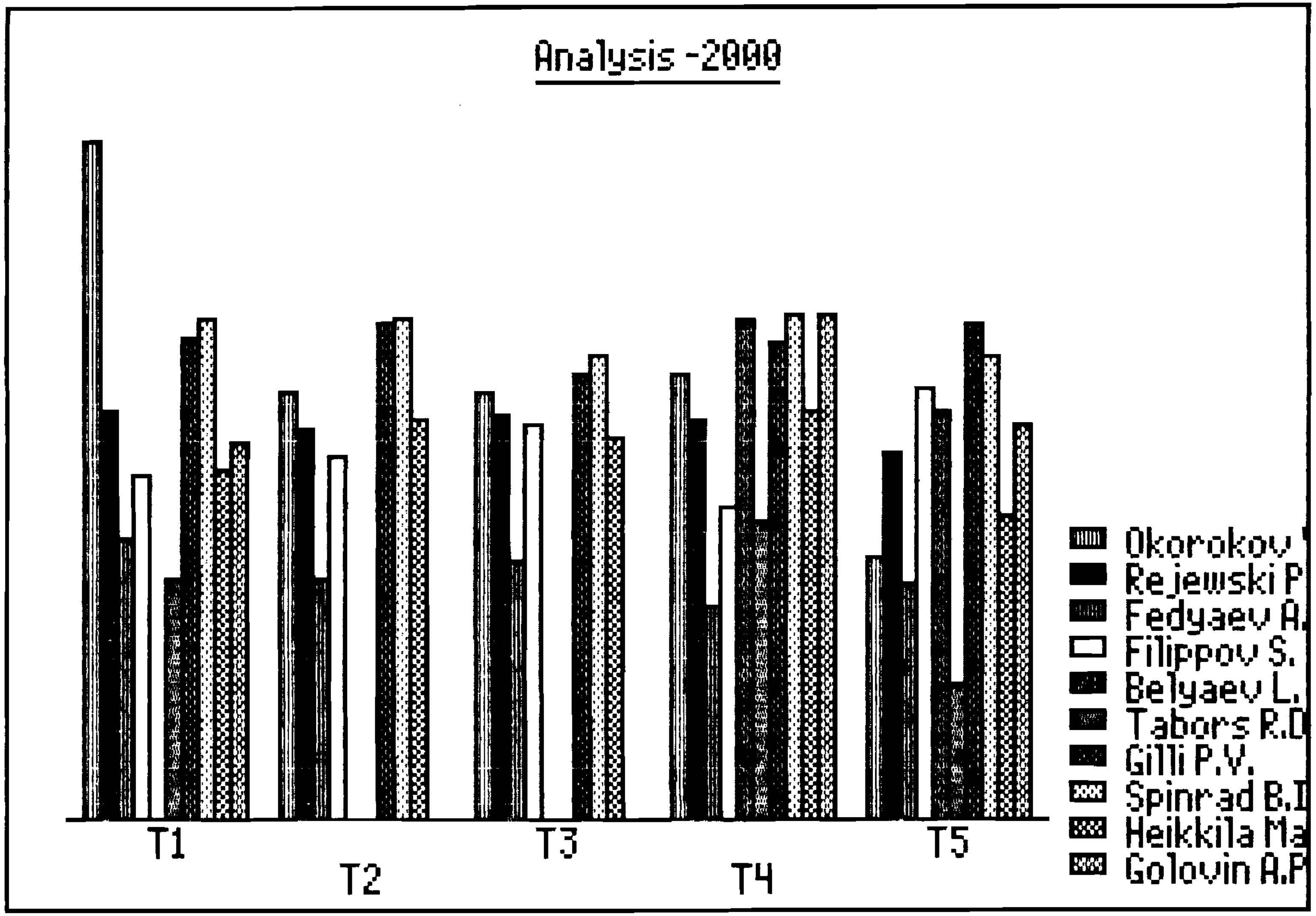


Figure 8. Sample from NRDB (sum scores for technologies, bar diagram).

Analysis -2000

N	Name	Country	Spec.	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T1
1	Okorokov V.	USSR	GEN	530	334	334	349	207	360	333	325	295	305	333	358	32
3	Fedyaev A.	USSR	HEAT	219	189	204	165	185	198	230	249	175	129			
4	Filippov S.	USSR	HEAT	271	283	309	247	338	172	285	210	317	315	336	275	31
5	Belyaev L.	USSR	ELEC				393	319	421			344	363		414	
10	Golovin A.P	USSR	GEN	296			395	311	429		264	310		453	300	29

Figure 9. Sample from NRDB (country filter in sum scores table).

T1 group analysis

N	Name	Country	Speciali	1987 I	1987 II	1987 III	1987 IV	2000 I	2000 II	2000 III	2000 IV
1	Okorokov	USSR	GEN	7.5	16.6	22.5	43.4	10.2	13.4	19.7	16.2
6	Tabors R.	USA	GEN	14.4	6.	6.	9.	7.	12.6	6.	8.5
10	Golovin A	USSR	GEN	12.4	13.	10.	14.8	10.4	13.	9.2	16.

Figure 10. Sample from NRDB (specialization - filter in group analysis table).

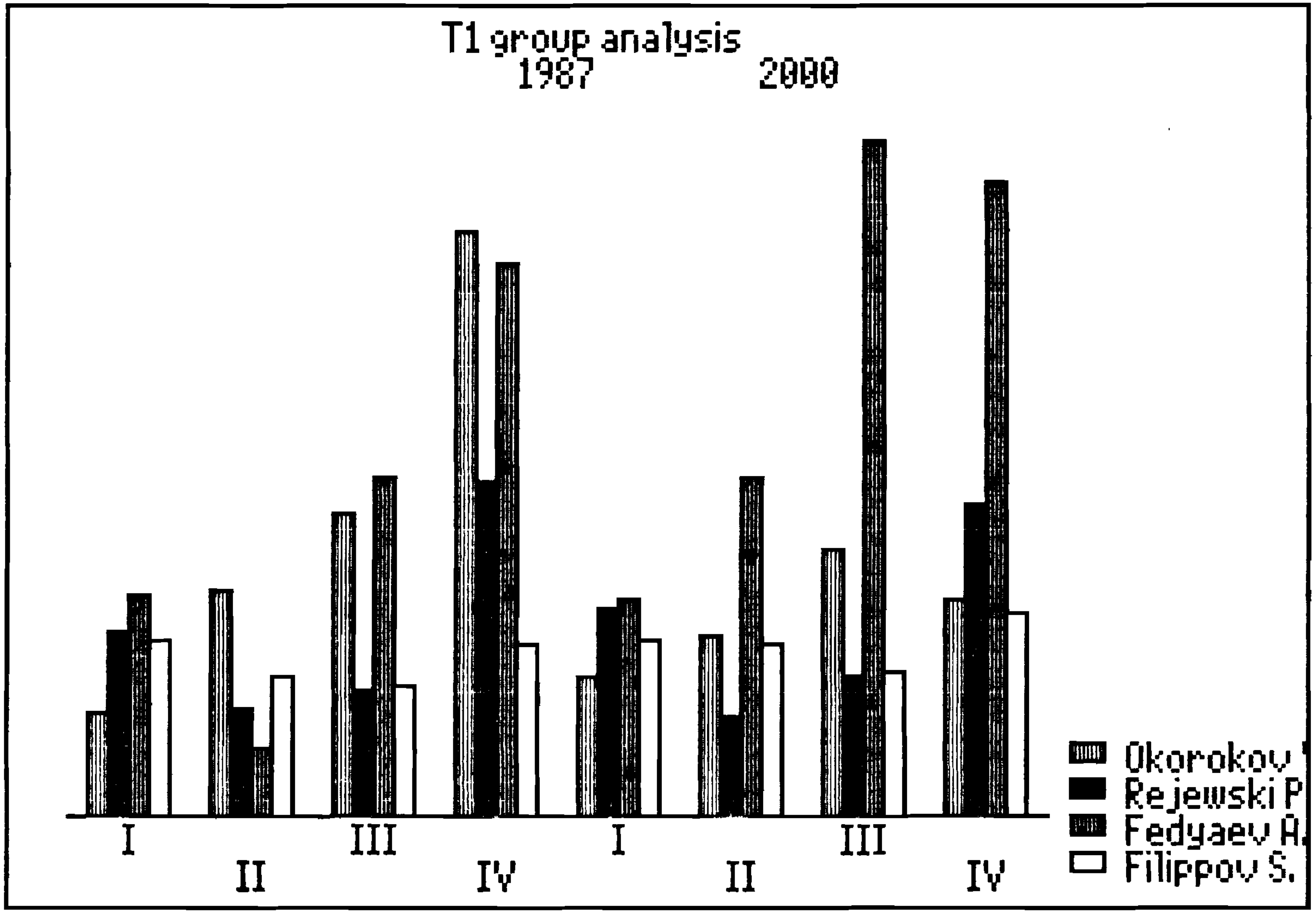


Figure 11. Sample from NRDB (T_1 group analysis, bar diagram.)

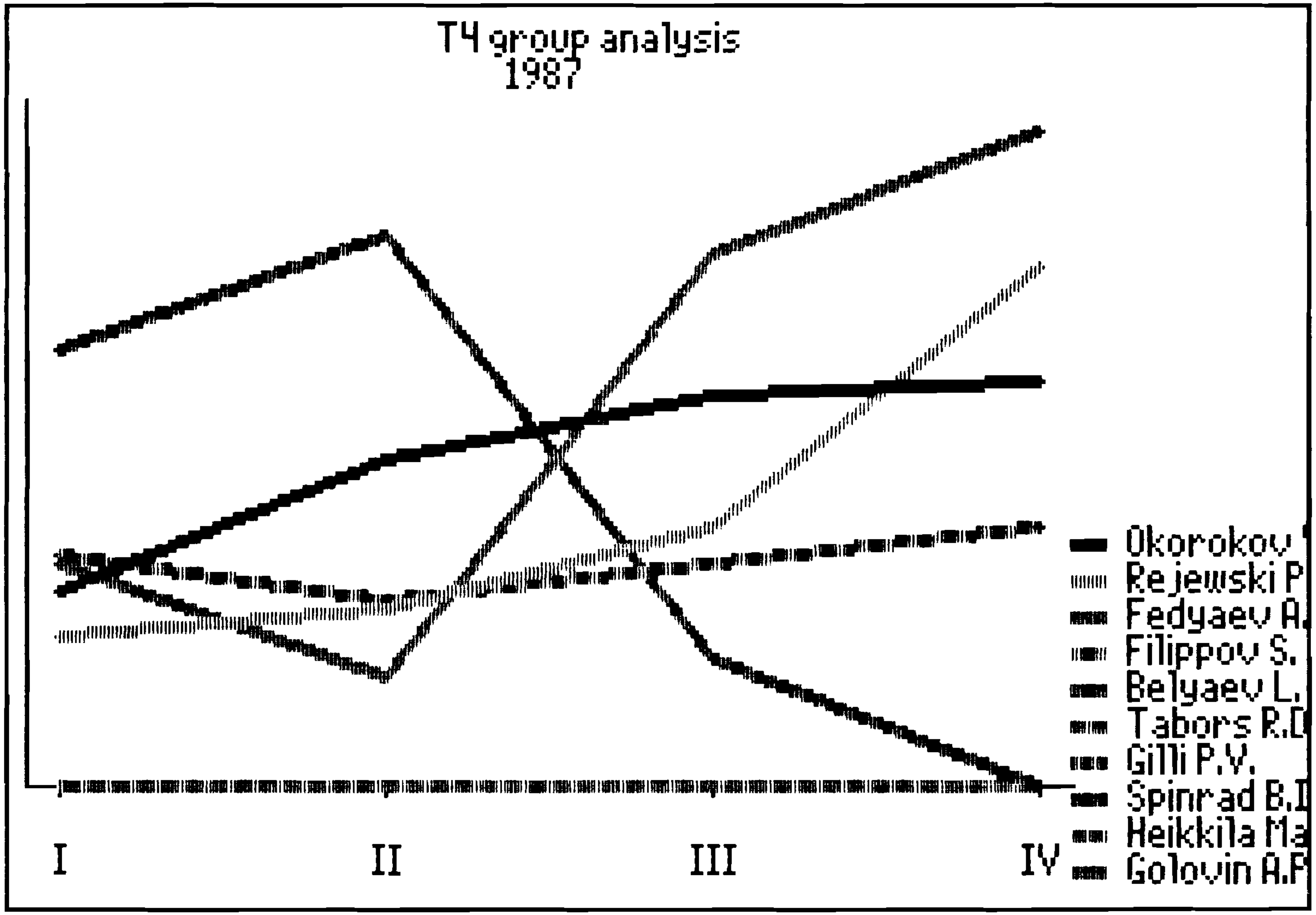


Figure 12. Sample from NRDB (T_4 group analysis, line diagram).

Integrated Estimates

N	Technology	Average 1987	MSD 1987	Average 2000	MSD 2000	Comments
1	T-1	310.444	22.372	318.666	32.443	[commen]
2	T-2	353.714	16.696	315.	24.228	
3	T-3	341.571	19.782	310.571	18.274	
4	T-4	337.6	26.693	318.9	23.914	
5	T-5	293.4	27.849	274.4	26.591	
6	T-6	343.3	28.59	338.8	28.201	
7	T-7	326.142	23.272	307.571	15.628	
8	T-8	292.	27.333	284.555	18.78	
9	T-9	302.3	22.545	299.1	18.113	
10	T-10	311.625	28.492	297.625	24.698	
11	T-11	341.375	30.112	321.75	28.992	
12	T-12	321.111	26.801	305.888	25.524	
13	T-13	319.	14.003	316.375	7.741	
14	T-14	324.5	16.962	302.25	12.233	

Figure 13. Table of Integrated Averaged Estimates.

T1 1987

N	Criteria	% No answers	% 1	% 2	% 3	% 4	% 5
1	R&D Time Requirement	20.	10.	20.	10.	30.	10.
2	Costs of R&D	20.	20.	30.	0.	20.	10.
3	Probability of R&D Succes	20.	0.	10.	10.	50.	10.
4	Capability of Ind.Manufac	20.	0.	20.	10.	30.	20.
5	Availability of Mater.&Re	20.	10.	0.	20.	30.	20.
6	Institutional Barriers	20.	20.	20.	20.	10.	10.
7	Social Acceptability	20.	10.	0.	60.	0.	10.
8	Level of Pollution	20.	0.	50.	0.	20.	10.
9	Flexibility of Siting	10.	20.	40.	20.	0.	10.
10	Waste Handling and Dispos	20.	0.	10.	50.	20.	0.
11	Availability of Cleaning	30.	10.	10.	30.	20.	0.
12	Consequences of Accident	30.	0.	10.	30.	20.	10.
13	Safety Characteristics	20.	0.	10.	30.	20.	20.
14	Adaptability to Types and	30.	10.	50.	0.	10.	0.
15	Outage Rate	20.	0.	10.	70.	0.	0.
16	Risk of High Damage	30.	0.	30.	10.	20.	10.
17	Capital Cost	20.	10.	40.	20.	10.	0.
18	Construction Period	10.	10.	30.	40.	10.	0.

Figure 14. Sample from NNRDB (technology 1).

1987

N	Criteria	Weight	Rating	Score	Average	MSD	Comment
1	R&D Time Requirement	3	1	12	9.375	1.457	
2	Costs of R&D	2	1	6	12.375	2.968	
3	Probability of R&D Succes	3	2	12	14.125	1.971	
4	Capability of Ind.Manufac	2	7	8	19.222	2.738	
5	Availability of Mater.&Re	3	7	12	20.444	3.366	
6	Institutional Barriers	3	1	6	8.875	1.94	
7	Social Acceptability	4	1	8	9.5	1.479	
8	Level of Pollution	7	5	21	18.375	3.171	
9	Flexibility of Siting	2	1	8	5.444	1.633	
10	Waste Handling and Dispos	6	4	24	11.75	2.51	
11	Availability of Cleaning	2	1	8	9.571	2.193	
12	Consequences of Accident	5	4	15	20.	3.522	
13	Safety Characteristics	10	4	30	18.625	3.413	
14	Adaptability to Types and	4	4	16	7.142	1.504	
15	Outage Rate	2	3	6	8.25	0.879	
16	Risk of High Damage	7	4	21	17.428	3.148	
17	Capital Cost	6	15	18	31.555	8.751	
18	Construction Period	3	3	12	9.222	1.585	
19	Efficiency of Energy and	11	11	33	30.125	12.557	

Figure 15. Sample from VDB (technology 1, expert 1).

Expert's Definition of the Criteria

Group Number	Evaluation Criteria	WEIGHTS of the CRITERIA 1987	2000
I	1. R & D Time Requirement		
	2. Costs of R & D		
	3. Probability of Successful Project's Development		
	4. Capability of Industrial Manufacturing		
	5. Availability of Necessary Matherials and Resources		
	6. Institutional Barriers		
	7. Social Acceptability		
II	8. Level of Pollution		
	9. Flexibility of Siting		
	10. Waste Handling and Disposal		
	11. Availability of Cleaning		
	12. Consequences of Accident		
III	13. Safety Characteristics		
	14. Adaptability fo Types and Sources of Fuel		
	15. Outage Rate		
	16. Risk of High Damage		
IV	17. Capital Cost		
	18. Construction Period		
	19. Efficiency of Energy and Resources Utilization		
	20. Multiproducts Availability		
	21. O & M Requirements		
	22. Commercial Acceptability of Products		
	23. Availability and Prices of Natural Resources		

Merit Ranking for Energy Technology

(SEE REVERSE SIDE FOR TECHNOLOGY DEFINITION)

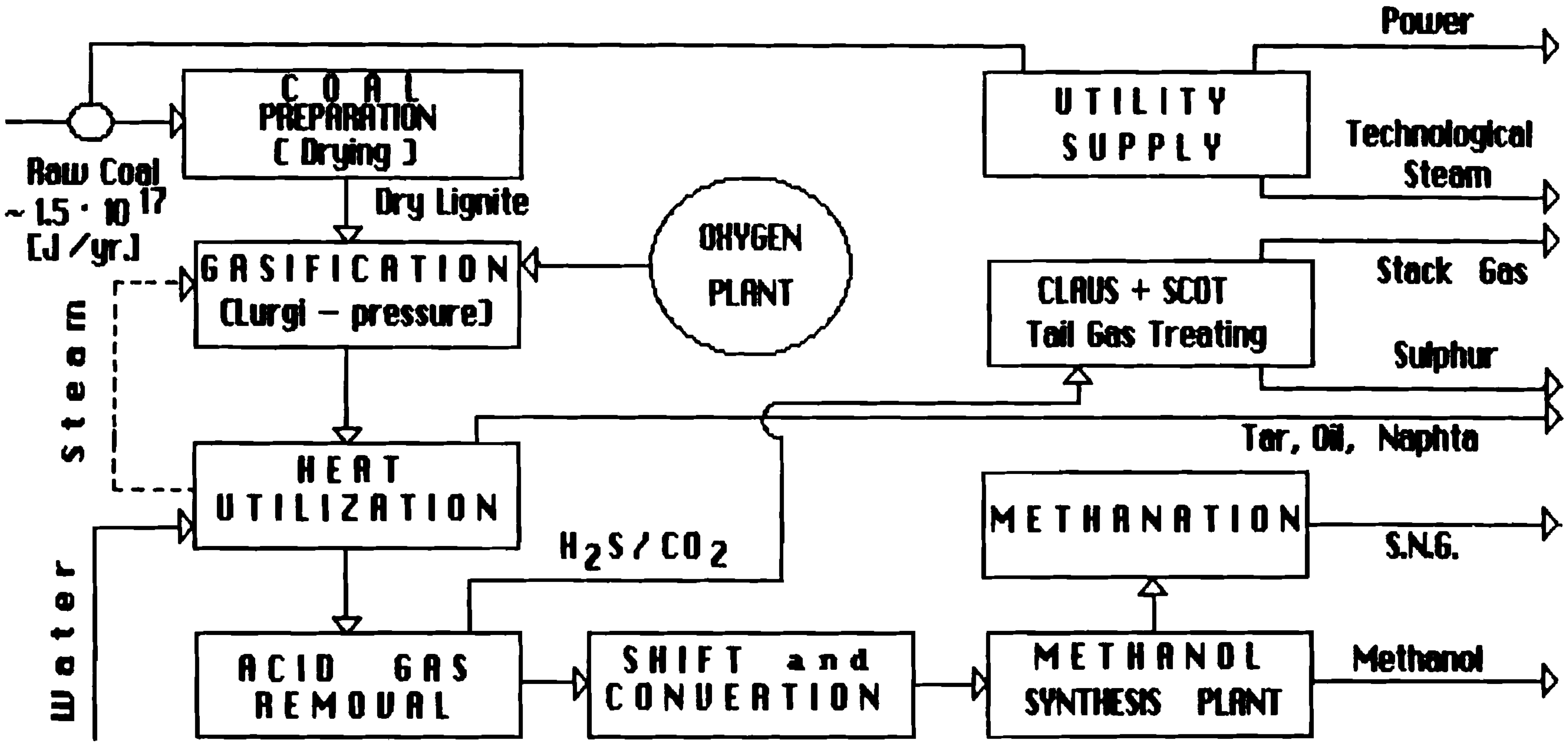
Group Number	Evaluation Criteria	RATING /Excellent/Good/Fair/ /Poor/Bad/ 1987	2000
I	1. R & D Time Requirement		
	2. Costs of R & D		
	3. Probability of Successful Project's Development		
	4. Capability of Industrial Manufacturing		
	5. Availability of Necessary Matherials and Resources		
	6. Institutional Barriers		
	7. Social Acceptability		
II	8. Level of Pollution		
	9. Flexibility of Siting		
	10. Waste Handling and Disposal		
	11. Availability of Cleaning		
	12. Consequences of Accident		
III	13. Safety Characteristics		
	14. Adaptability fo Types and Sources of Fuel		
	15. Outage Rate		
	16. Risk of High Damage		
IV	17. Capital Cost		
	18. Construction Period		
	19. Efficiency of Energy and Resources Utilization		
	20. Multiproducts Availability		
	21. O & M Requirements		
	22. Commercial Acceptability of Products		
	23. Availability and Prices of Natural Resources		

CRITERIA GROUPS ASSESSMENT

Weight \ Group	I	II	III	IY
W - 1987				
W - 2000				

Techn. \ Groups	I 1987	II 1987	III 1987	IY 1987	I 2000	II 2000	III 2000	IY 2000
T1								
T2								
T3								
T4								
T5								
T6								
T7								
T8								
T9								
T10								
T11								
T12								
T13								
T14								

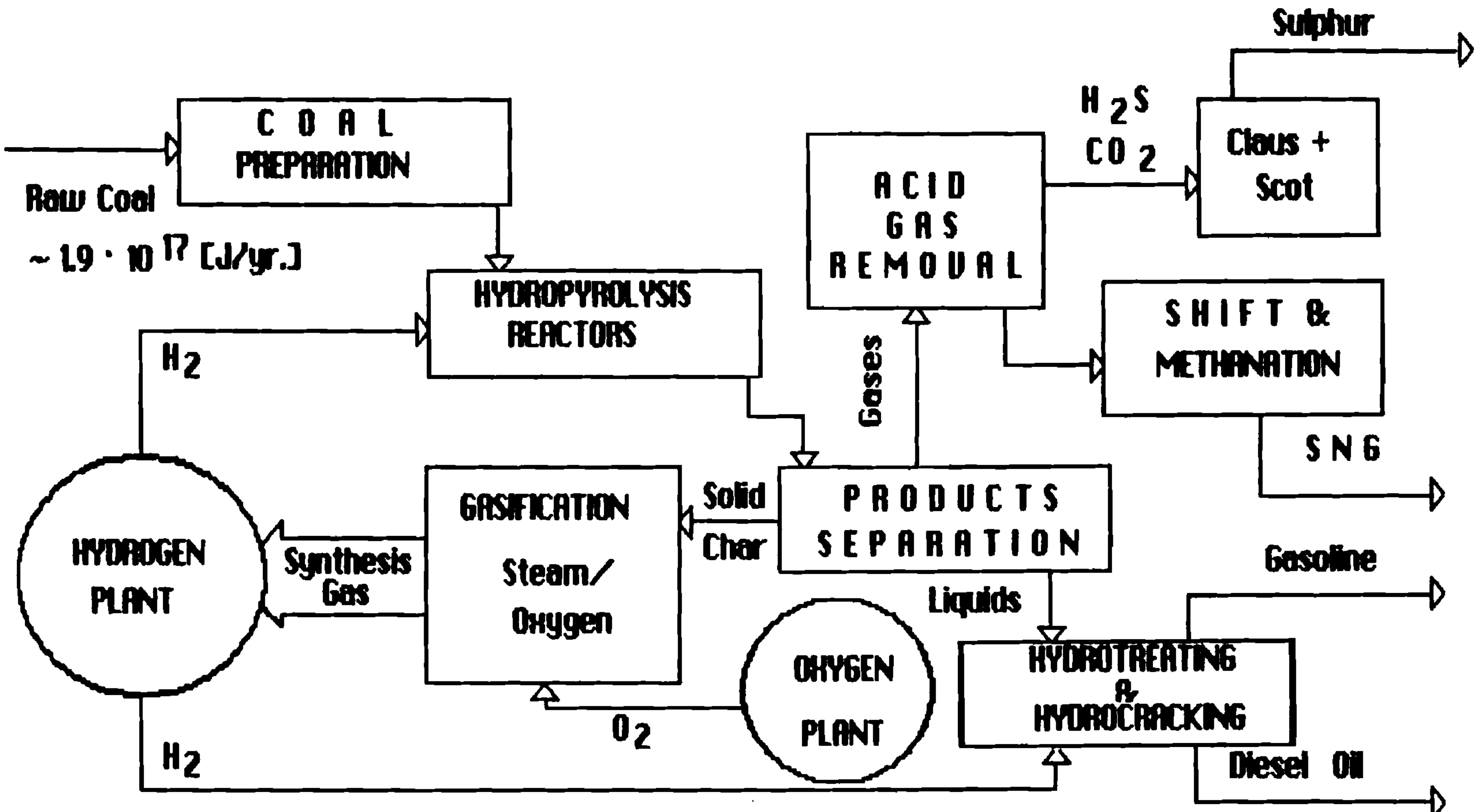
Appendix 2



LURGI PRESSURE GASIFICATION + CO-PRODUCTION OF METHANOL and SNG

TEMPERATURE: < 900 C   PRESSURE: 20 – 30 bar (gasification)
50 – 60 bar (Low Pressure CH_3OH Synthesis)

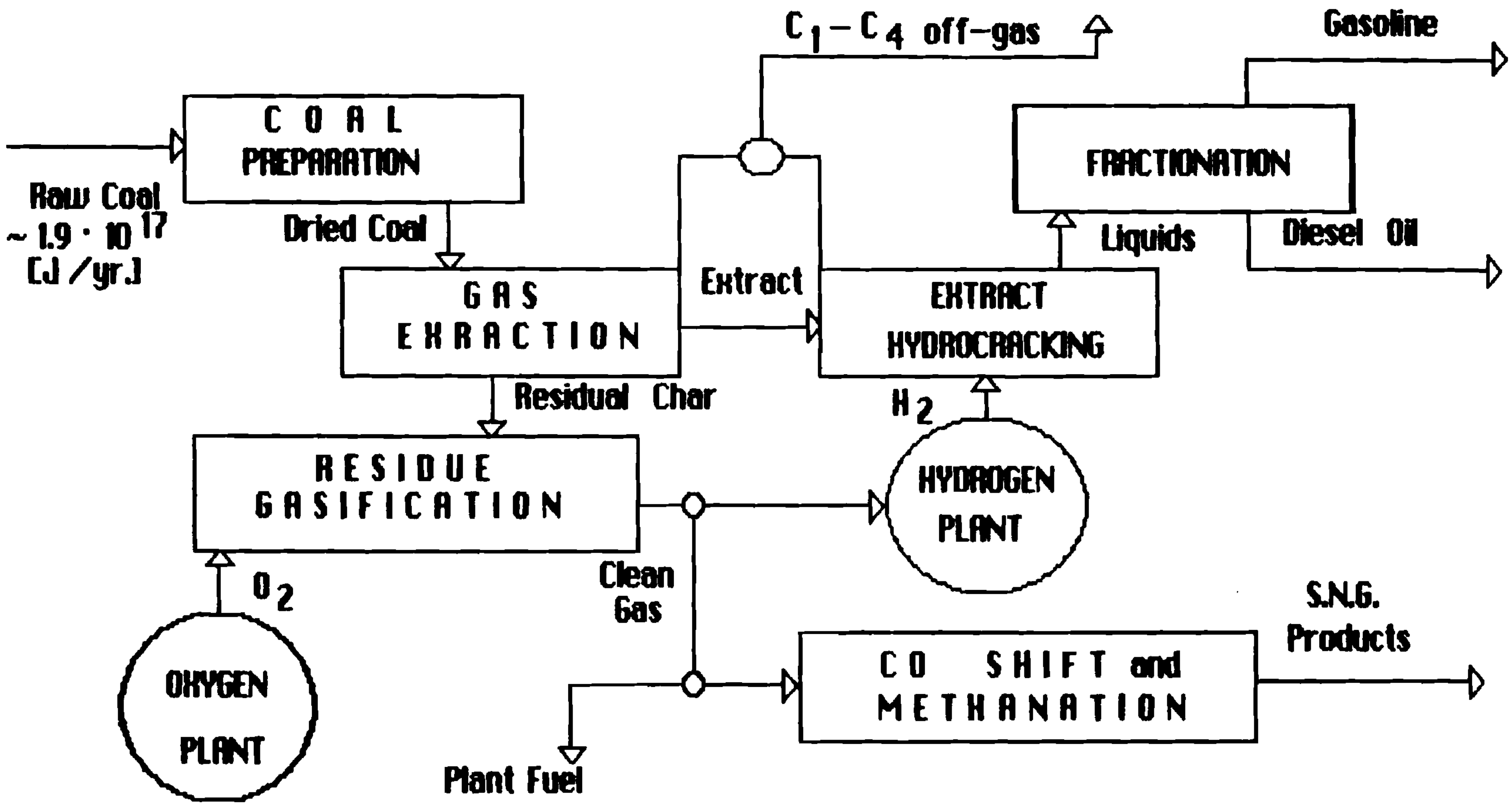
Fixed Capital Investment for the plant Mln.$US(1986) 1400 – 1600   ECE = 63.6 %



HYDROPYROLYSIS of bituminous coal

INTEGRATED MOTORFUELS & S.N.G. PRODUCTION **E.C.E ≅ 65 – 70 %**

Fixed Capital Investment for the plant Mln.$US (1986) 1700 – 2300



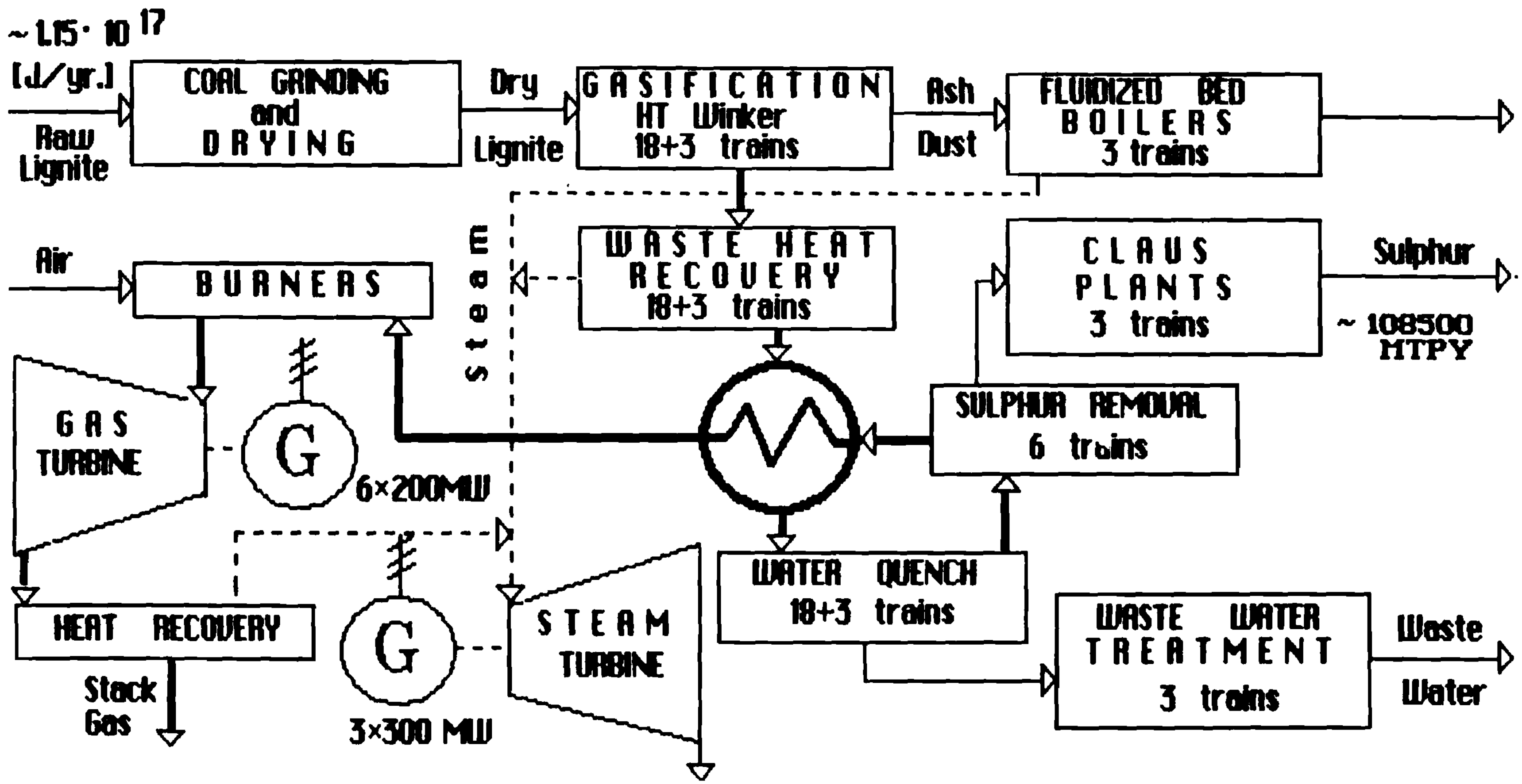
SUPERCRITICAL EXTRACTION

E.C.E. = 67.7 %

Temperatures 350 - 450 C ; Pressures 100 - 200 bar

Based on National Coal Board supercritical toluene extraction of bitumious coal

Fixed Capital Investment for the plant Mln.$US (1986) 1300 - 1800

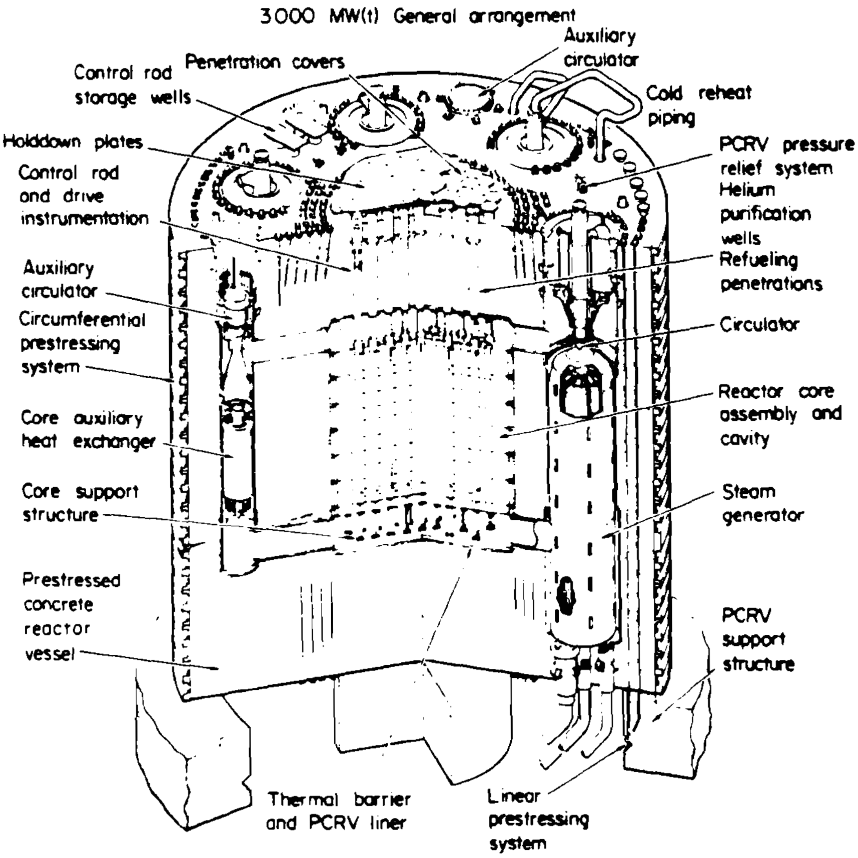


COMBINED CYCLE POWER STATION WITH INTEGRATED COAL GASIFICATION

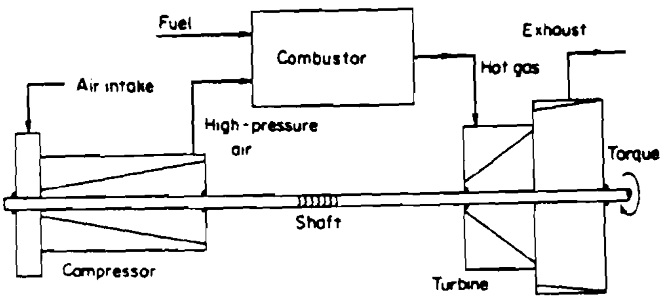
E.C.E = 44 %   NET POWER 3×650 = 1950 MW   NET ENEGRY PRODUCTION ~ $5.05 \cdot 10^{16}$ [J/yr.]

High Pressure Steam - 120 bar   Gas Turbine Inlet Temperetue - 1100 C.

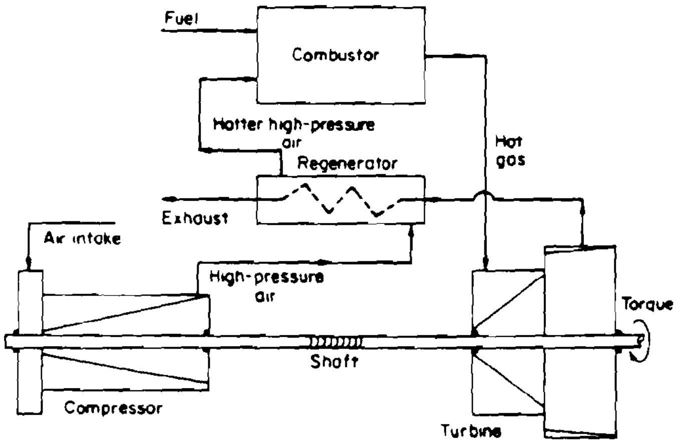
Fixed Capital Investment for the plant Mln.$US(1986) 2200 - 2600.



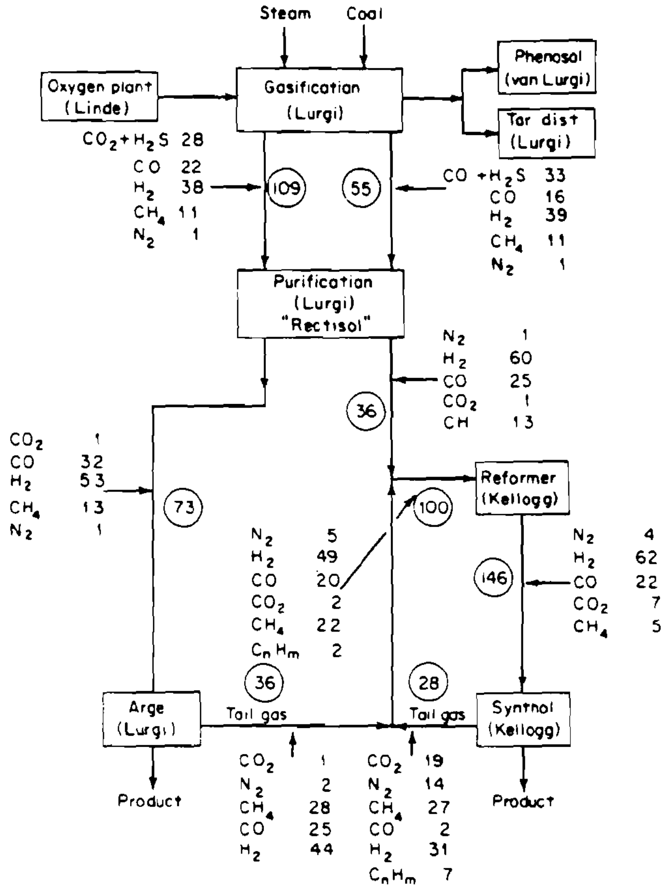
Nuclear steam system of a 3000 MW (thermal) high-temperature gas-cooled reactor (HTGR)



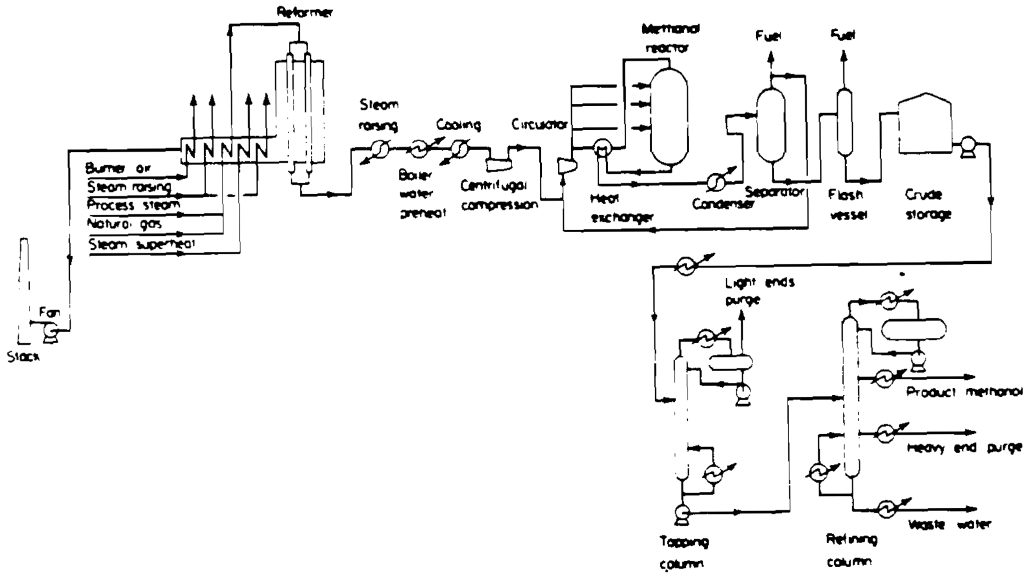
. Gas-turbine configuration exhibiting basic Brayton or Joule cycle.



Gas-turbine configuration with regeneration.



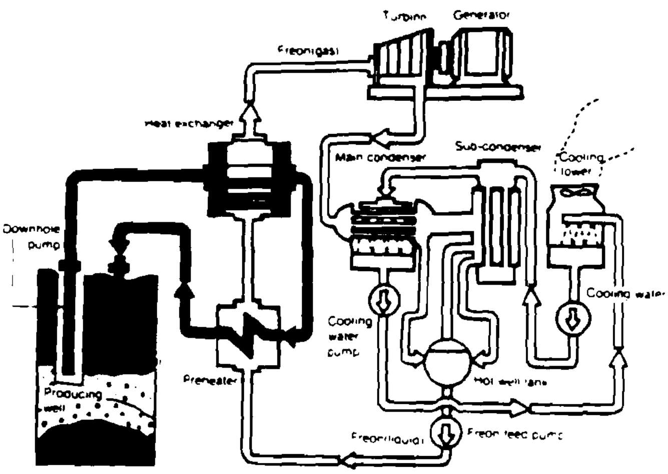
Basic flowsheet of original plant at Sasol. Compositions are given in volume percent. Volumes (within circles) are 10^6 standard cubic feet per day. *(Reproduced by permission of the source: South African Coal, Oil and Gas Corporation Limited.)*



ICI low-pressure process for producing methanol from natural gas. *(Davy Powergas Ltd.)*

Geothermal Energy

Being situated on the Pacific Rim volcanic belt, Japan's geothermal energy resources are abundant, and since this energy is virtually the only indigenous resource that the country possesses, considerable hope is being placed on the development of geothermal energy.



Flow Diagram of Binary Cycle Power Plant

Technology Development

For the purpose of effective utilization of Japan's estimated huge hot water resources, NEDO is developing a binary cycle power generation plant for effective utilization of hot water resources, and hot dry rock systems for utilization of the thermal energy of hot dry rocks thousands of meters below ground level.

Development of a Binary Cycle Power Generation Plant

In a binary cycle power generation plant, the heat from hot water is transferred to a working fluid with a low boiling point, and the resultant pressurized secondary fluid is used to drive a turbine which generates electric power. If this method can be effectively used to utilize the vast amounts of medium-temperature hot water that are believed to exist underground, such systems can contribute to utilization of geothermal hot water energy. Because such medium-temperature water does not have sufficient power to reach the surface by itself, it is necessary to develop a downhole pump (DHP) capable of forcing 170°C ~ 200°C hot water hundreds of meters to the surface without a decrease in temperature.

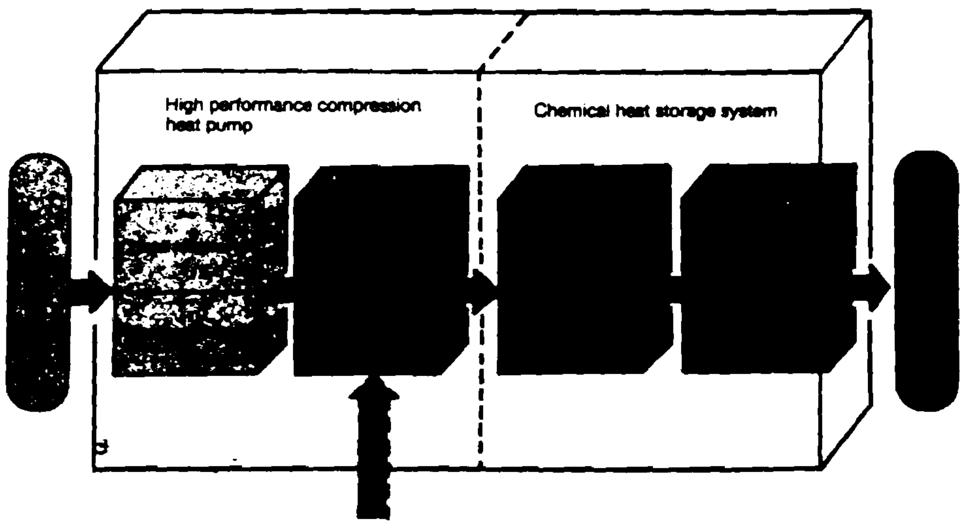
The DHP is 20 cm in diameter and about 10 m in length. Research is presently being undertaken on the development of the basic technology for shaft seals, seal oil, stator coils and cables. A first test pump, which has a water pumping capacity of 50 tons per hour, has been undergoing testing at a hot water well (water of 170°C) since 1986. Based on the results of these tests, a second pump with a capacity of 100 tons per hour will be designed and constructed in order to upgrade the technology to a practical level by 1988.

In addition to the designing of a 10MW binary cycle system, a well is being drilled in Oita Prefecture in preparation for the construction of a demonstration plant, and investigation is underway on the temperature, pressure, and permeability of the reservoir.

Super Heat Pump Energy Accumulation System

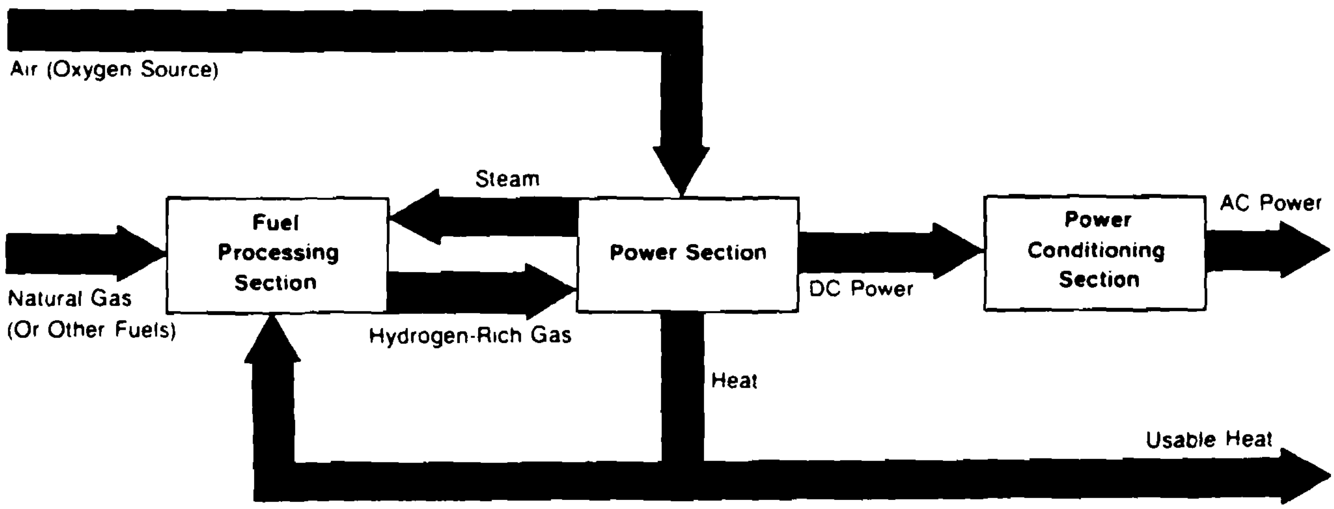
Another system with capabilities of load levelling is the super heat pump energy accumulation system. In order to make it possible to meet the increasing demand for heat, efforts are being directed towards the development of systems capable of utilizing waste heat.

This system consists of very high-performance compression heat pumps and a chemical heat storage system. The former uses off-peak electricity to produce heat at high temperature, and the latter stores the heat at a high density so that it can then be used for the heating or cooling of buildings or as an industrial-use large-scale heat source.



Concept of Super Heat Pump Energy Accumulation System

Fuel Cell Power Plant Functional Diagram



COAL GASIFICATION IN A MOLTEN IRON BATH (Coal,Iron Gasification 'GIG')