国際応用システム解析研究所のエネルギー研究について

1 9 7 5年5月

財 団 法 人
政 策 科 学 研 究 所
Institute for Policy Sciences, Japan

国際応用システム解析研究所のエネルギー研究について

1975年5月

今　井　隆　吉

国際応用システム解析研究所（International Institute for Applied Systems Analysis）はウィーン郊外Laxenburgにあり，米，ソが主体となって出資をしているが，わが国からも一部出資がなされ，日本人研究員も参加している。IIASAの研究の一環としてエネルギー世界戦略があり，W. Héfele（前カールスルーエ研FBRリーダー）が主催して26人の研究員（part time を含む）により広汎な研究が進められている。5月27日に非公式advisory committee があり，小生もその一員として参加したので以下にプロジェクトの概要を紹介する。方法論その他参考とすべきことが多く，またわが国のエネルギー研究と連絡をとることはIIASA側も希望している。（なおエネルギープロジェクト予算は年間約1000万弗）

1. 対象とするエネルギー源は

fission （FBR）

fusion （D－T）

太陽熱

石　炭

地　熱

をとりあげ，夫々について maximum utilization のシナリオの下に制約(constraints)と長所を明らかにし，optimum mix を考えることを可能にするという気宇想大なプロジェクトであり，1973年7月に第一回大会を行なって方向を定めた上で過去2年間にわたり以下のような研究を行なって来た。それらの結果は別添文献 list にあるような形で公表されている。

2. 各エネルギー源について現在のエネルギー形態から完全に新エネルギーに移行するまでの technology transition（技術移行）をＬＰによって試みている。

a) fission； fission への完全な移行には約６０年を要する計算となり，低コストウランと石油が夫々どのくらい available かが主要 constraint となる。核燃料サイクルに１万トンの Pu を input して normal operating loss と accidental loss を計算することで問題点を探す。放射性 pollution(特に waste) がどれだけ constraint になるか等が検討されている。

b) fusion； fission と fusion の比較が W. Héfele と C. Starr (EPRI) によって最近出され，両者が環境に与える影響或いは実現のタイミング等についての議論は最近ソ連でも Working Group が作られる等，主としてこの角度から問題がとり上げられている。

c) 太陽熱についてはアメリカの宇宙技術の input もある模様であるが，技術移行の検討に加えて，土地利用の問題が specific にとりあげられている。

d) 石炭については主として外部専門家（米，英，独，チェコ）に依存するが，特に原子力におけるような厳密な方法論を石炭に適用することに重点がおかれ，この意味での ＩＩＡＳＡ の役割りには興味が持たれている。

e) 地熱についてはごく最近手がつけられ初めたばかりである。

3. 人的，社会的，自然的環境との関連をシステム手法によって明らかにすることがプロジェクトのもう一つの重要な側面である。

a) 廃熱が天候に与える影響は当初可なりの制約になると思われた。この為英気象庁のコードをカールスルーエ計算機にかけ 1.5×10^{14} ワットの熱源２つを想定して数値計算を行なった。米国（オークリッジ，RAND）との協力もされている。今までのところ特に waste heat が主要な constraint になりそうな徴候は見られていない。

b) resilience とは non－linear なシステムに負担をかけ続けると或る閾値を境に量から質への変換が起きることを指している。問題をまず一般解として明らかにする努力がされているが，このconcept がとり上げられているのは一人当りエ

ネルギー消費の増大がどこまで続くか，人口増とエネルギーその他の問題を考える時のモデルにとり入れることを考えるからである。

c) risk evaluation は特にIIASAとIAEA（国際原子力機関）の共同研究として進められているが，risk model, voluntary と nonvoluntary risk, public と private risk, objective risk と subjective perception 等のテーマがとり上げられている。

d) 遠い将来のこととして，エネルギーislandが考えられている。海水ウランを燃料とし原子力エネルギーを液体水素又はアンモニアとして外部に積出す形式で，いわば現代の油田に代るものが技術によって形成出来るかどうかの可能性をモデル化して検討する。

e) 新技術の市場性の一般条件

f) energy park；これは d) に比べてもっと現実的に現在の技術によって，たとえば国際燃料サイクルパークのようなものを考え off－peak 時のエネルギー利用も検討するもので Weinberg の nuclear park の概念と似たものである。（Alvin Weinberg もエネルギー advisory committee のメンバーとしてIIASAと関係が深い）

g) Safeguards 理論の一環として accountability を検討し，特に決定理論により inventory taking を分析する。このほかエネルギー施設 siting の決定手段を formalize した形で考える構想もある。

4. エネルギー資源，エネルギー需要について特に新しくデータを入手することはIIASAが独自に行なうことは大変であり，従って埋蔵量推定或いは決定手法のシステム的評価，エネルギー需要モデルの作成等に関心が集中している。この5月には夫々のテーマについてLaxenburg で国際会議が開かれ，資源探査の motivation と探査手法の関連など興味ある討議が行なわれている。

5. その他および今後の問題

IIASAとしては過去2年間の成果をベースとして，「systems implications of various energy alternatives」を考え，特に評価に当って「anticipated environmental impacts」に主眼を置く形として，2～3のmodel societyを選定して各種方法論を適用することで問題を整理してみることを考えている。

これに対してadvisory committee では2種類のコメントが出された。

(i) global model だけで全体を取扱わずに先進国(市場エコノミー，計画経済，)後進国(前と同じ)の4つぐらいに分けることは出来ないか。夫々にとって，特に最適政策決定の条件が違い過ぎるから。これに対してIIASA側からmodel bloc相互間のcoupling (interaction)を「無し」とするか「complete free trade」とすれば可能であるが，現実に似た形の相互関連をmodel化することは今のところ極めて困難であると手法上の問題が説明された。今後の検討課題とする。

(ii) 従来の手法でシステム解析可能な要因ばかりが選び出されているが，それよりもっと異なった種類のテーマに対してどのようなapproach をするかをきちんと決める必要があるのでは無いか，たとえば国際政治の急変，長期大量資金の調達に伴う問題，社会的acceptance のcriteriaを単なるrisk／benefitだけに依存して良いのか，consensus 決定の社会機構は何か など いずれも現代の大きな問題であり，これらの立場を明確にした上でシステムアナリシスの中で扱うか，外に出してしまうのかをはっきりさせる必要がある。また夫々の技術についてacceptable な aspect と unacceptable な aspectがあるのであればglobal strategyにはglobal monitoring scheme が伴なう可きでないか。

5／27のmeeting は特に小生の都合で短時間に限られたので，これらの問題について突込んだ意見の交換が出来なかったので出来れば年内に正式な advisory committee を開きたいということになった。IIASAのエネルギープロジェクトについては上記2点以外にも基本的なアプローチそのものを批判する余地はあると思うが，しかしこのような考え方に立って多勢の国際的な研究者を動員して大きなシステム分析を進めていることは大いに注目し今後の交流を図ることが大切であると痛感した。

(付) "The IIASA Project on Energy System"

"The Comparison of Energy Options"

"Research Program 1975, Energy Systems"

"Risk Assessment and Societal Choices"

"Research Publications and Internal Working Papers"

"Energy Project Conferences"

W. Häfele May 22, 1975

The IIASA Project on Energy Systems

I. Scope

The work of the IIASA Project on Energy Systems started in the summer of 1973 with the IIASA Planning Conference on Energy Systems. The Proceedings of the Conference experienced an unforeseen large distribution and elicited a high response. The paper by W. Häfele on "Energy Systems" which was reprinted in the IAEA Bulletin also gained much attention. The shortened version of the paper as published in the American Scientist also received wide spread interest.

This helped to establish the scope of the Energy Project. It is of a medium and long range nature without leaving aside more short range aspects. In the long range there is more than one option for a practically unlimited supply of energy, while the short range problem is a sufficient supply of fuel, in particular of oil. The most interesting question therefore is the transition from these short range conditions to the long range situation. This points to the period of 10-40 years from now.

The characteristics of the scope of the energy work at IIASA are in particular the aspects of timing and decision making in connection with technological strategies.

II. Energy Options

In the long range there are four and a half options for the supply of energy that are not at all or only very mildly resource constrained:

a) nuclear fission (breeding)
b) nuclear fusion (D-T reaction)
c) solar power
d) coal (half an option)
e) geothermal energy

In the course of the project, possibly all these options will be identified and described in view of their system implications.

a) the option of nuclear fission

During 1973 and 1974 the attention was on the option of nuclear fission. A. Manne and W. Häfele built a LP model that describes the strategies for the transition from fossil to nuclear fuels. It was published recently. R. Avenhaus, W. Häfele and P.McGrath have written a major paper that concentrates on non-economical considerations for the deployment of a large fuel cycle. This paper is in publication. P. Sint prepares an objective function for pollution as an alternative for the objective function that asks for discounted costs. The work on the option of nuclear fission was meant to press for comprehensive views. A whole literature exists on each more detailed aspect as this option has experienced much long range planning -- much in contrast to other technologies.

b) the option of nuclear fusion

Recently C. Starr and W. Häfele published a paper that marks a beginning in the comparison of fission and fusion breeders. Starting from there, a task force was formed to make such a comparison in greater depth and with participation from both sides, fission and fusion (see VI). A comprehensive report might be expected by the end of this year.

c) the solar option

With the remarkable assistance of the National Academy of Sciences in Washington it was possible to get Dr. Weingart to IIASA and to provide broad background information on that option, particularly coming from the Aerospace Corporation. At IIASA he is supported by Mr. N. Weyss. A. Suzuki and L. Schrattenholzer extensively apply and develop the LP model for technological transitions. A total of three major papers on the solar option are expected to be ready by this summer, concentrating on a technological survey, the identificaiton of system problems and constraints and the application of the LP procedure to the problem of a transition from fossil fuels to an all solar society.

d) the coal option

Contacts were made to the U.S. Geological Survey, the German Ruhrkohle, the British Coal Board and the CSSR group at Ostrava with the hope of setting up a task force that would work on the identification and description of the coal option. By that a truly large scale use of coal resources is referred to, say a factor of 10 or more if compared with today's operations (see VI). A first and small workshop was held along these lines. If the participation of the above mentioned institutions can be fully assured, a comprehensive report on that option could be expected by the end of next year. Work along these lines is pursued by. M. Grenon, W. Sassin and C. Marchetti.

e) the geothermal option

Work has only recently been started on this option by M. Grenon. But there are indications that the French National Member Organization might be helpful in starting this work much in the same way as the USA National Member Organization was helpful in the case of the solar option.

The work on the various options follows--for methodological reasons--the idea to carry each option to the extreme, that is to provide all of the primary energy this way. It is felt that such an extreme consideration brings to the forefront the strengths and weaknesses of each option. It should therefore be possible to identify sequences of decisions that could lead to optimal mixes of such options. The exclusive consideration of each option is therefore not an end in itself, but a tool for a later synthesis.

III. More Specific Tasks

The 1973 Planning Conference pointed to the problem of embedding the flow of energy into the

- hydrosphere
- atmosphere

- ecosphere
- sociosphere

It is anticipated that this will constrain the use of long range options that are free of resource constraints while the short range options are rather characterized by the fact that they are resource - and that is fuel - constrained. In a more general sense, to understand the constraints that come from embedding is one of the major themes of the Energy Project. It is against that background that the following more specific activities have to be seen:

a) <u>the impact of waste heat on the climate</u>

Weinberg and Washington started in 1971 a line of investigation that tried to identify impacts of large amounts of waste heat on the global climate. The results were not conclusive. It was felt that such climate impact could come out to be a constraint in the above mentioned sense. Contacts were made through the British National Member Organization with the British Meteorological Office. They made available their computer code for their large global atmospheric circulation model. It was operated at the computer center of the Kernforschungszentrum Karlsruhe. {east of Japan / west of Bra.. Africa}
Two numerical experiments were made looking into the impact of $2 \times 1.5 \times 10^{14}$ Watt on the global climate. Each 1.5×10^{14} Watt were concentrated in energy parks. At the end of April a small expert meeting was held for presenting and evaluating these results. With the present state of the art of climate evaluation no major impact was identifyable in this round of investigation.
A. Murphy from the National Center for Atmospheric Research at Boulder, Colorado, USA, conducted most of the work. He was assisted by C.H. Yang, Bedford, Mass., USA, and G. Spannagel from Karlsruhe, FRG. A report that summarizes the work of this phase will be available by this summer. This activity forms part of the interface to the Water Project and the food interests of IIASA. Along

(As far no basis to think waste heat provides upper limit.

this line more work is intended.

b) resilience

The term resilience was introduced by C.S.Holling, project leader of the Ecology group. It refers to the finite capability of absorbing impacts in a system that is governed by non-linear relations. While it has been helpful in conceiving certain schemes it was felt necessary to look into a quantitative scheme of dealing with the aspect. Specifically, it is hoped that resilience can be made an objective function in a LP or dynamic programing procedure. If compared with optimal solutions that use other objective functions, and specifically discounted costs, a formalized policy analysis and support for decision making under uncertainty is pressed for. This is expected to be of importance in the comparison of options. But the more general implications of the resilience approach may be by far more important. This resilience investigation is a common line with the Ecology and the Methodology projects.

A first very simple model was conceived by W. Häfele. It considers a socio-technical set of non-linear relations that relate population and per capita energy consumption. Nevertheless it captures the essence of the resilience idea as it makes apparent topological basins that appear desirable or undesirable,respectively. This model is now being generalized and made somewhat more realistic, considering population (labor for that matter), energy and capital, with risk perception being endogenous in the model. R. Grümm and R. Avenhaus, together with W. Häfele are involved in that. Especially to be mentioned here are the contributions by C. Winkler and D. Bell of the Methodology Project.

c) risk evaluation

The joint IAEA/IIASA Study Group on Risk Evaluation is now fully operational. It concentrates on the understanding and the modeling of the risk aspect. Among other things one attempt is made to distinguish between voluntary and involuntary risks, between public and individual risks and objective risks and their subjective per-

realistic need fulfilled
IAEA participation

ceptions. A first set of reports on the value of lives in decision making has been finished. From IIASA's side Mrs.H.Velimirovic and Miss J.Linneroth participate in that group. Later, P.D. Pahner will join them. The team leader is H. Otway, IAEA. The scope of work of this group covers the aspect of public acceptance of technological measures, including nuclear power. Already now the work of this group is receiving a great deal of attention as it is only at its beginnings. A major set of results is to be expected at the end of this year.

d) market penetrations, energy islands

C. Marchetti has made comprehensive studies on the penetration of markets by new technologies. It appears that to a very high precision the logistic curve allows for the representation of such market penetrations.

possible scenario in 100 years

C. Marchetti gives major emphasis to the evaluation of a long range normative scenario where a major portion, if not all, of the primary energy demand of a region or continent is met by nuclear power installations on an island in one of the oceans. The energy produced would be shipped as ammonia or liquid hydrogen much in the same way as is the case with oil today. Such islands in the oceans would therefore be a substitute for oil fields. The normative scenario may be instrumental in understanding the potentials and material dimensions of nuclear power.

using U from ocean

off peak for H_2 production

e) secondary energy systems, energy parks

W. Häfele and W. Sassin have studied the applications of nuclear energy for uses other than the generation of electricity. The findings were presented at the recent joint European Nuclear Society/American Nuclear Society meeting in Paris (April 1975) and turn out to be a basis for understanding the implications of the large scale deployment of energy systems. The emphasis goes to secondary, centralized energy systems. W. Sassin, after his arrival at IIASA, will evolve from there and establish a working liaison with the Urban Project on this basis.

(international fuel cycle parks)

(decision theoretical aspects)

f) accountability

Evolving from the accounting of nuclear material in context with the IAEA safeguard system, R. Avenhaus has written a major monograph of such (generalized) accounting systems. It includes aspects of gaming and optimization and procedures for inventory taking. This monograph will be one of the first contributions to the IIASA Handbook and establishes a link to the Survey Project of IIASA.

g) siting (too difficult)

An attempt is made to formalize procedures for decision making in site selection. J.Gros is trying to apply work that he did at Harvard, R. Keeney and R. Avenhaus look into the policy issues of siting a reprocessing plant.

IV. Energy Resources, Energy Demand

Understanding energy resources is an important basis for the Energy Project. A policy was adopted to use the data given at the World Energy Conference of 1974 (Detroit, Handbook) as a basis for the IIASA Energy Project. IIASA is too small a group to start a major data gathering processes of its own. Instead, the emphasis is on the evaluation and comparison of methods for the assessment of resources. M. Grenon is conducting that work. Previously it was N. Kourochkin who started to pursue this aspect. The major conference in May 1975 is a first benchmark for that work.

Equally important is the understanding and modeling of energy demand. The econometrical approach to it is led by W. Nordhaus and P. Tsvetanov. In 1974, R. Eden helped to incorporate data from the U.K. More on the engineering side is the effort of J.-P. Charpentier. He studies the energy content of a wider variety of products in industry and agriculture.

understanding energy →

first 2 yrs, following 1973 summer conference (1st); – worked on 2nd iterative steps (end up in revised book); from now on concentrate on methodological study

In 1974 J.-P. Charpentier concentrated on the compilation of existing models for energy demand and supply. The first published compilation received attention; at present J.-P. Charpentier is preparing a follow-up version of it. In May 1974, a IIASA conference was held on energy models. This was a first benchmark. The conference on energy demand in May 1975 is already the second benchmark.

Both our work on resources and on demand are considered an ongoing theme that is expected to continue for a longer period of time.

V. Comparison of Options. An Outlook

After having explored to some extent the scope for the Energy Project as envisaged in 1973, a major paper (or book) following up the Proceedings of the 1973 Planning Conference is envisaged for the end of 1975 beginning of 1976. As we go along this should allow no more to concentrate on methods for the comparison of options. Recently the United Nations Environmental Program in Nairobi, the International Atomic Energy Agency in Vienna, and the World Health Organization in Geneva have jointly approached IIASA with the idea to have IIASA develop a set of procedures for the comparison of energy options. The Energy Project is taking up this proposal. It is intented to make it the backbone of the future work of the Energy Group and, to that extent, follow a process of concentration. (Attached to this document is a proposal for such work.)

VI. Remarks on the Conduct of Work

a) task force

The Energy Group of IIASA is very small in absolute terms. Besides looking more generally for cooperation it will in particular pursue the idea of joint task forces. The task forces now in operation or preparation were mentioned above. They are the following:

1) fusion-fission breeders

Participants: - University of California, Berkeley, U.S.A.(fusion)
- University of Wisconsin, Madison, U.S.A. (fusion)
- Kernforschungszentrum Karlsruhe, F.R.G.(fission)
- Academy of Science, Moscow, U.S.S.R.(fusion,fission)

This work is supported by the Electrical Power Research Institute at Palo Alto, California, U.S.A.

2) coal option

Participants: (to be confirmed)
- U.S. Geological Survey,Reston, Virginia, U.S.A.
- Gesamtverband Deutsche Ruhrkohle, Essen, F.R.G.
- British Coal Board, London, U.K.
- Ostrava-Karvina Coal Mines, Ostrava, C.S.S.R.

The intent is to continue and extend this scheme of conducting IIASA work,particularly so because this might make it easier to include industry in the activities of the Project.

b) countries visited by the project

Besides inhouse work, collaborative work, task forces and conferences the Project considers it necessary to have individuals or teams visiting the member countries and interested institutions. Here is a list of such visits:

- U.S.S.R.: visit by H. Raiffa, W. Häfele, March 1973
  visit by W. Häfele,M.Grenon,T.Koopmans,C.Marchetti, W. Nordhaus, December 1974
  visit by W. Häfele, J.P.Holdren, J. Kulzinski, G. Kessler, February 1975
  visit by M. Grenon, P. Tsvetanov, February 1975
- U.K.: visit by W. Häfele, May 1973
- France: visit by W. Häfele, June 1973
  visit by W. Häfele, M. Grenon, April 1975
- U.S.A.: visit by W. Häfele, November 1973
  visit by W. Häfele, September 1974
  visit by M. Grenon, October 1974

- Canada: visit by W. Häfele, September 1974
- F.R.G.: visit by H. Raiffa, W. Häfele, November 1974
- Pakistan: visit by W. Häfele, May 1975
- C.S.S.R.: visit by W. Häfele, C. Marchetti, M. Grenon, W. Sassin, P. Tsvetanov, May 1975

A visit of the Energy Project to Bulgaria is planned for October 1975.

DRAFT

The Comparison of Energy Options:

A Methodological Study

SUMMARY

In the past energy-related decisions have often been dictated by shorter-term considerations combined with market forces; however, it is now necessary to include the systems implications of various energy options - especially the environmental impacts. A study is outlined which would feature several normative scenarios, incorporating model societies, geographies and meteorologies, for the purpose of developing a general methodology for the comparison of energy options. This generalized model could then be used for applications to specific problems.

Seven sub-tasks requiring effort in order to develop the methodological approach are identified and described. It is estimated that the proposed study would require 24 scientific man-years and 30 man-years of scientific support over a three year period. The study would be conducted by the International Institute for Applied Systems Analysis, with financial support from UNEP, in consultation with IAEA, WHO and UNSCEAR (?).

I. INTRODUCTION

The supply of energy is a problem with ever increasing world-wide implications; therefore, energy-related decisions require careful long-range planning. The development of the technological measures necessary for the exploitation of various energy options, and their eventual penetration of the energy market, requires long time periods and large investments. In the past short- and medium-term considerations, combined with the related effects of economic forces, tended to favour certain technologies; however, it has now become mandatory to include the systems implications of various energy alternatives in their evaluation. The systems implications include the anticipated environmental impacts - especially the embedding of energy into the atmosphere, the hydrosphere and the sociosphere [1].

The selection of this systems approach for comparing various energy options is appropriate; however, it is first necessary to develop a consistent and comprehensive methodology prior to specific applications. The intent of this paper is to outline a study which would develop this methodology.

II. THE APPROACH

An actual comparison of energy options (i.e., nuclear, coal, shale oil, solar, hydropower, geothermal) requires an overwhelming amount of data and must concentrate upon the details of the specific situation under consideration. The study to be proposed here will not take this direction; rather, it is an attempt to develop general viewpoints and methods which might later be used for specific studies. The emphasis throughout is on a comparative approach.

A small number of normative scenarios, probably three, will be considered. This will involve the definition of two or three model societies with model geographies and model meteorologies. The model societies will be specified in terms of size, growth rate and a long-term projection for the expected equilibrium values. The model geographies will include population density and distribution variables as well as assumptions related to geological features. The model meteorology considers wind velocity distributions and rainfall patterns. This modelling method was successfully used in a recent IIASA study on strategies for the transition from fossil to nuclear fuels [2].

This model approach has the advantage of allowing the dominant parameters to be identified with minimal manpower requirements. Further, through the use of "model" situations, the possible political implications of specific situations may be avoided. Thus the methodology may be developed by modelling at a higher degree of aggregation (global, regional) but can later be used for actual comparisons at a lower level of aggregation (national, local).

III. METHODOLOGICAL TASKS

This section will describe in more detail areas in which work is required in order to provide the bases for methodological development.

1. Econometric Model

A macro-economic model will be developed which will relate the demand for energy (in a few categories) to the demands for capital, labor, education and other parameters. The model will combine the determinants of both energy demand and supply within the same framework by integrating both econometric techniques and input-output* analysis along the same lines as the growth model developed by Hudson and Jorgenson [3]. The demand equations will be specified using standard econometric techniques and the supply side will be specified with the use of input-output techniques. The input-output part may make use of a family of computer programmes developed at Irkutsk, USSR.

The model incorporates the determinants of both demand and supply for energy and, as such, endogenously** determines energy demand. This contrasts with most macro-economic models which treat energy demand as a time dependent exogenous variable. The approach will require that demand is equal to supply in physical terms for each type of energy and, in addition, that demand and supply are consistent with the structure of energy prices.

2. Methods and Categories for the Assessment of Resource and their System Implications

Systems implications

Data on energy resources are a complex matter. Besides the difficulties involved in the acquisition

---

* Input-output analysis, in the form originated by Leontief, is useful for a very detailed analysis of supply predicated on a fixed technology at a specific point in time.

** Simply stated, an endogenisation model provides, in the case of energy, energy demand as a function of time as a calculational result. An exogenisation model, in contrast, would require an assumed $E = f(t)$ relationship as an input.

and handling of these data, it is difficult to establish appropriate categories in order to determine their relative usefulness. The systems implications of energy resources refer primarily to the environmental impacts of mining and quarrying. A major meeting, to be held by the IIASA Energy Project in May, 1975, will focus on resource assessment methods and the systems effects. Co-operation in this area has already been established with the U.S. Geological Survey, the USSR Academy of Sciences and other institutions. The proposed study will not have to concentrate on actual resource data: the handbook on resources published at the World Energy Conference (Detroit, 1974) appears to provide a sufficient basis for this work.

3. Constraints

One of the most difficult tasks in evaluating the various energy options is that of identifying the constraints that may accompany their development. In the case of nuclear power, some of the potential constraints (e.g., physical protection, fuel reprocessing with zero radioactive release, the disposal of actinides) have emerged only recently. An even more striking example is that of tritium. The handling of tritium is one of today's constraints in the deployment of nuclear power plants, yet tritium was only discovered as a fission product as recently as 1959.

The identification of constraints for the fossil-fuel options is still unclear. For example, the ultimate disposition of CO_2 between the oceans and the atmosphere has recently been questioned. This is an item which could have grave consequences - possibly leading to drastic changes in global weather patterns.

In the case of solar energy it now seems that there may be a constraint in the provision of the large amounts of materials required if vast areas are to be covered by solar power conversion devices.

The foregoing provides only some examples of constraints that may be envisaged. Constraints must be studied in relation to both the construction and operation of energy facilities in order to produce a list of constraints for each energy option as well as predictive models.

4. Risks

A special and important constraint which must be treated separately is that of risk. The Joint IAEA/IIASA Research Project on this topic was formed in mid-1974 and it is anticipated that this group will provide a major input into the proposed study. Specific research topics now in progress include: the application of cost-benefit principles to standard setting, the perception of technological risks, the determination of societal preferences related to risk acceptance, the transmission of scientific information and interest group dynamics [4]. This work is closely related to the public acceptance of technological innovations.

5. Linear Programming Models for the Identification and Comparison of Technological Strategies

The core of the envisioned methodology will be a flexible, comprehensive linear programming model for the identification of technological strategies. For the nuclear option it will be a refinement of the recently-published IIASA model by Häfele and Manne [2]. The constraints descussed under item 3 above will be incorporated into the model.

It is important here to use more than one objective function* so that policy analysis may be carried out under a variety of conditions. The following are envisaged as objective functions:

a) Minimum discounted costs (possibly for various discount rates);

b) Primary energy consumption;

c) Environmental quality.

One major point for attention in this LP model is that of the timing for the transition into the various energy options.

Another important point is the determination of shadow prices**. Of particular interest are the shadow prices of the starting dates of new technologies and shadow prices for the rigorousness of environmental standards and other constraints. At present the IIASA is applying this approach to the solar energy option and a rough comparison is already possible as the same format has been used for the nuclear option.

---

* An objective function may be simply defined as any function which identifies policy goals.

** Shadow prices are the changes in cost which result from changes in constraints; they may be interpreted as the pressure introduced upon the objective function of the system by any particular constraint. (Mathematically: the partial derivative of the objective function with respect to any parameter.)

6. Secondary Energy Systems and Modes for Geographical Deployment

Attention must also be given to secondary energy systems as well. Freedoms are allowed through flexibility in the selection and matching of primary and secondary systems. Site selection is an important concept here as are nuclear fuel cycle parks or energy parks; therefore, modes of geographical deployment will influence the comparison of options [see Reference 5]. This topic has strong interactions with risk evaluation and the minimization of environmental insult.

7. Procedures for the Establishment of Standards

Shadow prices indicate the economic cost of environmental standards; although it is clear that such standards are a necessity. The problem of comparing completely different types of environmental impacts is the essence of the energy option comparison problem. In the case of nuclear energy the publications of the ICRP clearly identify this problem. The intended approach is to formalise, as much as possible, procedures for the establishment of standards. Part of the formalisation is that of reducing the problem of energy option comparisons to one of standards and their shadow prices. This enhances the manageability of choices and assessments by simplifying the elements of the judgements which, in the final analysis, must still be made.

IV. SYNTHESIS

The results of the tasks discussed above will be synthesized through the concept of decision trees . For each model society, and each energy option, a decision tree will be constructed which identifies the sequence and logical inter-relation of the energy-related decisions.

V. MANPOWER AND TIME

Approximately 24 scientific man-years and 30 man-years of scientific support effort will be required to complete this study. It is envisioned that the work could be completed in a three year period. These estimates assume that the results obtained to date by the IIASA Energy Project and the Joint IAEA/IIASA Research Project will be incorporated into the study.

VI. CONDUCT OF THE STUDY

It is proposed that the IIASA be responsible for the conduct of this study, with financial support from UNEP, in consultation with the IAEA, the WHO and UNSCEAR (?).

The study could, and should, start in the Autumn of 1975 with the first interim progress report expected in 1976. The study would then be completed in 1978.

REFERENCES

[1] Häfele, Wolf, "Energy Systems", International Atomic Energy Agency Bulletin, Vol. 16, No. 1/2, 1974, p. 3.

[2] Häfele, Wolf and Alan S. Manne, "Strategies for a transition from fossil to nuclear fuels". Energy Policy, p. 3, March, 1975.

[3] Hudson, Edward A. and Dale W. Jorgenson, "U.S. Energy Policy and Economic Growth 1975-2000". May, 1974.

[4] Otway, Harry J., "Risk assessment and societal choices", International Institute for Applied Systems Analysis Research Memorandum RM-75-2, February, 1975.

[5] Häfele, Wolf and W. Sassin, "Applications of nuclear power for other than electricity generation". Presented at European Nuclear Energy Conference, Paris, April 21-25, 1975.

International Institute for Applied Systems Analysis

RESEARCH PROGRAM 1975

ENERGY SYSTEMS FEBRUARY 1975

ENERGY SYSTEMS

(Project Leader W. Häfele)

1. FRAMEWORK OF THE PROJECT

The ENERGY Project views the energy problem in a medium and long-range perspective. This implies a somewhat global approach. It leads to the observation that the special problem of adequate fuel supply is of a short and medium-term nature. So it is important to focus on the timing of a transition from limited fossil fuels to practically unlimited non-fossil fuels.

For the long-range supply of sufficient amounts of energy, more than one option exists, with nuclear and solar being the prominent ones. The criterion on which to decide the appropriate mix of these energy options is oriented toward the problem of the proper handling of large amounts of energy. This is often referred to as the problem of energy embedding. The problem of embedding must, therefore, be identified in greater detail. This involves interactions of energy with the hydrosphere, the ecosphere, the atmosphere, and the sociosphere. The latter, among other things, is seen in the light of the problem of standards and risks.

A salient feature is that of siting large technological facilities. Public acceptance and the multiple objective decision process are key words here. Finally, the focus is on decision oriented procedures that allow the comparison of energy options and come to grips with the siting problem.

During 1974 the major thrust of the Project was to study the nuclear options, both from the aspects of strategies and the unified description of systems (side) effects, such as pollution or waste disposal. Also, in 1974 the emphasis was on the econometric modelling of energy demand and supply, and the work on the problem of climate and water. While the work on the nuclear option is completed in a preliminary sense, the work on the modelling of energy demand and the work on the climate have to continue.

Against this background the following tasks form the 1975 Research Program of the ENERGY Project:

2. IMPLEMENTATION

2.1 In-house Research

All tasks mentioned below will, to some extent, depending on funds available, be pursued in-house. This in-house research will be supported by the help of the U.S. National Academy of

Sciences in the work on the solar option, and by the U.S. Geological Survey for the work on the energy resource problem. Several efforts are being made now to gain additional outside support in order to avoid a drastic cutback of the envisaged research program.

2.1.1 The solar option

(W. Häfele, J. Weingart, N. Weyss, A. Suzuki)

After a first round completion of the work on the nuclear option during 1974, work has to concentrate on the solar option. Much of this study will involve the later part of 1974, but the completion will only take place during the early months of 1975. A survey on solar technology and strategies for a transition from fossil fuel to an all solar energy economy that complement the similar study for the nuclear option, completed in 1974, have to be pursued. Also, the system effects of the solar option (land use, material consumption, climate feedback) have to be assessed in a first order approximation. For the lack of funds it will not be possible to continue this work beyond July 1975.

2.1.2 Energy demand

(J.-P. Charpentier, W.D. Nordhaus, P. Tsvetanov)

Mathematical modelling of energy demand and supply has been a major subject in 1974. Now the ENERGY Project more specifically concentrates on the demand side. The relations between specific industrial and agricultural products and their energy input are to be studied in greater detail. A medium-range study, a long-range study as well as a study for low and high energy consumptions are envisaged. Econometric procedures for the demand studies will serve to integrate the aspect of pricing.

2.1.3 Energy/resources trade

(M. Grenon)

The study of problems of energy resources and reserves and the compilation of data is a continuous task of the ENERGY Project. In 1975 research will be pursued in three areas:

- energy resources assessment with emphasis on methodological questions, on the problem of definitions and on the analysis of data;
- energy production problems, in particular the problems of large scale mining and the energy content of mining operations;
- world energy trade including energy policies, in particular conservation policies and the problem of commodities coalitions.

Research in these areas is closely linked to the research on energy demand and will be oriented to assist the comparison of energy options.

2.1.4 Siting/decisions/policy analysis

(R. Avenhaus, G. Baecher, J.G. Gros, W. Häfele, R.L. Keeney)

Siting of large technological facilities in general, and nuclear power plants in particular, is one of the most ardent problems of today. The related decision and policy making process comprises competing objectives of more than one group and the ranking of problems to be faced. An attempt will be made to incorporate such objectives, together with environmental and more traditional economic considerations, into a formalized scheme of decision and policy making. In addition the problem of standard setting will be approached with the help of utility theory in order to treat standards as endogenous variables rather than exogenous constraints. This project activity will be pursued with a smaller effort than originally expected in close collaboration with the METHODOLOGY Project.

2.1.5 Risk evaluation

(J. Linnerooth, Ph.D. Pahner, H. Velimirovic)

In 1974 the IAEA formally agreed to pursue the sub-project of risk evaluation jointly with IIASA. Contrary to earlier expectations this work only began at the end of 1974. The reproductibility of the Starr Quasi Laws, the applicability of the utility approach to the perception of risks, and the psychological techniques for the quantification of the perception of technological risks, are the first subjects of the study.

It should be realized that this activity is strongly related to the problem of siting decision making and policy analysis.

2.1.6 Climate/water

(C. Marchetti, A. Murphy, N.N.)

In 1974 investigations were started to identify and study the impact of large amounts of waste heat. The numerical circulation model of the British Meteorological Office, Bracknell, U.K., has now become operational for IIASA purposes, and such numerical experiments are envisaged for 1975. On a more regional basis, the feedback of waste heat to the moisture cycle will be investigated further. Here questions of water management come up.

2.1.7 Large-scale uses of coal

(M. Grenon, C. Marchetti, N.N.)

Besides pursuing the nuclear and the solar options for the long-range supply of large amounts of energy, the implications of large-scale uses of coal also have to be studied. During the early parts of 1975 this can be done on a limited scale only. This will permit us, however, to get a rough picture so that it may be referred to in the presentations at "The IIASA Conference 1975". During the second half of 1975, however, these studies should gradually come to the forefront depending on funds available.

2.1.8 Strategy models and comparison of options

(R. Avenhaus, W. Hafele, W.D. Nordhaus, P. Sint, A. Suzuki, J. Weingart)

The development of possible strategies for the transition from the current situation to future asymptotic solutions of the energy problem provides an important basis for the comparison of options. Research in this area concentrates on the development of an econometric energy model; special emphasis will be given to the internalization of abatement measures for all kinds of environmental pollutants.

The comparison of the nuclear option and the solar option and, to some extent, with the coal option is one of the major objectives of the ENERGY Project for 1975. For this comparison research will be pursued on generalized objective functions, on general concepts for describing the behavior of highly complex systems such as the resilience concept and in the related mathematical area of differential topology jointly with the METHODOLOGY Project.

2.1.9 Material accountability

(R. Avenhaus)

The work on material accountability and its verification, which was developed in the course of the nuclear material safeguards analysis and which was applied to environmental and other problems, will be continued on a small scale. A monograph on the whole subject will be written in 1975.

2.2 External Collaborative Research

The work on energy demand will be pursued in collaboration with M.I.T. Energy Laboratory at Cambridge, Mass., U.S.A., and with the International Federation of Institutes of Advanced Study (IFIAS), Stockholm, Sweden.

As regards work on energy resources and trade, in addition to the U.S. Geological Survey at Washington, U.S.A., there will be links to IAEA and to Ruhrkohle AG at Essen, F.R.G., and institutions in the U.S.S.R.

The work on risk evaluation is pursued jointly with the IAEA. Both the IAEA and the IIASA provide the funding for a certain number of scientific man-years. Over and above that, the IAEA has asked certain member states to send scientists to the task force free of charge to the IAEA (and IIASA). The response has been unexpectedly good.

The work on the problem of climate and water will be pursued jointly with the British Meteorological Office at Bracknell, U.K., and the National Center for Atmospheric Research at Boulder, Colorado, U.S.A. Efforts are under way to establish the necessary links with the Hydrometeorological Office in Moscow, U.S.S.R.

Work on the large scale uses of coal is prepared for a joint pursuance with the British Coal Board, U.K., OKR at Ostrava, C.S.S.R., and the Ruhrkohle AG at Essen, F.R.G.

Besides, there is a close link with the nuclear research centers of Karlsruhe and Jülich, F.R.G. The main thrust is on the joint investigation of the siting problem and on the work on strategy models, but Karlsruhe also joins in for the operation of the global circulation models.

These collaborative ventures are the most prominent ones. In addition there are many more links as outlined for instance in the 1974 Research Program.

2.3 Contribution to IIASA's Clearinghouse Function

The study on the solar option by its very nature fits into IIASA's clearinghouse function.

Also, the work on energy demand, on energy resources and trade, and on risk evaluation in 1975, are geared toward this function.

For early 1975 a task force is envisaged that is similar to the task force which, in May 1974, prepared a survey paper on the modelling of energy demand and supply.

The necessity of living up to the clearinghouse function bears upon all project activities over and above these specific efforts.

3. CONFERENCES AND WORKSHOPS

The following conferences and workshops are envisaged for 1975:

3.1 Workshop on the Impact of Waste Heat on the Climate

Two or three numerical experiments that study the impact of a given amount of waste heat on the distribution of climatological patterns as a function of the geographical position of such releases are expected to be ready by the end of the year. Before executing additional numerical runs, it will then be mandatory to invite meteorological experts to discuss these results in depth. This workshop is scheduled for April 28 - 30, 1975.

3.2 Conference on Energy Demand Patterns

The studies on energy demand patterns will be a major input to the expected IIASA Conference 1975. In fact, it is against the background of such studies that an assessment and a comparison of options are to be made. In order to utilize the expertise of the member countries and to check our own results, this workshop is scheduled for May 22 - 23, 1975.

3.3 Workshop on Energy Resources

For similar reasons it will be necessary to have a workshop on energy resources. It will take place on May 20 and 21, 1975, and the possible topics will include data collection, modelling of resources assessment and of time-evolution of resources.

3.4 Joint IAEA IIASA Workshop on Risk Evaluation

Work on risk evaluation is complex and methodologically difficult, and only now beginnings are being made in a few places in the world. Probably by the end of 1975, enough first results will be available to allow for a first exchange with these groups engaged in similar work. It is intended to participate in a joint IAEA/IIASA workshop that facilitates this exchange.

3.5 The Advisory Committee on Energy Systems

The Advisory Committee on Energy Systems which acts as counsel to the ENERGY Project, has been established in 1974 and will have its first meeting early in 1975.

4. PROJECT INTEGRATION

Bilateral project collaboration develops with the WATER Project. The work on climate/water is meant to identify the interactions between energy/water and the climate. The large requirements for cooling water arising with energy conversions quite strongly relate to the problem of water management.

The impact of waste heat leads to the problem of water quality and thereby to the ecology of aquatic systems. The pollution problem is of direct concern to the ECOLOGY Project.

Collaboration with the URBAN Project will take place on the work of siting and decisions, and of climate and water.

It is also expected to cooperate with the BIO-MEDICAL Project on the question of cost/benefit/risk ratios.

It is expected that the decision process orientation of the the ENERGY Project leads to a multilateral collaboration with the WATER/URBAN/ECOLOGY Projects.

5. SUPPORT RESOURCES

5.1 Methodological Needs

The ENERGY Project requires methodological assistance in dealing with the econometric aspects of demand studies.

It further needs help in the general area of conflict resolution, multiple objective optimization, and game theory as well as in formal decision theory and policy analysis.

Finally, the ENERGY Project requires methodological assistance in the field of qualitative risk studies. It seems particularly necessary to include established psychological techniques.

5.2 Computing Needs

There is one major requirement for computing help. The numerical experiments for the simulation of the impact of waste heat on the climate require about 20h each on an IBM 370/185 computer. Arrangements have been made to provide such computational assistance outside Vienna. Otherwise, the requirements for computer time will be such that they can be satisfied within the Vienna area.

6. LONG-RANGE CONSIDERATIONS (INTO 1977)

The IIASA ENERGY Group is small. It would be fruitless to try to compete with large study groups such as the M.I.T. Energy Laboratory and others. Almost all of these groups concentrate on near and medium-term considerations of technological and market developments. However, it is becoming more and more obvious that the underlying problems are fundamental both in nature and in the methods required to deal with them. While in the past the energy problem was largely a problem of hardware, it is becoming more and more a problem of dealing with "soft" problems such as the siting of large technological facilities, the comparison of things that are traditionally incomparable like the solar and the nuclear options, and the aspect of timing during transitions. IIASA, however, is uniquely equipped to deal with these decision oriented problems and, therefore, the ENERGY Group should lay great stress on these aspects instead of attacking the broad energy problem in full. In particular, it is the cooperation with other projects such as WATER, ECOLOGY, URBAN, BIO-MEDICAL, METHODOLOGY, and others that must be made use of. The more the work at IIASA consolidates, the more this feature will come to the forefront.

More specifically, it should be outlined that the ENERGY Project is trying to attack the problem in a phased approach. The two-year period between the summer of 1973 and the summer of 1975 is for the study of the nuclear and the solar options and their comparison. The period from the summer of 1975 to the summer of 1977 will concentrate on the geothermal option and the large scale use of coal accordingly, while the studies on the climate and the interface between energy and water as well as resource, supply and demand studies, will evolve further.

As in the summer of 1975, the date of "The IIASA Conference 1975", the summer of 1977 is considered a major time target for the ENERGY Project.

Framework of the Project	CONDUCT OF RESEARCH				Conferences and workshops (subject and date)		Project Staff Status (man-months)			
ENERGY I	Anticipated Results, Form and Target dates of their presentation (incl. reports, seminars, etc.) II	Cooperating IIASA Projects III	Cooperating outside organizations IV	External Financing V	At IIASA VI	Participation in outside events VII	Definite IIASA commitments VIII	Uncommited IIASA funding IX	Formalized outside funding X	Total XI
1. Solar Option	Strategies of transition, comprehensive description including systems and side effects		U.S. National Academy of Science	no			15	1		16
2. Energy Demand	Energy input of goods and products, econometric treatment of pricing		MIT Energy Laboratory, IFIAS	no	Workshop: Energy Demand Patterns May 22/23		29	13		42
3. Energy Resources/Trade	Energy Resources assessment, energy production problems and world energy trade	ECOLOGY URBAN WATER	U.S.Geological Survey, IFP, IAEA, Ruhrkohle AG	no	Workshop: Energy Resources May 20/21		8	7		15
4. Siting/Decisions	Inclusion of utility considerations and discounted costs in multiple objective functions	BIO-MED. ECOLOGY URBAN WATER	GfK, Karlsruhe	yes			8	4.5	3.5	16
5. Risk Evaluation	Reproducibility of the Starr quasi laws, quantitative approach to risk perception		IAEA	yes		IAEA Workshop (jointly with IIASA) late 75	23			23
6. Climate/Water	Impact of large amounts of waste heat	ECOLOGY URBAN WATER	BMO, NCAR, Hydromet. Office, Moscow, GfK Karlsruhe	not yet	Workshop: Climate Modelling April 28/30		12	14.5		26.5
7. Large Scale Uses of Coal	Strategies of transition, implementation and side effects		OKR, CSSR, Ruhrkohle AG	no			3	6.5		9.5
8. Strategy Models and Comparison of Options	Development of econometric energy models; general methods for describing complex systems; comparison of nuclear, coal and solar option		GfK, Karlsruhe, KFA, Jülich	not yet			10	0.5		10.5
9. Material Accountability	Application to economic and environmental problems (monograph)			no			3			3
General							11			11

RM - 75 - 2

INTERNATIONAL INSTITUTE FOR IIASA APPLIED SYSTEMS ANALYSIS

RESEARCH MEMORANDUM

RISK ASSESSMENT

AND

SOCIETAL CHOICES

Harry J. Otway

February 1975

SCHLOSS LAXENBURG
2361 Laxenburg
AUSTRIA

RM-75-2

RISK ASSESSMENT AND SOCIETAL CHOICES

Harry J. Otway

February 1975

RISK ASSESSMENT AND SOCIETAL CHOICES*

Harry J. Otway**

Many countries are experiencing a period in which traditional values are being questioned; plans for further technological progress are being met by a variety of demands for a closer examination of the benefits and risks of large-scale technologies. In this paper the concepts of risk assessment are presented and a model is proposed which illustrates the importance of socio-psychological mechanisms in the acceptance of technological risks. The research plan of the Joint IAEA/IIASA Research Project is outlined: this work is directed toward gaining an improved understanding of how societies judge the acceptability of technologies and how societal attitudes and anticipated responses may be better integrated into the decision-making process. Some preliminary results are reported.

I. BACKGROUND

Standards of living have improved considerably during this century, largely due to the benefits made possible through the development and deployment of new technologies. As technological systems became larger, and more complex, they have offered increasingly attractive benefits which have become an integral part of life, thereby creating demands for more progress. This process of reinforcement has lead to increasingly complex, and therefore fragile systems, which have become fundamental to sustaining the social fabric.

With this increase in scale the negative side-effects of technology, which detract from the societal benefits, began to receive more attention. Some of these side-effects have been rather obvious, such as new safety hazards, while others have been more subtle and, therefore, more difficult to predict and detect; e.g., mental health problems, new health hazards, complicated environmental interactions, technological unemployment, mental health problems, changes in basic social institutions.

Consequently there appears to be a growing awareness that increased consumption of goods and services has not brought a commensurate increase in "happiness." Plans for further progress are being met by a variety of

---

* The views expressed in this paper are those of the author, and do not necessarily reflect those of the Project Sponsors.

**Joint IAEA/IIASA Research Project, International Atomic Energy Agency, Vienna, Austria.

individual and group demands for a closer examination of the risks and benefits of science and technology; there appears to be a gradually evolving social structure which tends to question much that is innovative as being potentially harmful. The patterns of public concern that have emerged in technologically advanced nations are also being observed in developing countries as they attain higher levels of productivity.

This has lead to a situation characterized by conflict; one segment of society may sponsor a proposal intended to fulfill a perceived societal need while other groups may be working actively in opposition - with different perceptions of their needs. Obviously technology cannot expand indiscriminately with society awaiting the results of operation to learn the nature and magnitude of the side-effects; however, neither can all further progress be rejected arbitrarily.

Societal-level decisions are especially important in the energy sector. Energy is a fundamental good in modern societies, energy production systems are among the larger-scale technological applications and the energy crisis, with its far-reaching effects, has limited available strategies and reduced the time available for exploring options. This is the background for the formation of the Joint IAEA/IIASA Research Project which is sponsored by the International Atomic Energy Agency (IAEA), the International Institute for Applied Systems Analysis (IIASA) and certain IAEA Member States; information on sponsorship and staffing is given in the Appendix.

The primary objective of the Joint Project is to do research directed toward gaining an improved understanding of how societies judge the acceptability of new technologies and how societal attitudes, and anticipated responses, may be integrated into the decision-making process. This has been referred to as the embedding of energy systems into the sociosphere (Häfele, 1974).

II. RISK ASSESSMENT CONCEPTS

A digression might be in order to introduce the concepts of risk assessment. These concepts have developed independently in a variety of disciplines, publishing in many languages, with the expected differences in usage and meaning. There is no intent to provide rigorous definitions; these will be evolved as interdisciplinary and international efforts proceed. Risk* will here refer to the undesirable effects associated with a specific activity considered in connection with their respective uncertainties. Risk is therefore a probabilistic term and has often been used as the statistically expected value of loss; for example, the probability of an average individual's chance of death, per year, from transportation accidents or the total risk (sum of individual risks) in a population group.** The most obvious risks, and easiest to conceptualise, are those relating to the health and safety of man and effects upon his environment, although there are many other effects, which in connection with their uncertainties can be considered as risks.

Risk assessment may be defined as any process in which risk considerations play an important rôle in forming an input to decision making. Risk assessments are made on a variety of levels, i.e., individual, group, societal, etc. and Kates (1974) has pointed out that the process may vary from highly intuitive to very formal. This typology of risk assessments, summarised in Table I, might range from the individual's intuitive feeling that it is safe to cross a street to a numerical analysis which serves as the basis for recommendations. Risk assessment has been described by Otway (1973) as occurring in two sub-tasks: risk estimation and risk evaluation, each of which may have the same range of intuitive-formal, individual-societal character.

---

* It is not considered necessary here to make a distinction between situations of the first kind, i.e., where the probabilities are known in principle, and those where the probabilities themselves are uncertain.

** This is somewhat too simple because the statistically expected value neglects the importance of the absolute magnitude of loss. It is known that societal preferences for risk acceptance may be widely different for events which have the same statistically expected value of loss but with different absolute magnitudes. Thus utility functions must also be considered when expressing risk levels. For an elementary explanation see, for example, Borch (1968). An application to energy system risks may be found in Papp et al., (1974).

TABLE I

RISK ASSESSMENT MODES

(Kates, 1974)

Mode	
0 step	No estimation, no evaluation There is no risk. Nothing you can do about it, so why estimate it.
1 step	Evaluation without estimation Decide whether risk is acceptable or not compared to other risks or benefits.
2 step	Estimation of risk, then evaluation Calculate likelihood of risk, then compare with other risks or benefits.
3 step	Fractionate risk, estimate combinations of individual risks, evaluate Reduce events to components. Calculate likelihood of event components and of consequences, combine, estimate risk, then compare with other risks or benefits.

Risk Estimation

Risk Estimation may be thought of as the identification of the second (and higher) order consequences of a decision and the subsequent estimation of the magnitude of the associated risks. For example, some of the earlier risk estimates for energy systems were made in the nuclear field in Canada (Siddall, 1959), the UK (Farmer, 1967; Beattie, 1967) and in the U.S.A. (Otway et al., 1969 and 1971). Starr et al. (1972) made a comparison of the risks from nuclear and fossil-fueled generating systems. The most recent, and by far the most comprehensive, risk estimates for energy systems are those of the U.S. AEC-sponsored "Rasmussen Study" (1974) which treated the risk of accidents in light-water reactor nuclear power plants. All of the aforementioned efforts indicated that the risks from these energy production systems were low in comparison to other risks common in society.

Risk Evaluation

This is the complex process of anticipating the societal response to risks; it is based upon an understanding of the relevant societal attitudes and preferences. This could be termed the "acceptability of risk."

Traditionally this has tended to consist of comparing estimates of risk with the levels of other prevalent risks which are already accepted by the society. For example, in the risk estimation studies cited earlier, Farmer and Beattie compared the predicted number of thyroid carcinomas due to iodine-131 exposure following reactor accidents to rates of naturally-induced thyroid cancers. Otway et al. used accident statistics and natural genetic mutation rates as a basis. Starr et al. added another dimension and proposed the relationship shown in Figure 1 for dividing risks into acceptable and unacceptable as a function of the perceived associated economic benefit. The Rasmussen Study compared the statistically expected value of nuclear accident risks with a variety of other accident risks and natural hazard risks. In addition, the disutility of infrequent, large-consequence accidents was also evaluated by similar comparisons over consequence magnitude and frequency of occurrence (Figure 2).

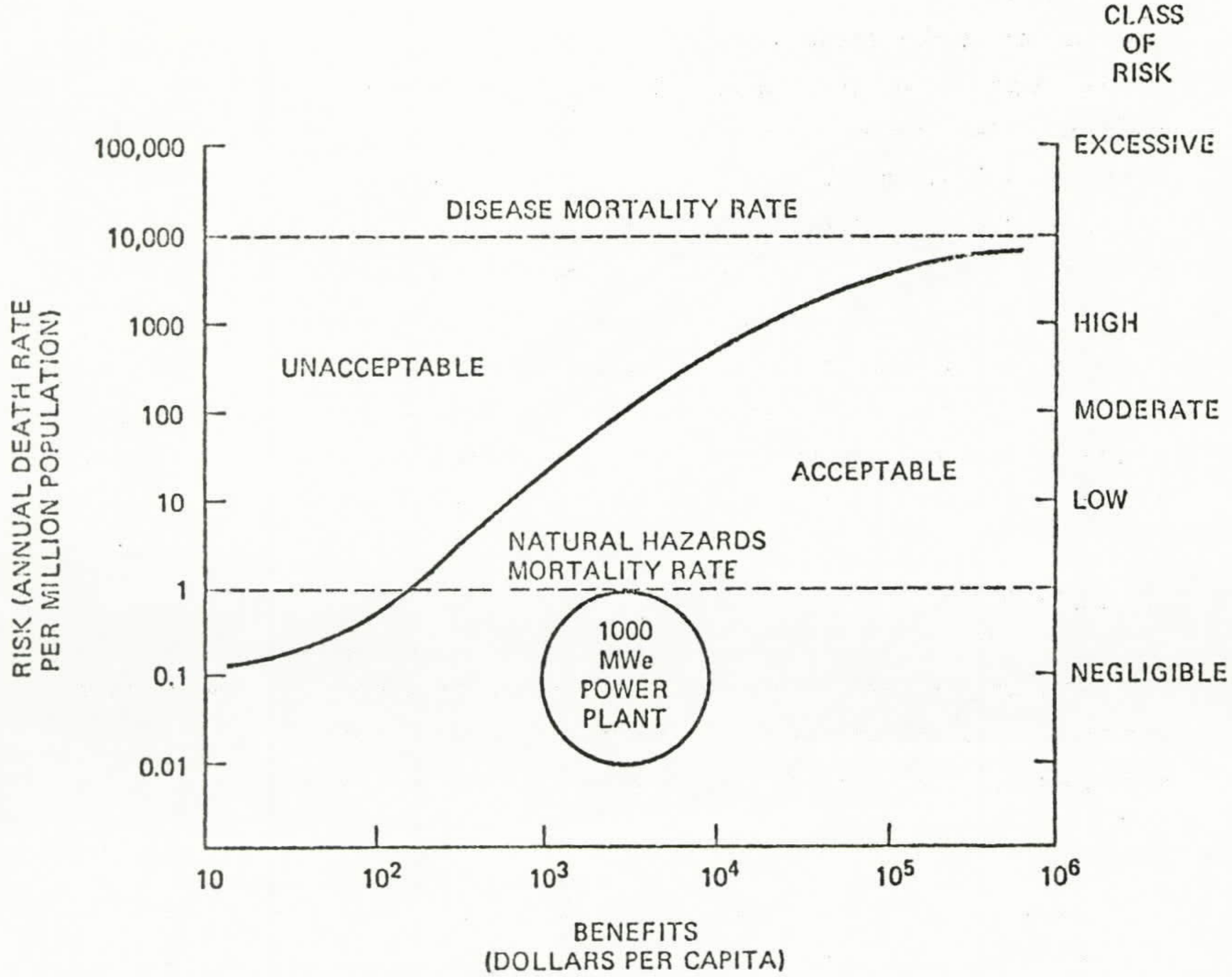


FIG. 1 HYPOTHETICAL RELATION OF INVOLUNTARY RISK VS. BENEFIT (STARR, 1972 AND 1974)

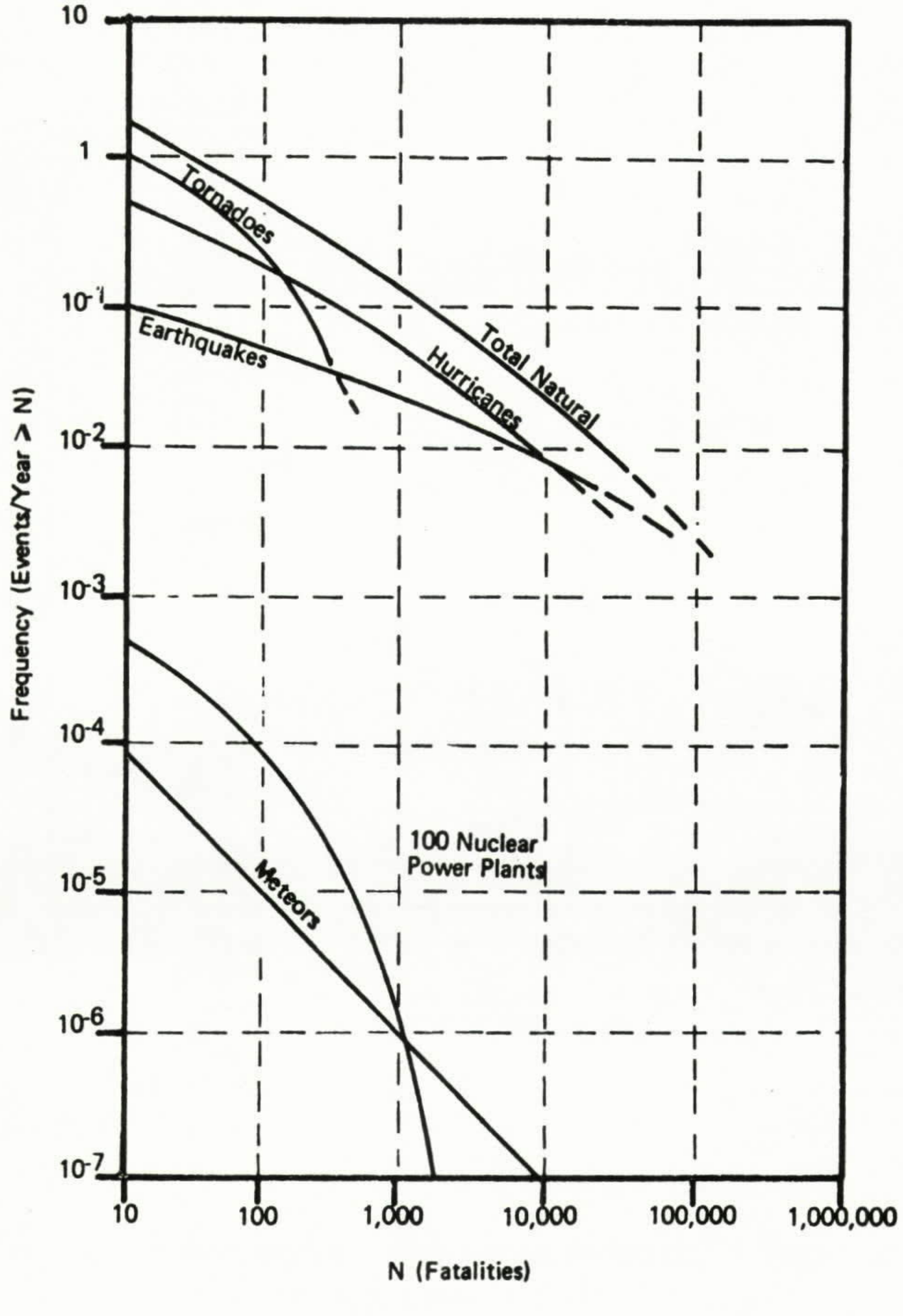


FIG. 2 FREQUENCY OF NATURAL EVENTS WITH FATALITIES GREATER THAN N (WASH-1400)

The tacit assumptions in the foregoing approaches to risk evaluation are that the preferences that society has revealed through its historical acceptance of risks can be extracted from statistical data, extrapolated to the future, and compared with other types of risk. Raiffa (1968) has pointed out some of the difficulties of this approach. The experience in the nuclear energy field would also indicate a problem in this respect. Estimated nuclear risks have been virtually negligible when compared to other risks which are widely accepted by society. The comparison of nuclear risk estimates with, for example, transportation risks or natural hazard risks is perhaps essentially meaningless because, for a variety of conscious and subconscious reasons, the latter risks are accepted while the nuclear risks are being frequently challenged. Obviously there are qualitative differences as well as quantitative (Montague and Beardsworth, 1974) and the quantitative data base available for deriving revealed preferences cannot, without a thorough consideration of psychological factors, adequately reflect the qualitative (Otway and Cohen, 1975).

The Dimensions of Risk

There is still much to be learned about the dimensions of risk and its acceptance. It is clear that the perception of risks is an important factor: **that the subjective assessments of risk are more influential in acceptance than are objective risk estimates or measurements.** It is known that man is, in general, a poor intuitive statistician and tends to mis-estimate probabilities, and therefore risks, due to psychologically determined factors (Edwards, 1968; Murphy and Winkler, 1973; Sjöberg, 1974). There are many factors which play a part in influencing perception although their relative importance is not well known. These include the degree to which a feeling of individual control over the risk or the outcome is felt, the physical nature of the risk itself, the degree to which a commensurate benefit is felt to accrue to those at risk, whether the outcome is composed of a chain of independent probabilities or a single event, the ability to imagine the risk or benefit, etc. There has been a paucity of research in the behavioural and social sciences on the reaction, fears, attitudes and beliefs of society with respect to the perception and acceptance of technological risks. One promising approach for learning about these phenomena is the application of sociometric and psychometric techniques which will be discussed later in this paper.

III. RISK AND SOCIETAL CHOICES

Figure 3 is suggested as a description, on the societal level, of the information flow involved in a risk assessment of a new, large-scale application of technology.* This figure is by no means precise nor are these relationships accurately known; the intent is to provide a discussion aide in order to point out areas of research interest.

Sponsor Acceptability

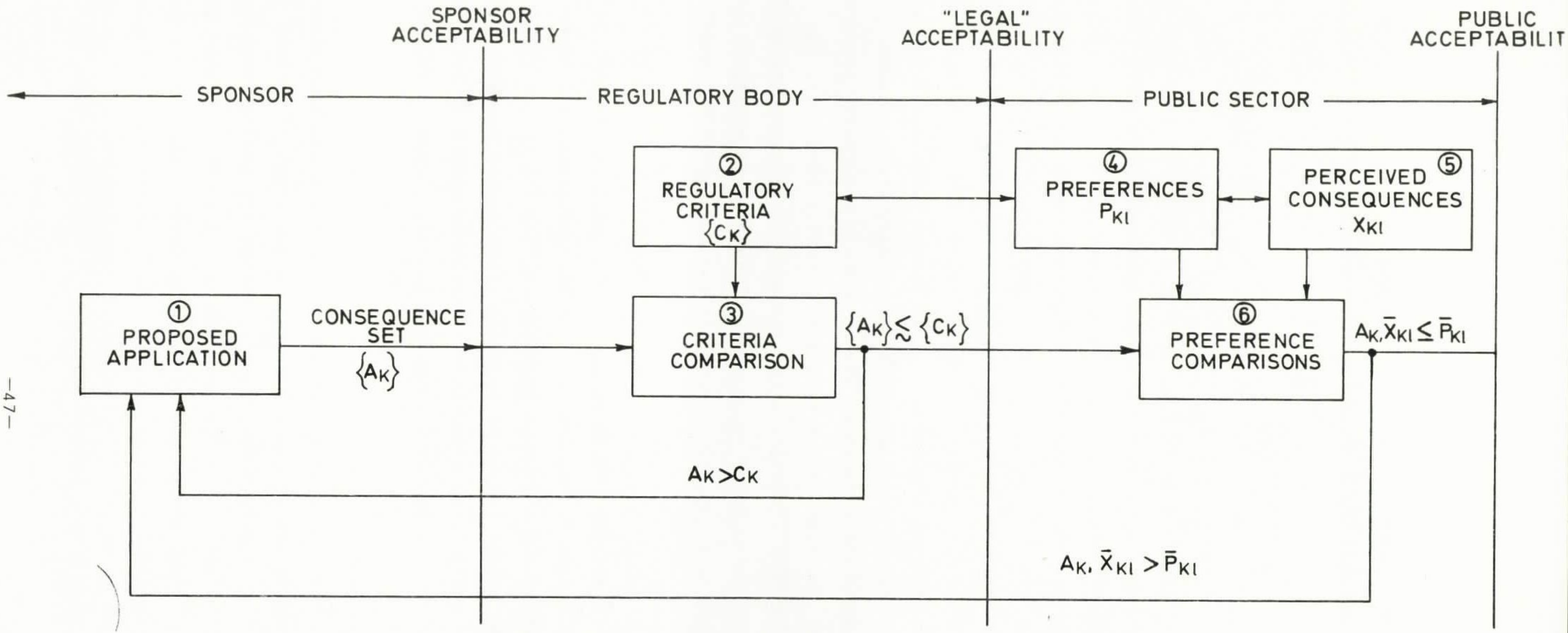
It is assumed that the proposed application is aimed at meeting some specific societal need (such as energy) and that the proposal is sponsored by some segment of society such as private industry or government. Simply stated, the sponsor will have made his internal decision that the application is capable, with a high degree of certainty, of providing the primary benefit intended and is, therefore, acceptable to him.

The decision to proceed with this project carries with it several implied consequences (second order, or side-effects) the sponsor must also find acceptable. These side-effects could include, for example, radioactive, chemical and thermal discharges affecting man and his environment, accident hazards, aesthetic effects, land-use commitments, natural resource utilization, etc. He most likely has not considered these side-effects as "risk" in the probabilistic sense in which they have been defined.** He has certainly considered the absolute, or nominal, magnitude of these effects and is fairly confident that they will satisfy the appropriate regulatory standards. He will also have considered, to the extent that the information was known and available to him, the preferences of society for this application and the anticipated societal responses.

---

* As an interesting aside it might be noted that Fig. 3 closely parallels the structural hypothesis of mental mechanisms proposed by Freud (1925).

** See Winkler (1973) for a discussion of the merits of deterministic vs. probabilistic models.



NOTE: MANY INTEREST GROUPS, l

≲ IS FAVOURABLE COMPARISON

> IS UNFAVOURABLE COMPARISON

— INDICATES WEIGHTED AVERAGE

WIDTH OF FEEDBACK CHANNELS MIGHT BE ZERO.

FIG. 3 RISK ASSESSMENT: INFORMATION FLOW MODEL

At this stage the sponsor submits the proposal to the responsible regulatory authorities and the line of "sponsor acceptability" is formally crossed.

"Legal Acceptability"

It is now necessary to compare (Box 3, Fig. 3) the predicted consequences of the proposed application with the applicable standards (Box 2) for regulating these effects. The actual comparison may be rather straightforward once the predictions of the effects have been made and verified.

The complicated part is the derivation of the criteria, or standards, which are shown in Fig. 3 as magically originating in Box 2. A desirable objective is to set rational standards so that unduly large resources are not invested to further reduce risks which are already insignificant. Where large investments are made in safety to provide marginally small reduction in risk then the expenditure is not efficiently beneficial to society and should be made elsewhere where the marginal risk reduction (risk reduction/unit expenditure) could be greater. This goal is sometimes referred to as balanced risk reduction (see Sinclair et al., 1972; Jammet et al., 1973).

This question of setting standards is not a trivial one (Keeney, 1974). A good deal of information is required such as the relationship between expected societal benefit and allowable risk levels, the "value" of risk, the relationship between actual levels of risk and these levels as perceived by those at risk, etc. This is an area where research is needed in order to use risk concepts more effectively in standard setting (Bresson, Fagnani and Morlat, 1974).

Note that at the output side of the comparison box a feedback channel is shown leading back to the original proposal in the event of failure to satisfy criteria. This feedback would act to change the implied consequences until the criteria are met. When the proposal satisfies the criteria we can say that the line of legal acceptability has been crossed and the proposal, for all practical purposes, first enters the public sector where acceptability will include the consideration of several additional factors.

Public Acceptability

Here the responses of individuals, and various interested groups, to the proposal gradually emerge. These groups use multiply-determined criteria to judge, and perhaps challenge, technological advances; that is, their preferences (Box 4) reflect their rational assessment of the facts (consequences) as they know them, their perception of these consequences (Box 5), and the effects of factors which may be buried deep in the nature of the groups themselves. These preferences are formed, in part, in the light of the past experiences of the individual and group.

It is important to note that this complex process operates on many organizational levels: the individual, the group, the societal or national, and perhaps even the international. In Figure 3 a number of interest groups is postulated which includes all these levels of interest. Box 6 shows the process of comparison which has been described. Here, the acceptability of the proposal to each group must be considered. In addition, by some unspecified process, each interest group's preference comparisons influence the final decision.

The interest group itself may be viewed as a confluence of social systems including individual responses, socio-psychological mechanisms, cultural factors, political considerations, economic influences and the information input of the scientific community. The interest group represents the focal point of the interactions of these various systems.

A generalization is that the individual response to a fear-provoking stimulus may lead to a variety of healthy or unhealthy defenses. The two most primitive are known as "flight or fight": apathetic physical and emotional withdrawal and denial that threat exists, or a readiness to retaliate. The latter response accounts in part for the opposition of the group to what is perceived as an external threat. In addition to external threats internal fears and anxieties may be projected onto a symbolic external object. As these fears are expressed, the individual finds others who think and act similarly.

An interest group reflects, to varying degrees, elements of its members' individual responses, characteristics of its societal-cultural environment, and an indication of the information it has received form the scientific community. The group, however, has its own characteristcs. Observations seem to support the following generalizations:

a) interest groups tend to form around affect-laden social-environmental concerns;

b) they tend to be solution-oriented rather than problem-oriented, inclined toward a dialectic adversary position rather than collaborative exchanges;

c) communication patterns are often distorted, especially in groups with a vertical status and power hierarchy;

d) new information may be accepted or rejected contingent upon the support it provides for group values and beliefs;

e) behavioural responses of members are influenced by the group so the strength and integrity of individual values is weakened.

Thus the interest group tends to be a body of persons emotionally committed to their position and screening factual information according to the utility it has for their position. They may be matched feature for feature by other groups supporting diametrically opposed positions. (Pahner, 1974, described some behavioural aspects of interest groups.)

Inter-relationships have been indicated in Figure 3 by feedback loops which show that an unfavourable comparison in the public sector can act to change the proposal, and further, that there may be some interactions between societal preferences and the perception of risks which could act to influence regulatory standards.

Summary

To summarize the discussion of Figure 3, the research activities of the Joint Project include the application of risk assessment concepts to standard setting (Box 2), the study of the perception of technological risks and benefits

(Box 5), methods for determining group and societal preferences relating to risk acceptance (Box 4) and the group dynamics and transmission of technical information which are involved in the comparison process (Box 6). This work will be discussed in more detail in the following section.

IV. RESEARCH PROGRAMME AND PRELIMINARY RESULTS

Figure 3 was used to point out areas where additional research could improve the application of risk assessment to making societal-level choices regarding the acceptability of new technologies. This Section will indicate specific lines of research being pursued by the Joint IAEA/IIASA Research Project and summarize some preliminary results.

Historical Examples of Risk Acceptance

Societal problems caused by technological progress are of acute concern to behavioural scientists and some specific historical examples may be identified. Some items of interest in understanding the general mechanisms of societal adaptation to new threats are: how the impacts of technological progress influenced social dynamics; how the institutions of the society reacted; what mechanisms were evolved to absorb these shocks; how people got the pertinent information and formed their opinions; how their perceptions of the hazard were formed and how they compared to reality.

A case study is being made treating one modern society and some traditional population groups in order to elucidate the behavioural aspects of adaptation to new threats. This study will also provide inputs into the design of surveys directed towards understanding risk phenomena. A survey of the literature reporting case studies relating to the impacts of technological progress on social systems has been completed (Velimirovic, 1975).

This work relates to testing the overall structure of Figure 3, as observed in practice, and provides background material for developing information related to Boxes 5 and 6.

The Estimation of Risk from Large Consequence - Low Probability Events

Some risk estimates have been made for large-consequence accidents which have a low probability of occurrence. This is a crucial topic in the case of nuclear power plants where the experimental data base required to make reliable estimates is much too small. It is difficult to deal with this problem using conventional mathematical methods. Therefore, the applicability of new methods, such as fuzzy set theory (e.g., Zadeh, 1973 and 1974), is being investigated. This is related to the estimation of consequences, Box 1, and the development of regulatory criteria, Box 2.

Theoretical Approaches to Risk Evaluation

One of the important factors in using risk-benefit principles in setting standards is the problem of expressing unlike variables in a consistant set of units so that approximate comparisons can be made. This is especially difficult when it is necessary to evaluate risks that involve the possible loss of life. Therefore, the Pareto theoretical approach to the evaluation of such risks is being developed and the appropriateness of using Pareto criteria for the treatment of statistically and non-statistically distributed risks is being examined. (This non-random distribution of risks and benefits within society has been an issue in many industrial siting controversies.) The effect of further variations will also be examined, such as how to treat risks that will occur in the future, or even be taken by future generations, where the benefits are received in the present.

Approximations of the individual's indifference function, or trade-off between perceived risk and required compensation, may be obtained either through controlled experimentation (surveys) or through the use of market data. In the design of experiments it is useful to first determine theoretically the meaning of the responses from the standpoint of Pareto welfare maximization. An attempt is being made to model the individual's "rational" responses to the acceptance of risks, including the subjective factors which might influence this response. Of particular interest is the complexity of the risk problem when the uncertainties involve life or death and thus the utility of compensation and the disutility of the risk may become nonadditive (Raiffa, 1969). A survey has been completed of the experience in France and the USA in applying cost-benefit techniques to the evaluation of projects which may alter human mortality

(Linnerooth, 1975). These theoretical treatments are primarily related to standard setting, Box 2.

Methodologies for Determining Societal Preferences

Two basic methods for determining societal preferences are the "revealed" preferences approach which relies upon historical statistical data, and the survey approach based upon sociometric and psychometric techniques. For example, Starr (1969 and 1974) has indicated the existence of preferences for the acceptance of technological risk which were based upon analysis of accident statistics. Psychometric techniques have yielded consistent results for societal preferences with respect to other types of risk. Both techniques are being critically reviewed to determine their limitations and to recommend directions for longer-term research (related to Box 4, Fig. 3).

Preliminary analyses (Otway and Cohen, 1975) indicate that the results of the Starr technique, which emphasises the mortality risks associated with various activities, are excessively sensitive to the assumptions made and handling of the data.

The Perception of Technological Risks

As discussed earlier, the perception of risks is a crucial factor in influencing societal response. Psychometric and sociometric techniques show a great deal of promise for gaining an improved understanding of how specific risks are perceived, which factors influence perception and their relative importance.

Golant and Burton (1969), working in natural hazards research, developed a Risk Avoidance Response Survey designed to rank various types of hazards (physical, social and natural) in terms of the perceived threat. This test was administered in Ontario, Canada, and produced the risk avoidance ranking shown in Table II. Correlations were done to determine the effects of various variables upon the rank order. The most significant factor was found to be the respondants experience, or lack of it, with a specific hazard. The rank-size correlation illustrating the effect of experience was 0.45.

TABLE II

RANKING OF HAZARDS BASED ON RESPONDENTS GREATEST AVOIDANCE MEASURES

TOTAL CANADIAN SAMPLE

(Golant and Burton, 1969)

Rank	Hazard
1	Auto Accident (Physical)
2	Attacked and Robbed (Physical)
3	Tornado (Natural)
4	Forest Fire (Natural)
5	Earthquake (Natural)
6	Failing in School or Job (Social)
7	Illness (Physical)
8	Loneliness (Social)
9	Flood (Natural)
10	Public Embarrassment (Social)
11	Being Disliked by Someone You Admire (Social)
12	Thirst (Physical)

This experiment has been applied in Austria to gain experience in this type of survey, to test computer programmes for data reduction and to check reproducibility. The avoidance ranking for the Austrian sample is presented in Table III (Otway, Maderthaner and Guttman, 1975). The overall cross-cultural comparison was found to be 0.62. The effect of experience upon perception was not well reproduced in this sample with a rank-size correlation between experienced and inexperienced respondants of 0.82. The most significant variable affecting the Austrian rank order was found to be the Ss self-rated ability to imagine himself in a specific hazard situation (rank-size correlation 0.59). In general, the American sample showed the highest avoidance response to natural hazards, whereas for the Austrian sample physical hazards were the most avoided.

A new survey which incorporates a magnitude estimation scale, allowing a numerical measure of disutility, has been developed and is being checked for feasibility. A significantly larger number of risk-related variables are included and paired comparisons are being used. This design draws upon the work of Wyler, Masuda and Holmes (1968), Holmes and Rahe (1967) and Holmes and Masuda (1973) on the perception of health and social hazards and is related to Boxes 4 and 5 of Figure 3.

The Determination of Societal Preferences

The use of field surveys for measuring societal preferences is closely related to the work on risk perception: the techniques described above will be modified for this purpose.

An effort is also being made to determine societal preferences as revealed by recorded data. As mentioned earlier (Otway and Cohen, 1975), preliminary results indicate that, since preferences for risk acceptance are multiply determined, historical accident data using few variables (Starr, 1969 and 1974) may be inadequate to give a true picture of the effects of socio-psychological mechanisms. Preferences toward risk are multiply determined within a broader network of socio-psychological relationships and the attitudes of any culture toward risk can only be understood by knowing its position within this framework. This framework can be investigated by trans-cultural, in-depth analysis using an iterative process of empirical multi-variable analysis combined with behavioural theories. This technique has been used by Gaspari and Millendorfer (1973), of the Study Group for International Analyses (STUDIA), for

TABLE III

RANKING OF HAZARDS BASED ON RESPONDENTS GREATEST AVOIDANCE MEASURES

TOTAL AUSTRIAN SAMPLE

(Otway, Maderthaner and Guttmann, 1975)

Rank	Hazard
1	Illness (Physical)
2	Auto Accident (Physical)
3	Attacked and Robbed (Physical)
4	Earthquake (Natural)
5	Loneliness (Social)
6	Failing in School or Job (Social)
7	Flood (Natural)
8	Forest Fire (Natural)
9	Tornado (Natural)
10	Thirst (Physical)
11	Public Embarrassment (Social)
12	Being Disliked by Someone You Admire (Social)

investigating the structure of the General Production Function for European countries. In co-operation with the STUDIA group it will be extended to the determination of societal-level preferences related to risk acceptance. This effort will also help define inputs for the survey work which was described earlier. As a preliminary step an extensive data base covering fifteen countries has been compiled. This work is related to Boxes 4 and 5 of Figure 3.

Ellis and Keeney (1972) and Keeney (1973) have described an assessment of the preferences of government officials for such attributes as air emissions, health effects and mortality. The determination of interest group preferences by the estimation of a knowledgeable, impartial observer has been applied to nuclear power plant siting by Gros (1974) and Gros et al. (1974). These methods will also be considered and results compared to those of the other methods.

Group Dynamics and Information Transmission

There is also the problem of how scientists develop and communicate information about environmental risks, and the part this information plays in societal assessment and response to risk, including interest group dynamics (Nizard and Tournon, 1972; Kates, 1974; Wilson, 1973). The mechanisms societies use in judging, and perhaps deciding to challenge, the acceptability of new technologies, which promise specific benefits but with the possibility of new apparent threats, are complex and rather poorly understood. In the specific case of nuclear power plants it has been observed that until a project is made known there is no pressing concern about nuclear hazards among most inhabitants of the area. Once the plans are announced, people soon become acquainted with thinking about the possible threats, real or imagined; they are forced by circumstances to form relevant opinions. The project then starts being judged on a number of levels: individual, group, community, national and perhaps even international. As the responses to the proposal gradually emerge it has been noted that various interest groups start to form, develop their sources of information and, in many cases, work actively to promote or oppose the proposed facility. The objections most often cited in opposition to peaceful nuclear energy programmes have been summarized by Häfele (1973) and a psychoanalytic viewpoint of the nuclear controversy has been presented by Guedeney and Mendel (1973).

Groups serve a mediating function between the individual and the larger society. People contact society and are, in turn, contacted by it through the small group. Just as it is difficult for an individual to influence the larger society, it is difficult for the larger society to mobilize the energies of the individual when he stands alone (Shepherd, 1964). Therefore, an understanding of small group dynamics is especially important in gaining an understanding of the societal acceptability of risks. Of special interest here is the rôle the group plays in weighting and aggregating individual preferences to form societal preferences.

Cross-Cultural Differences

Risk perception and societal preferences for risk acceptance would be expected to be dependent upon culturally determined factors; therefore, the results of this work will be examined for cross-cultural differences. It is anticipated that this could be made possible through the excellent international contacts of the sponsoring organizations and the multinational character of the Joint Project staff.

V. CONCLUSIONS

Though some efforts have been made toward placing technological risks in perspective through the comparison with other types of common risks, this approach is limited in its ability to consider the effects of socio-psychological mechanisms in risk acceptance. There has also been very little research done in the behavioural sciences in this respect.

As stated earlier, a primary objective of the Joint Project is to gain an improved understanding of how societies judge the acceptability of new technologies and how societal attitudes, and anticipated responses, may be integrated into the decision-making process. For this purpose, research is needed in the following areas: the perception of societal needs by individuals and groups, how risks and benefits are perceived and the nature and importance of the variables influencing perception, the group dynamics and information transmission involved in aggregating individual preferences into societal preferences, and methodologies for assessing societal preferences related to risk acceptance.

The Joint Project has made a start on research in these areas.

APPENDIX

ORGANIZATIONAL ASPECTS OF THE JOINT IAEA/IIASA RESEARCH PROJECT

Sponsorship

The Joint Project was formed in mid-1974 pursuant to an agreement between Dr. Sigvard Eklund, Director General of the IAEA, and Prof. Howard Raiffa, Director of the IIASA.

Professional staff for the Joint Project come from three sources approximately equal in their contributions: IAEA scientific staff, IIASA Research Scholars, and scientists from IAEA Member States seconded to the Project on a cost-free basis. The research programme outlined for the Project reflects a mixture of the specific interests of these three sources of sponsorship. The IAEA also provides office space and support service while the IIASA has contributed the services of additional well known consultants.

Organization

Organizationally the Project comes under the Energy Systems Project of the IIASA, led by Prof. Wolf Häfele, and the IAEA Department of Technical Operations - Division of Nuclear Safety and Environmental Protection respectively headed by Dr. Yuri Chernilin (Deputy Director General) and Dr. Jacques Servant (Division Director). Dr. H. J. Otway, IAEA, is Project Leader of the joint effort.

Staffing

As of February 1975 the Joint Project consisted of seven professional and two General Service staff. The IAEA and the IIASA are represented by two scientists each while Japan, U.S.A., Sweden and the U.K. have each provided seconded scientists. The Joint Project expects to reach a steady-state staffing level of about 11 scientists in mid-1975 with the addition of another IIASA Research Scholar and a secondment from France and two from the Federal Republic of Germany.

Contracts

Additional scientific support is obtained through IAEA-sponsored research contracts with the University of Vienna, Psychology Institute, and the Study Group for International Analyses, Vienna.

Miscellaneous Information

The following disciplines will be represented in the Joint Project:

Physics	Economics	Psychiatry
Public Health	Anthropology	Medicine
Engineering	Sociology	Psychology

Seven nationalities are represented in the Project and Project staff are proficient in a total of seven major languages: English, French, German, Italian, Japanese, Russian and Spanish.

REFERENCES

Beattie, J. R., "Risks to the population and the individual from iodine releases", Nuclear Safety 8, (573), 1967.

Borch, K. H., "The economics of uncertainty", Princeton University Press, Princeton, N. J., 1968.

Bresson, G., Fagnani, F. and Morlat, G., "Etudes coût-avantages dans le domaine de la radioprotection (aspects methodologiques)". Presented at IAEA/WHO Seminar on Radiological Safety Evaluation of Population Doses and Application of Radiological Safety Standards to Man and the Environment, IAEA-SM-184/29, Portoroz, Yugoslavia, 20 - 24 May, 1974.

Edwards, Ward, "Conservatism in human information processing". In B. Kleinmuntz (Ed.), "Formal representation of human judgement". Wiley, New York, 1968.

Ellis, H. M. and Keeney, R. L., "A rational approach for government decisions concerning air pollution". In "Analysis of public decisions", A. Drake, et al., (Eds.) MIT Press, Cambridge, Mass., 1972.

Farmer, F. R., "Reactor safety and siting; a proposed risk criterion", Nuclear Safety 8, (539) 1967.

Freud, Sigmund, "Das Ich und das Es", Gesammelte Schriften, 6. Band, Internationaler Psychoanalytischer Verlag, Vienna, 1925.

Gaspari, C. and Millendorfer J., "Prognosen für Oesterreich", Verlag für Geschichte und Politik, Wien, 1973.

Gros, Jacques, "A Paretian approach to power plant siting in New England", Ph.D. dissertation. Havard University (1974).

Gros, J., Avenhaus, R., Linnerooth, J., Pahner, P. D. and Otway, H. "A systems analysis approach to nuclear facility siting". Presented at IAEA Symposium on Nuclear Facility Siting, IAEA-SM-188-50, Vienna, December, 1974. Published as International Institute for Applied Systems Analysis Research Memorandum RM-74-29 (1974).

Golant, S. and Burton, I., "Avoidance-response to the risk environment". Natural Hazard Research Working Paper No. 6, Dept. of Geography, University of Toronto, 1969.

Guedeney, C. and Mendel, G., "L'angoisse atomique et les centrales nucléaires". Contribution psychoanalytique et sociopsychoanalytique à l'étude d'un phénomène collectif, Payot, Paris, 1973.

Häfele, Wolf, "Hypotheticality and the new challenges: the pathfinder rôle of nuclear energy", International Institute for Applied Systems Analysis, Research Report RR-73-14, December, 1973.

Häfele, Wolf, "A systems approach to energy", American Scientist 62, (438-447), 1974.

Holmes, T.H. and Masuda, M. "Life change and illness susceptibility", Separation and Depression, AAAS, (161-186), 1973.

Holmes, T. H. and Rahe, R. H., "The social readjustment rating scale", J. Psychosomatic Res. 11, (213), 1967.

Jammet, H., Mechali, D. and Lacourly, G., "Analyse des coûts et des avantages et rapport entre le coût et l'efficacité des systèmes de contrôle". Presented at the Consultants' Meeting on Methods for Establishing the Capacity of the Environment to Accept Radioactive Materials, IAEA-PL-533/13, Vienna, 7-14 December, 1973.

Kates, R. W., "Environmental risk assessment", ICSU/SCOPE: communication of environmental information and societal response, Draft, 1974.

Kates, R. W., "Risk and rare events; a three nation study of disaster prevention in nuclear energy programmes", Draft, 1974b.

Keeney, Ralph L., "A decision analysis with multiple objectives: the Mexico City airport", The Bell Journal of Economy and Management Science, 4, No. 1, (1973).

Linnerooth, J., "The evaluation of life-saving: a survey", International Institute for Applied Systems Analysis, Research Report, 1975 (in press).

Montague, Susan and Beardsworth, E., "Benefit/Risk - a critique and cultural analysis for non-quantitative risk assessment". Brookhaven National Laboratory, Draft, 1974.

Murphy, A. H. and Winkler, R. L., "Subjective probability forecasting in the real world: some experimental results". International Institute for Applied Systems Analysis, Research Report, RR-73-16, 1973.

Nizard, L. and Tournon, J., "Perception sociale et demandes sociales en matière d'environnement". Syposium International, Methodologie et Analyse Socio-economique de l'Environnement. Grenoble, 12-15 Decembre, 1972.

Otway, H. J., "Risk estimation and evaluation". Proceedings of IIASA Planning Conference on Energy Systems. IIASA-PC-3, 1973.

Otway, H. J. and Erdmann, R. C., "Reactor siting and design from a risk viewpoint". Nuclear Engineering and Design, 13, (365), 1971.

Otway, H. J. and Cohen, J. J., "Revealed preferences: comments on the Starr benefit-risk relationships". International Institute for Applied Systems Analysis, Research Memorandum, 1975 (in press).

Otway, H. J., Maderthaner, R. and Guttmann, G., "Avoidance response to the risk environment: a cross-cultural comparison", International Institute for Applied Systems Analysis, Research Report, 1975 (in press).

Pahner, P. D., "Behavioural aspects of interest groups", International Institute for Applied Systems Analysis, Working Paper, November, 1974.

Papp, R., McGrath, P. E., Maxim, L. D. and Cook, F. X. Jr., "A new concept in risk analysis for nuclear facilities", Nuclear News, (62-65), 1974.

Raiffa, Howard, "Decision analysis: introductory lectures on choices under uncertainty". Addison-Wesley (1968).

Raiffa, Howard, "Preferences for multi-attributed alternatives", Memorandum RM-5868-DOT/RC, April, 1969.

"Rasmussen Study", "Reactor safety study: an assessment of accident risks in U.S. commercial nuclear power plants". Draft, USAEC, WASH-1400, 1974.

Shepherd, Clovis R., "Small groups: some sociological perspectives". Chandler Pub. Co., Scranton, Pa. (1964).

Siddall, E., "Statistical analysis of reactor safety standards", Nucleonics 17, (64-69), 1959.

Sinclair, C., Marstrand, Pauline and Newick, Pamela, "Innovation and human risks", Centre for the Study of Industrial Innovation, SPRU, University of Sussex, 1972.

Sjöberg, Lennart, "Decision making and the evaluation of risk". Royal Swedish Academy of Engineering Sciences, IVA-rapport 63, (57-61), 1974.

Starr, C., "Social benefits vs. technological risk". Science 165, (1232-38), 1969.

Velimirovic, Helga, "An anthropological view of risk phenomena", International Institute for Applied Systems Analysis, Research Memorandum, 1975 (in press).

Wilson, Tay, "Information generation and its application to three transportation areas". Presented at the First International Congress on Technology Assessment, 27 May;2 June, 1973, The Hague, Netherlands.

Winkler, Robert L., "Risk and energy systems: deterministic vs. Probabilistic models". International Institute for Applied Systems Analysis, Research Memorandum, RM-73-2, September, 1973.

Wyler, A. R., Masuda, M. and Holmes, T. H., "Seriousness of illness rating scale", J. Psychosomatic Res. 11 (363-374), 1968.

Zadeh, L. A., "On the analysis of large-scale systems", University of California (Berkley), College of Engineering, Electronics Research Laboratory Memorandum, ERL-M418, 1974.

Zadeh, L. A., "Outline of a new approach to the analysis of complex systems and decision process", IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-3, No 1 (28), January, 1973

International Institute for Applied Systems Analysis

Research Publications and Internal Working Papers

of the

Project: Energy Systems

July 1973 - May 15, 1975

prepared for the

Advisory Committee to the Energy Project

Schloß Laxenburg

A-2361 Laxenburg

Austria

1973

PC-73-3	Proceedings of IIASA Planning Conference on Energy Systems, July 17-20, 405 pp.; Internal Supplement 48 pp.
RR-73-1 Reprint	Energy Systems, W. Häfele, July, 45 pp.
RR-73-5	The Fast Breeder as a Cornerstone for Future Large Supplies of Energy, September, 60 pp.
RR-73-6	Systems Aspects of Environmental Accountability, R. Avenhaus and W. Häfele, September, 43 pp.
RR-73-13	Reactor Strategies and the Energy Crisis, W. Häfele and W. Schikorr, November, 40 pp.
WP-73-11	Notes on the Häfele-Schikorr Model of Reactor Strategies, A.S. Manne, November
RR-73-14 Reprint	Hypotheticality and the New Challenges: The Pathfinder Rold of Nuclear Energy, W. Häfele, December, 19 pp.
RM-73-6	World Energy Consumption, J.P. Charpentier, December, 5 pp.
WP-73-17	Approach to Statistical Publications on Energy, N. Kourochkin, December

1974

RR-74-2 Game Theoretical Treatment of Material Accountability Problems, R. Avenhaus and H. Frick, January, 41 pp.

RR-74-4 Hydrogen: Mechanisms and Strategies of Market Penetration, A.S. Manne and C. Marchetti, March, 25 pp.

RR-74-5 Waiting for the Breeder, A.S. Manne, March, 47 pp.

RR-74-6 Energy Choices that Europe Faces: A European View of Energy, W. Häfele, March, 37 pp.

SR-74-1-EN Project Status Report: Energy Systems, April 5, 141 pp.

CP-74-3 Proceedings of IIASA Working Seminar on Energy Modelling, May 28-29, 342 pp.

RR-74-7 Strategies for a Transition from Fossil to Nuclear Fuels, W. Häfele and A.S. Manne, June, 70 pp.

RR-74-10 A Review of Energy Models: No. 1 - May 1974, J.P. Charpentier, July, 113 pp.

WP-74-29 Introduction to Some Aspects of Energy Conservation and Energy Demand, R.J. Eden, July

RR-74-12 Credible Interval Temperature Forecasting: Some Experimental Results, A.H. Murphy and R.L. Winkler, August, 50 pp.

RM-74-17 Hydrogen Market Penetration: Further Refinements on the Strategy for Research, J.P. Ponssard, September, 10 pp.

WP-74-43 Evaluating the Solar Energy Option as a Long-term Major Energy Option for Mankind, J. Weingart, September

RM-74-19 The Häfele-Manne Model of Reactor Strategies: Some Sensitivity Analysis, H. Konno and T.N. Srinivasan, October, 34 pp.

WP-74-59 Fuel Cycle for a Transient Reactor System, G. Mara, October

RR-74-19 An Incentive-Tax Model for Optimization of an Inspection Plan for Nuclear Material Safeguards, A. Suzuki, October, 49 pp.

RR-74-20 Future Energy Resources, W. Häfele, November, 28 pp.

RR-74-21 Game Theoretical Treatment of Material Accountability Problems: Part II, R. Avenhaus and H. Frick, November, 22 pp.

	Energy Project Presentation to IIASA Council, W. Häfele, November
RM-74-29	A Systems Analysis Approach to Nuclear Facility Siting, J.G. Gros, R. Avenhaus, J. Linnerooth, Ph.D. Pahner, and H.J. Otway, December, 23 pp.
RM-74-30	Sensitivity Analysis on Hydrogen Utilization Factor of the Häfele-Manne Model, A. Suzuki and L. Schrattenholzer, December, 24 pp.
WP-74-72	Thoughts on the Establishment of Standards, R.L. Keeney, December

1975

RR-75-2	Studies on Energy Resources in the IIASA Energy Project, M. Grenon, January
	Research Program 1975, Project: Energy Systems, February
RM-75-2	Risk Assessment and Societal Choices, H.J. Otway, February
RM-75-4	A Study on the Demand Aspects of the Häfele-Manne Model - An Application of the Mathematical Technique of the Hoffman Model, A. Suzuki and R. Avenhaus, February
RM-75-5	Revealed Preferences: Comments on the Starr Benefit-Risk Relationships, H.J. Otway and J.J. Cohen, March
RM-75-8	Overview on Techniques and Models used in the Energy Field, J.P. Charpentier, March
RM-75-10	World Modelling from the Bottom Up, W.D. Nordhaus, March
WP-75-25	Objective Functions, W. Häfele, March
WP-75-44	Mental Maps: Without Spaghetti They are Baloney, W.D. Nordhaus, April

ENERGY PROJECT CONFERENCES

1973

IIASA Planning Conference on Energy Systems, July 17-20, Laxenburg

1974

Working Seminar on Energy Modelling, May 28-29, Laxenburg

Project Status Report: Energy Systems, April 5, Laxenburg

1975

Task Force on Fusion-Fission, February 21-26, Laxenburg and Moscow

Coal Task Force, March 24-26, Laxenburg

Energy and Climate Meeting, April 29-30, Laxenburg

IIASA Conference on Methods of Assessing Energy Resources, May 20-21, Laxenburg

Workshop on Energy Demand, May 22-23, Laxenburg

Planned for the rest of 1975

Project Status Report: Energy Systems, Bulgaria

Workshop on Energy Systems and Climate Modelling, Laxenburg

IIASA-IAEA International Workshop on Risk Assessment, Laxenburg or Vienna

Workshop on Comparing Fusion and Fission Breeder Reactors, Laxenburg