THE 31ST JAIF
ANNUAL CONFERENCE
第31回原産年次大会

APRIL 20～22, 1998

JAPAN ATOMIC INDUSTRIAL FORUM
日本原子力産業会議

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平成十年四月二〇日
（社）日本原子力産業会議
会長　　向坊　隆

議長、ご臨席の皆様、日本原子力産業会議の向坊でございます。

第三十一回原産年次大会の開催にあたりまして、主催者を代表して、一言所信を述べさせていただきます。

はじめに、国の内外から多数の方々がこの大会にご参加くださいましたことに、心から厚くお礼申し上げます。

さて、わが国が現在ひとつの「転換期」にさしかかっているということは、誰もが感じていることではないかと思います。第二次世界大戦後の荒廃からわが国が立ち直り、世界経済においても、大きな地位を占めるまでに発展してきたという半世紀の歴史のなかで、わが国のさまざまな制度やシステムは、大変大きな役割を果たしてきました。

しかし、国際化あるいは地球化といった新しい情勢をうけて、現在これらの制度やシステムは何等かの形で見直しを迫られています。政治や行政の改革はもちろんですが、経済、教育、さらにはアカデミズムにいたるあらゆる分野で、われわれはそれぞれ改革に取り組んでいく必要があります。

原子力開発の分野では、軽水炉による発電が順調に進展し、経済的で安定的な主要電源の位置を占めるにいたっていますし、アイソトープ放射線の利用は、目覚しい発展を遂げている医療分野をはじめとして、各方面において既に国民生活に定着しております。これらはまさに原子力関係者の長年の努力が実ったものといえましょう。

一方、今後関係者が取り組まなければならない課題としては、核燃料サイクル・バックエンドの開発など、さまざまなものがあります。これらの開発過程にあって、ここ数年に生じました幾つかの不祥事は、時代の先端を走っていると自負していた原子力の分野にあっても、危機管理などの面において、わが国の、いわゆる「制度疲労」と無縁でないことを思い知らされました。

核燃料サイクル・バックエンドの確立などの課題に取り組んでいくためには、まず動燃事業団を改組して設立される「核燃料サイクル開発機構」が、十分に機能することが大切ですが、これに留まらず、原子力開発に係わる現在の諸制度も、新たな目で検討される必要があります。それはもちろん、転換期にきた日本の社会システムの改革という流れの中

で、積極的に取り組まれなければならないことであり、最も緊急の課題であります。

そこで私は、この年次大会が改革への基本的理念を模索し、新たな発展へ挑戦する契機になって欲しいと考え、動燃事業団の改革に取り組まれ、ご専門の工学設計の分野はもちろんながら、今や社会の設計についても指導的役割を果たされておられる、吉川弘之東京大学名誉教授に準備委員長をお願いした次第です。日本学術会議会長をはじめとする、さまざまな公務のため、極めて多忙にもかかわらず委員長をお引き受けいただいたことに、厚くお礼申し上げます。吉川先生のお考えは、この後の講演にてご披露されますので、是非、注目してお聞きいただきたいと存じます。

さて、今回の年次大会の基調テーマは、「原子力－新たなる挑戦」でありますが、地球温暖化問題は、エネルギー関係者がこぞって挑戦しなければならない課題です。地球温暖化については、科学的根拠が曖昧であるという意見もありますが、これが人類にとって、忍び寄る確実な危機であることは、間違いないと思います。この危機を真摯に受け止めれば、発電段階で全く温暖化ガスを排出しない原子力発電が、温暖化の防止に、大きな役割を果たしていかなければならないことは明らかです。原産は各国の原子力関係者と協力して、断固としてこの考えを国内外の一般市民の方々に訴えていく所存です。

今後私たちが挑戦していかなければならない技術課題としましては、高速炉やより進んだ放射性廃棄物の処理処分の実用化、さらには高温ガス炉や核融合炉の開発などがありますが、私はこれらの大プロジェクトを国際的分担方式ですすめていくことを提唱したいと思います。

私達原子力関係者は、原子力技術の潜在能力に確信を抱くあまり、その確信を一般市民と分かち合ったり、一般市民の懸念を理解しようとする努力を怠っていたかもしれません。原産は、原子力開発に係わる知識や情報を広く一般市民に伝え、また、市民の声が原子力開発に反映されるよう、今後とも一層の努力をし、原子力開発に対する意見集約のセンターとして、積極的な活動を行ってまいります。

今回の年次大会ではいつもの通り、市民の意見交換の会を開催しますとともに、今後の原子力開発を担う若い人たちの意見交換の場として、はじめて、ヤング・ジェネレーション・フォーラムをもうけました。このような場で活発な意見交換が行われることを期待し、本日からの五つのセッションの成果とともに、本大会が原子力開発を少しでも前進させられることを念じまして、私の所感とさせていただきます。

ご静聴ありがとうございました。

Remarks for the 31st JAIF Annual Conference

by

Dr. Takashi Mukaibo

Chairman of the Japan Atomic Industrial Forum (JAIF)

April 20, 1998

Mr. Chairman and everyone attending the conference today: welcome to the 31st JAIF Annual Japan Conference. I am the chairman of the Japan Atomic Industrial Forum, Takashi Mukaibo.

As the chief representative of the organization responsible for the conference, I stand before you today to deliver an opening address. Before I begin, however, let me first express my heartfelt thanks for the great number of participants in the conference, both from Japan and abroad.

Well, I believe that most people are aware that Japan now stands on the verge of another turning point in its history. Since rising from the ashes of the Second World War, the nation has developed to the point where it occupies an important position in the world economy. In the past fifty years, the structures and systems in Japan have played an extremely important role in that development.

However, the new winds of internationalization and globalization have now compelled changes, somehow, to be wrought in those structures and systems. While they naturally include reforms in politics and the national bureaucracy, we must also engage in a broader range of reform in the fields of economics, education, and even academism.

In the area of nuclear energy development, the generation of electricity by light water reactors (LWRs) is advancing smoothly in Japan, with their having attained the status of a major electricity source that is both economical and safe. Moreover, the broad use of radioisotopes and radiation has gained an important foothold in the lives of the people, especially having shown brilliant progress in the field of medicine. These are truly the fruits of many years of efforts by the people involved in the development.

Meanwhile, there are many tasks remaining for us to deal with, including the establishment of the back-end of the nuclear fuel cycle and . In the process of that development, though, several unfortunate incidents have occurred in the past few years that serve to underscore a certain fact. That is, even the field of nuclear energy, which has prided itself for being at the forefront of the times, is no stranger to the systemic exhaustion that plagues Japan, such as in the field of crisis management.

In order to grapple with such tasks as the establishment of the back-end of the nuclear fuel cycle and , it is important to get the new nuclear fuel cycle development organization -- established to succeed the Power Reactor and Nuclear Fuel Development Corp. (PNC) as part of the reform process -- up and running smoothly. But our efforts cannot stop there: the various existing systems dealing with nuclear energy development need to be reviewed from a new perspective. Needless to say, the most urgent task facing us is to engage in that review actively, in the context of the more general reform of Japan's social system as the country enters a turning point.

I believe that the proceedings at this conference, where basic ideas of reform will be explored, will provide the opportunity for us to rise to the challenge before us. I entrusted Dr. Hiroyuki Yoshikawa, professor emeritus at the University of Tokyo with the job of chairing the program committee for the conference. Not only has he been playing a leading role in the field of engineering design, but he has recently taken a leadership in social design as well on account of his own engineering expertise. As you know, he has been involved in the reforms of PNC by chairing its directive committee. I am deeply appreciative of Dr. Yoshikawa's having agreed to serve as program committee chairman despite his extremely busy schedule, which includes the presidency of the Science Council of Japan. He will personally deliver a lecture later on in the conference that will explain his ideas. Please listen closely to what he has to say at that time.

Now then, moving to the main theme of the conference this year -- "Nuclear Energy: New Challenges -- we can argue that the issue of global warming is one that everyone involved in energy must grapple with. While some people point out that there is no firm scientific evidence for global warming, it is definitely a crisis looming before all of humanity. A serious view of the crisis leads to the obvious conclusion that nuclear power generation can play a big role in preventing global warming, given its lack of greenhouse gas emissions during the power-generating stage. JAIF is endeavoring strenuously to present this idea to the public, both to Japanese and overseas audiences, with the cooperation of nuclear energy interests worldwide. As for technological issues that still need to be resolved, one can cite the development of fast-breeder reactors (FBRs), the realization of a more advanced method to dispose of radioactive wastes, as well as the development of high-temperature gas reactors and nuclear-fusion reactors. I would like to take this opportunity to advocate an international division of labor for these grand projects.

As professionals involved in the nuclear industry, we are already convinced of the latent potential of nuclear power technology. However, we may have been lax in sharing that feeling with the common people, failing to understand their worries and concerns. JAIF will strive even harder in the future to inform the public broadly about knowledge and information related to the development of nuclear energy, as well as to ensure that their ideas are reflected in that process. Our aim is to carry out such activities dynamically as a center that brings together all sorts of opinions related to nuclear energy development.

As usual, this year's JAIF Annual Conference includes a forum for the exchange of opinions among the public. For the first time, also, we have organized a "young generation's forum" to hear out the opinions of the young people who will take charge of nuclear power development in the future. I really look forward to a brisk exchange of opinions at these forums, as well as to the success of the conference's five sessions, which start today. If this year's conference can contribute even a little bit to the advancement of nuclear power development, I will be satisfied.

Thank you for your patience in listening to my address.

第３１回原産年次大会
原子力委員会委員長代理所感

本日、第３１回 原産年次大会が、内外から多数の方々の御参加を得て、かくも盛大に開催される運びとなりましたことをお慶び申し上げます。ここに至るまで向坊会長、吉川大会準備委員長はもとより、大会の開催に尽力された、多くの方々のご苦労に敬意を表する次第です。

皆様ご承知の通り、日本はその資源に恵まれず、狭い国土に多くの人が住むと言う自らの宿命を克服すべく、また原子力の開発を通して世界に貢献すべく、原子力開発に着手し、４０余年を経過しました。その間国民の理解と支援に支えられて順調に発展し、今や日本は世界の原子力先進国の仲間入りを果たしたと、自他ともに認めるようになりました。その結果我が国の原子力政策や原子力開発への取り組みは必然的に世界的視野が求められています。 アジアの一隅で、平和利用に専念してきた日本は、冷戦構造が崩壊した現在の状況をとらえ、２１世紀に人類が平和と豊かさを求めて自然と共存し、調和のある文明を築いて行く上で、原子力に何が期待されるかを考える時期に来ています。

世界は産業革命以来、築き上げてきた化石エネルギーの文明が、その排出側の問題に悩み、曲がり角を迎える中で、自然との調和を図る環境論的視点を重視する文明への転換を図っています。 人類文明を支える総合科学技術に育つ可能性のある原子力もこのような世界的動きの中で自らの研究開発の方向を定めていくことが求められています。

その中心課題の一つが地球温暖化防止における原子力の役割です。

昨年１２月京都で開催された、「気候変動に関する国際連合枠組条約第３回締約国会議」俗称（COP－3）においては、温室効果ガス削減に係る数値目標が盛り込まれた議定書が採択されました。これに課せられた責任を果たすことが、特にエネルギーの大量消費国

において喫緊の課題です。エネルギー大量消費国の一つである日本においても、広範な政策分野にわたる対策と国民各層における取り組みが必要とされており、省エネルギーなどエネルギー需要側の努力はもちろんのこと、非化石エネルギーの導入促進が不可避の選択になっております。

このような要求に原子力がどう応えるかが今問われていると申せましょう。確かに、原子力発電はすでに我が国においても安定したエネルギー供給源としての地位を確立しており、資源の有限性と偏在性に見られる、エネルギー供給構造の脆弱性を解決すると言った資源論的観点に加えて、炭酸ガスを排出しない原子力は環境論的観点からも期待が深まっています。

原子力委員会は１９５６年以降、その原子力政策の中で一環して原子力発電の開発とともに、安全確保の重要性と核燃料サイクルの確立を訴えて来ています。　炭酸ガスを排出しないのは確かに大きなメリットですが、それだけでは決して十分ではありません。炭酸ガスにくらべてより日常性に乏しい、放射線と放射性物質の扱いに真摯に取り組み、国民に安心して原子力に接してもらえるようにすることは、原子力に対する国民の理解と支援を得る上で不可欠なことです。

核燃料サイクルの確立は資源論と環境論の両者が原子力に求めるものを同時に達成する上で避けて通れないものです。

ここで核燃料サイクルの確立と安全確保に関連した最近の動きを見てみましょう。

原子力委員会は核エネルギー資源をリサイクルして資源の有効利用を図ることと、放射性廃棄物の量を減らし、環境から隔離することで、環境負荷の低減を図ることが、原子力を長期にわたって安定的に利用する上で不可欠なことと認識し、これを積極的に推進する事を委員会決定や委員長談話の形で表明してきました。

しかし、不幸なことに、動燃の文珠におけるナトリウム漏洩に始まる一連の出来事とその不適切な処理と対応は社会に大きな衝撃を与え、国民は今までの原子力開発がそのまま

新しい世紀に引き継がれるものではなく、この段階でその目的理念から開発体制まで、全体にわたって、再確認することを求めました。これは「安全から安心へ」に表現されるように、安全最優先の確認と情報公開の要求に現れています。 また核燃料サイクルの重要性に関して原子力開発の全体像と長期展望を提示する中での位置付けを求めています。

このような認識のもと動燃の抜本的な改革を行うこととし、現在、事業の重点化や経営機能の強化を通じて社会に開かれた体制作りの作業が進められています。本年2月には動燃を「核燃料サイクル開発機構」に改組する法案が国会に提出され、4月14日には衆議院で可決され、参議院において審議がおこなわれることになっています。

核燃料サイクルの確立は、21世紀の科学技術に問われる条件を満足し、文明に貢献出来る原子力の基本的課題に挑戦する大きなテーマです。新法人が世界でもまだ達成されていない核燃料サイクルの確立の持つ意義を十分認識し、その開発を通して社会の期待に応えてくれることを心から期待するものです。また同時に国民各位がこの研究開発の持つ意味を十分理解され、支援されることを望んでいます。

一方国策民営で特徴つけられる日本の原子力で、 プルトニュームの軽水炉利用や、青森県六カ所村における再処理工場の建設、使用済み核燃料のリサイクル資源としての貯蔵等が目下の核燃料サイクルを促進し、またゆとりを確保するための重要な方策であり、官民の役割分担と協力によって、国民合意を図り、着実に進めていくことが大切です。

近年国民の間に関心が高まっている高レベル放射性廃棄物の処理、処分に付いては、その着実な対応がきわめて重要であると認識し、専門部会と懇談会を設置し、原子力の専門家に限らず、各界のオピニオンリーダー等々のご参加を得て審議を重ねて参りました。処分の技術的検討では、、2000年までに技術的信頼性等を示すことを目指した研究開発続けられています。一方、社会的、経済的側面についてもこれまで審議を続ける一方、国

民各層の意見を求めて、日本の各地で懇談会を開催して来たところです。 近く報告がまとまる段階に来ており、それに基付いた実施体制や必要な制度の整備を着実に進める努力をして参ります。

さらに、核燃料サイクルの将来の確立に取って大きな存在となる高速増殖炉については、高速増殖炉懇談会を設置して国民各層のご意見も伺いながら、審議を進めてきた結果、昨年１２月に報告書がまとめられました。高速増殖炉が将来の非化石エネルギー源の有力な選択肢であるとの報告書の結論を尊重し、放射能消滅による環境負荷の低減能力にも期待をかけてその実用化の可能性を模索し、研究開発を進めて参ります。その際高速原型炉文殊は有力な研究開発のツールになります。文殊に付いては万全の安全確保対策を施し、地元の方々の理解と支援を仰ぎながら、段階を踏んで着実に対応を進めて参ります。

さて、今後の日本の原子力を語るに当たって国際的視野は不可欠であります。日本は原子力開発の当初より、核拡散防止には積極的姿勢を示してきましたが、引き続き核不拡散条約（ＮＰＴ）に基ずく国際的責務を誠実に履行するとともに、補償措置の強化、効率化方策についてのＩＡＥＡとの協議を着実に進めて参ります。また、世界的に核軍縮を推進するために、包括的核実験禁止条約（ＣＴＢＴ）による国際的な核実験禁止の枠組みが早期に実現されるよう努力していくとともに、我が国としても引き続き国内体制の整備を推進して参ります。

原子力の安全に関しては、原子力の安全に関する条約の実施により、高い安全水準が世界的に達成、維持されるよう積極的に貢献するとともに、使用済み燃料管理の安全及び放射性廃棄物管理の安全に関する合同条約についても、早期に締結できるよう検討を進めているところです。

さらに大切なことは、日本が原子力平和利用の先進国として、世界の原子力の平和利用に積極的に協力、貢献する事であります。平和利用の推進と安全向上への貢献は近隣ア

ジアの国々が自らの原子力開発を進める上で日本に強く求めているところです。アジア諸国との協力は此までの実績に加えてさらにいっそう主体的取り組みを必要としています。協力するかしないかが問題なのではなく、どうすれば成果があげられるかを考える段階に至っています。

終わりに

此までお話ししましたように社会から提起された問題の解決への努力は次第に姿、形を整え、来るべき２１世紀に向けての躍動が原子力の世界にも感じられるようになってきました。確かに、 新しい科学技術を社会に導入していくのが決して容易でないことは歴史の示すところでもあります。しかし原子力開発の全体像と長期展望を明確にして分かりやすい形で国民に提示説明し、理解と支援を求める努力が国民とともにある原子力には必要です。 此までに学んだところは、ａｃｃｏｕｎｔａｂｉｉｌｉｔｙとともにｌｅａｄｅｒｓｈｉｐの重要性であります。事業主体の裁量権と当事者責任、あるいは国民合意へ向けての議論の中でアカデミアの果たす役割等に期待がかかっています。これらは先進国の研究開発では当然のことといえるのかもしれません。

原子力政策決定への国民参加は、原子力政策円卓会議から出発して原子力委員会の公開、専門部会や懇談会の公開、意見公募等を通じて、定着してきています。 新円卓会議については諸般の事情で遅れましたことをお詫びし、可及的速やかに開催する事とします。

さらに、２１世紀にいっそう高い段階に移行するであろう原子力について、その目的と理念は何か、政治、経済、社会にどう調和していくかなどの議論をおこない、将来へ向けて原子力の研究開発及び利用について、その目的内容を明らかにし、ガイドラインと現実方策を示すことが求められています。皆様はすでに私の言わんとしていることが近い将来具体的は議論や審議につながっていくことを御賢察のことと思います。

皆様方におかれましても、今後よりいっそうの御支援、御協力を賜りますようお願い

申しあげるしだいです。

最後に、本年次大会が実り多き大会となること祈念致しまして私の挨拶ととさせていただきます。御静聴ありがとうございました。

1998年4月20日

原子力委員会委員長代理　　　藤家　洋一

Status and Prospect of China's Nuclear Power Program

Jiang Xinxiong
President
China National Nuclear Corporation

China needs nuclear power.

China has uneven distribution of unrenewable energy resource in terms of the national geography. China enjoys rich coal resource, main part of which is located in the north. The hydro resource is located in the west and southwest. The densely populated and economically developed eastern coastal provinces short of energy resource. have increasingly large demand for power supply. Coastal East China needs nuclear power. If the provinces in that area continue to count on their fossil-fueled plants, the stress on transportation and environment will be growing.

In mainland China, 2 NPPs (3 units) are in operation. The total installed capacity is 2100MW, accounting for 1% of the national total.Under construction are 4 NPPs (8 units) with capacity of 6800MW.

China's energy policy is to optimize structure of fossil-fueled plants, to develop hydro power with main efforts and to develop nuclear power commensurately.

Policy for China's nuclear power program:
1)to capitalize on the existing nuclear power technical basis;

2)to pursue the nuclear power localization and standardization;

3)to adopt advanced proven nuclear power technology;

4)to stick to the principle of " self-reliance as the major goal plus Sino-foreign cooperation".

Status and Prospect of China's Nuclear Power Program

Jiang Xinxiong
President
China National Nuclear Corporation

Mr. Chairman,
Ladies and gentlemen,

I am pleased to be invited by the JAIF to participate in the 31st Annual Conference of the Japan Atomic Industry Forum to meet many old and new friends. I would like to express my thanks to the Japanese host for the invitation, and my respects to Japan Atomic Industrial Forum for its excellent organization job for the Conference, and I wish the Conference great success.

I really appreciate the opportunity of exchanging our views. Now I would like to brief on the current status and prospect of China's nuclear power program.

I. China's Need for Nuclear Power

China started up nuclear power program in early 1970's with two-fold need behind: we need to make peaceful use of nuclear energy; the coastal east China needs nuclear power supply.

China has uneven distribution of unrenewable energy resource in terms of the national geography. China enjoys rich coal resource, main part of which is located in the north. The hydro resource is located in the west and southwest. The densely populated and economically developed eastern coastal provinces, short of energy resource, have increasingly large demand for power supply.

China mainly depends on fossil fuel power supply with a proportion of 81.5%. If the coastal provinces in that area continue to count on their fossil-fueled plants, a great deal of coal will be transported across the long distance from the north to the south, causing growing stress on transportation and environment.Nuclear power is a clean and efficient energy resource. The option of developing nuclear power on the southeastern coast is the need of economy and the logical power supply structure. For these reasons, the first two NPPs of mainland of China are located in the coastal Southeast.

II. Current Status of China's NP

In mainland of China, two NPPs are in operation and 4 NPPs(8 reactors) are under construction.

2.1 Two NPPs in Operation

Qinshan NPP

Qinshan NPP, located in Hangzhou Bay 120km southwest to Shanghai, is a 300MW PWR unit with self-reliant design, construction and operation. Since put into commercial operation in 1994, has enjoyed sound record, with the load factor of around 80% during the past 3 years.

Daya Bay NPP

Daya Bay NPP, located in Daya Bay area 65 km east to Shenzhen, has 2 900MW PWR units imported from France. Since put into operation in February and May, 1994, the load factor has remained around 75%.

With years of NPP operation, we trained management and technical personnel and accumulated valuable experience and lessons.In 1997, the total generated electricity in China amounted to 1,135 billion kWh, of which nuclear power accounted for 1.27%, amounting to 14.4 billion kWh; the total installed capacity exceeded 250 GW, with nuclear power 2.1GW, which accounted for 0.84% of the total. So far, the nuclear power accounts for a minor part in China's power generation.

II. 4 NPPs under Construction

As decided by the Chinese government, commencement of 4 additional NPP projects is scheduled for the 9th Five-year Plan Period (1996-2000): Qinshan Phase II, Guangdong Lingao, Qinshan Phase III and Lianyungang NPP, including 8 units with a total installed capacity 6.6 GW.

Qinshan Nuclear Power Phase II is located at the Yangliushan site, 2 km south of Qinshan Phase I site. The 2x600 MW PWR units, based on self-reliant design and construction, and some equipment imported from foreign countries. The first concrete pour was on June 2, 1996; Unit 1 is expected to be connected to the grid and generate electricity in 2002.

Guangdong Lingao NPP, 1 km west of Daya Bay NPP, includes 2 French-designed PWR units with total installed capacity 2x1,000 MW. The design and equipment necessary for the project are all supplied by French. The first concrete was poured on May 15, 1997. The construction is now proceeding as scheduled, and the plant will be fully completed and put into operation, as planned, in 2003.

Qinshan Phase III located at Tanglangshan, 800 m east to Qinshan Phase I site, includes 2x700 MW CANDU-6 HWR units. AECL is contracting the project through a turn-key mode with Canadian export credits and commercial financing. The first concrete will be poured in June 1998, and the plant is planned to complete and put into operation in 2003.

Lianyungang NPP, located in Lianyungang area 300km north to Shanghai includes 2 Russian-origin improved WWER-1000 91-type PWR units with a total installed capacity 2x1,000 MW. The design of the project and the main equipment for both nuclear and conventional islands will be supplied by Russia, and some equipment procured from other countries, including digital I&C from German Siemens. And the Chinese party will handle civil engineering, erection and project management. The project will be financed partially by Russian government loans, and the remainders at home by the Chinese party, while part of foreign export credits and commercial loans will be adopted. As predicted, the first concrete pour is scheduled for the second half of 1999; Unit 1 completed in 2004.

III. Prospect for China's Nuclear Power Development

Per capita installed capacity of power generation is rather low in China, only 0.18 kW in 1997, one third of the world average level, which is far from meeting the demand of the national economic development.

At present, the power structure comprises coal-fired power making up 81.5%, hydropower 17.2% and nuclear power 1.3% only. Construction and operation of a large number of coal-fired power plants have caused serious stress on transportation and environmental protection.

China, particularly the economically-developed eastern coastal area needs nuclear power development.

China's energy policy is to optimize structure of fossil-fueled plants, to develop hydro power with main efforts and to develop nuclear power to a commensurate degree.It means that nuclear power growth is required but remains in a certain level. Nuclear power, as a clean energy resource, is a right option for the coastal area lacking in coal and hydro resource. Nuclear power expects fast growth in China for next century.

The 9th National People's Congress has just concluded in China.

The new government will work out the national energy development planning. Whatever scale China's future nuclear power development is, the following factors will be considered:

1) To capitalize on the nuclear power technical base in China

With nearly 20 years' efforts, we completed 2 NPPs and 8 nuclear power reactors are under construction. China has exported, in turn-key form, a 300 MW PWR NPP to a neighbor country. A strong management and technical team specialized in nuclear power design, research, construction and operation has been fostered. This is the base and task force to continue our nuclear power program. We will utilize the technical force to fulfill new development.

In past 20 years, with the nuclear power growth, a complete PWR fuel cycle has been established.

2)Localization and Standardization

Problems exist despite the great achievements in China's nuclear power program in recent 10 years. One problem involves diversity of reactor types.We have both LWR and HWR types. Among the LWRs, there are self-designed 300 MW and 600 MW units, and 1,000 MW units introduced from France and Russia.

Localization and standardization of nuclear power construction must be realized in China for the sake of further development of nuclear power in the next century.We failed to form a nuclear power industrial system that fits in with China's realistic conditions. For a developing country like China, the failure to centralize the use of our limited human resource and funding source is not favorable to nuclear power sustainable growth.

In order to lower nuclear power construction cost, shorten the construction period and ensure the sustainable nuclear power growth, China must take the localization and standardization approach to go ahead with the 21st century's developement.

3) To adopt advanced and proven nuclear power technology

The construction of 4 additional NPP projects (8 nuclear power units) is scheduled for the 9th Five-year Plan Period (1996-2000). For the development plan after the year of 2000, the new government will work out planning.To optimize China's energy structure, nuclear power must cover a reasonable proportion in the power generation. According to the estimates of experts, if the nuclear portion would be 5%,the nuclear installed capacity will be 30 GW and 40 GW in 2010 and 2020 respectively. But the nuclear installed capacity of the 11 reactors operated and constructed at present amounts for only 8.7 GW.

Principal technical guideline for China is PWR type as the major selection in China. It will not be changed for the future. The NPP for construction in the 10th Five-year Plan period (2001-2005) might not be the new generation advanced NPP but surely it will be improved and technically proven type and gradually transitioned to new generation advanced NPPs. China does not build untested prototype reactor with no operation records. We will adopt advanced but proven nuclear power technology.

Nuclear power technology, just like other technologies, develops and improves continuously and the perception of nuclear power is also growing. We will follow up on the world nuclear power technology trends.With the technical guideline of PWR as the major type, we do not discriminate against other nuclear power technologies with distinguishing safety, advanced and economic merits.

4)Self-reliance as the main effort plus Sino-foreign Cooperation

The on-going reform and opening-up policy favors China's nuclear power program. Actually, the successful nuclear power program benefits from this policy. Qinshan NPP is our first self-reliant designed NPP. Some of the important equipment was imported from foreign countries. For example, its pressure vessel and core barrel are from Japan. The design, construction and all the equipment of Daya Bay NPP are handled by French. During these years, we have enjoyed cooperation with foreign firms effectively.

With nearly 20 years' hard work, China has built certain strength in nuclear power industry. We still stick to the principle of self-reliance as the focus plus Sino-foreign cooperation.

China's nuclear power market is open to foreign companies to participate in our program. We will continue to need international cooperation. Then we will select foreign partners based on the following priority factors:

1. technical scheme to fit in China's reality
2. helpful to China's localization goal
3. advanced and proven technology
4. favorable financing conditions.
5. economic competitiveness

China's nuclear power program is one part of the world nuclear power community. So we must share our lessons, strength and support to work together to make nuclear power a well-accepted safe, clean and economic energy by the public and a lasting sustainable energy.

Thank you for your attention.

The Future of Nuclear Power in France

Yannick d'Escatha
Administrator General, French Atomic Energy Commission

Thank you Mister Chairman, Ladies and Gentlemen,

First of all, I would like to express my great pleasure to be a guest of the 31th Japan Atomic Industrial Forum Conference and all the more so to share this honor with such distinguished speakers. This morning's session is devoted to the many challenges facing nuclear power development.

Actually, a discussion is being prepared in France which can be identified with that of the renewal of the French nuclear power park. After a period of intensive construction culminating today with the commissioning of level N4 (Slide N1), the French nuclear system has reached maturity, with an operational nuclear power park that is safe, competitive and environment-friendly. The discussion bears on the content and the precise schedule of the decisions that will have to be made in the coming decades by Government authorities and industry to replace the nuclear power generation capacity, as the power plants reach the end of their lifetimes, starting around the year 2010. This discussion is legitimate as the present context is in full evolution whether in terms of economy (particularly with the opening of the electricity market), or environment with the commitments made at the Kyoto Conference relative to greenhouse gas emissions. Concerning this last point, respect for the environment, I mean, I am sincerely convinced that the dynamics initiated in Kyoto cannot be stopped and that the public will recognize the advantages of nuclear energy. But for the nuclear industry, this globally favorable context comes with growing requirements, not only for competitivity with respect to other sources of energy, but also concerning safety and the ability to satisfactorily manage the long-lived radioactive wastes.

The mission entrusted to CEA is therefore to maintain the nuclear alternative open up to the year 2010, to enable Government authorities and industry at that time, to make the decisions concerning the energy policy for the 21st Century.

It is in this long-term perspective, and with a view towards preparing the choices for the 2010 timescale, that the Government has adopted the major orientations which I shall briefly review now.

SUPERPHENIX IS ABANDONED

Complying with its commitments, the Government decided to abandon the breeder reactor Superphénix, not for reasons of safety, but because the system no longer seemed to have any short-term industrial prospects. This prototype, launched in the 70s in a context of energy shortage and fears of tension in the uranium market, no longer appears adapted to the priority requirements of today's economic context.

Nevertheless, Superphénix represents a wealth of technology, developed by highly motivated and competent teams. So benefits must be reaped from the experience accumulated, and research on fast neutrons should be steadily continued for a more distant future.

MASTERING THE BACK END OF THE FUEL CYCLE

Mastering the back end of the fuel cycle, that is to say the management of the spent nuclear fuel and the resulting wastes, is a major challenge, if nuclear energy is to be accepted by the public. The Government recalled its attachment to the December 30, 1991 law, on research concerning long lived radioactive wastes, and it stressed the complementarity of the three research lines of this law : the separation and transmutation of long-lived radionuclides (line 1), disposal in deep geological layers, retrievable or not (line 2) and long-term surface interim storage (line 3).

So research on transmutation will be continued up to 2004 thanks to the re-starting of the fast neutron research reactor, Phénix (Slide N2).

By the end of the first half of the year, the Government will make its decisions concerning the sites selected for the installation of underground laboratories, designed to study storage conditions for radioactive wastes in deep geological layers.

The Government also wishes to intensify research on long-term surface and sub-surface interim storage.

Under the terms determined by the law, in 2006, after 15 years of research along these 3 lines, Parliament will decide on the management of these wastes. The research, undertaken on the three complementary lines of the law, should enable all possible alternatives to be studied, and all choices to be left open for Parliament, to make a decision concerning the strategy for management of long lived waste.

TRANSPARENCE AND NUCLEAR MONITORING

In the third and last place, the Government recalled the importance of transparency, which is a major factor for public acceptance of the nuclear option. To improve this, the Government asked the President of the "Parliamentary Office for the Assessment of Scientific and Technological Choices " to make proposals. This report is expected for next July 31.

- So the Government clearly reasserted its commitment to nuclear power and, in conformity with its missions, CEA is called upon to play a major role in the preparation of the decisions that will be made in 2006 for the back end of the cycle, and in 2010 for the renewal of the nuclear power park. CEA must, in particular, be vigilant so that, at the time of the decision-making, the nuclear option remains fully open, which means that all impediments or questions regarding its implementation be resolved. It must thoroughly and impartially explore the various possible scientific and technical alternatives, and propose, to the Government and to industry, a whole range of solutions.

- In fact, nothing would be more harmful to the future of nuclear power than conveying the feeling that the decision-makers have already chosen a single and inescapable path. The studies made by CEA with its industrial partners, in the framework of a ministerial mission coordinated by Misters Mandil and Vesseron, show, on the contrary, that the nuclear industry offers great flexibility of choice (systems, composition and operating methods of a park, type of fuels, implementation of recycling, dedicated management of waste and so on), as well as flexibility in time. Indeed, the options may, if so desired, be used in parallel, and one can switch from one to another in the course of time.

- This implies, however, developing a long-term vision over 50 years. The facts of life are tenacious : after some dozen years, we must be prepared to deal with a shortage of oil and gas, as well as of U_{235} Beyond that will be available on one hand Coal (but with the already well known consequences on CO_2 and other discharges detrimental to the environment), and on the other hand uranium with the condition to be able to burn all the uranium, then (calling on) plutonium and fast neutrons.

In this context, what are the great scientific and technical challenges CEA must face with a commitment to results in coming years ? In my opinion, there are 7 of them.

a) First challenge : A new generation of reactors

- Replacing the present park, (as the power plants reach the end of their lifetime), should fit into the very long term (planning policy) for power equipment, and hence into the energy " mix " the optimization of which the government must ensure for the next century. This optimum will combine nuclear, gas, renewable energies, energy savings in proportions that must be able to adapt to a changing energy picture during the next 50 years and even beyond (let's recall that the new generation European Pressurized Water Reactor EPR is designed with a life span of 60 years).

- The new reactor generation must therefore provide full guarantee in terms of safety and operation, while meeting growing requirements in competitiveness and flexibility compared with other forms of energy, which also benefit from scientific innovation and technological advances. The experience gained with more than 1000 reactor-years* in France and Germany, but also the advantage of standardization and keeping of the (safety framework) must be however valorized by making possible to consider this new reactor generation in the continuity of pressurized water reactors.

- CEA's clearly determined goal is to contribute, along with its partners in industry and research, to optimize performances of EPR : French-German pressurized water reactor project, to develop and certify the computing tools required to meet this goal, and to completely validate the very ambitious options adopted, especially concerning control over serious accidents. This is why CEA is backing the project to build, in the next decade, a first unit which would allow a life size demonstration of the whole of this experience. The experimental feedback from such a demonstrator will make it possible to pinpoint and plan the required changes, (prior to its deployment) in the renewal of the park. Demonstrating these performances, will contribute to strengthening, when the time comes, the validity of the new generation nuclear proposal and its acceptance by the public.

- Of course, this goal in the framework of park renewal is not in contradiction with the endeavors undertaken by CEA with its industrial partners to ensure the best operating conditions for the present park, including extending its life span.

- As for the usefulness of fast neutrons, this is not questioned over the long term, keeping in mind that the commercial phasing-in of FNRs is not anticipated before about forty years. The strategy adopted by CEA upon request of the Government following the abandonment of Superphénix is to go on with research in fast neutrons field based on 3 stages :

First stage, Phénix, a small size reactor particularly easy to operate in terms of short cycle and measurements. Following extensive renovation work done by CEA, the Safety Authority decided it was possible to resume power up to 2004, to carry out the research program on the transmutation of long-lived wastes ;

* **Second stage, the** optimized **so called Jules Horowitz reactor**, the

commissioning of which is planned for the year 2005;

* **Third stage, the perspective in the European framework of a hybrid system demonstrator** consisting of a particle accelerator coupled with a fast neutron sub-critical reactor in accordance with the principle recalled recently by Professor Rubbia.

b) Second challenge : High Performance Fuels

Another goal pursued by CEA is the optimization of fuels, with a view towards extracting the main part of the energy content of uranium, directly or after reprocessing-recycling. The burnup of UO2 fuels can still be increased, thus making it possible to extend their operating life and the duration between 2 refuelings, a very significant economic asset (next slide N3). MOX, which already allows an additional amount of the fissile energy potential to be used in competitive conditions, can have its performances raised to the same level (in term of burn-up) as those of UO2 fuel, to take the place of standard fuel.

- About the front end of the fuel cycle, the goals are clear : be able to ensure, when the time comes, that the industrialization of AVLIS process will be able to pick up where EURODIF leaves off (next slide N4). AVLIS is the enrichment process by atomic vapor laser process. The first-rate scientific and technical results obtained by CEA last year must not hide the fact that a lot of work remains to be done to bring this process up to the necessary level for an optimized industrial operation, in terms of performance, availability, reliability or, in short, competitivity.

c) Third challenge : Long-Lived Waste Management

- To keep the nuclear option open until 2010, a coherent set of long-lived waste management methods must have been defined, accepted by the public, and their regulations specified. I say a coherent set because here again, I should like to insist on the necessary opening up of options and on the flexibility of their implementation in time. Indeed, due to its very nature, management of the nuclear fuel cycle requires lengthy steps but which, on the other hand, provide time to account for changes in the economic or political context and to incorporate innovations stemming from research. Hence the importance of retrievability in this case.

In view of the 2006 deadline set by the law, CEA is devoting a large and increasing share of its resources to research on the back end of the cycle :

- Phénix will allow to continue experimentation of alternatives for a massive burnup of plutonium thanks to fast neutrons, and the experimentation of alternatives developed in the framework of the SPIN program for the transmutation of minor actinides and long-lived fission products. Moreover, the so called Jules Horowitz (RJH) reactor project is optimized in view of sustained research on fast neutrons.

- CEA is also intensifying its effort in 1998 and 1999, (on the conditioning and long-term surface or sub-surface storage of waste packages and spent fuels). This work will result next year in (very long term) surface storage concepts concerning the various categories of wastes. Moreover, CEA is in charge of submitting to the Goverment, before the end of the year, a report on the concept, the advantages and the feasibility of a long-term sub-surface interim storage.

d) **Fourth Challenge : Mastering Dismantling**

It is of course important for the nuclear industry to be able to demonstrate to the decision-makers, as well as to the public, the complete mastery of the life cycle of its facilities, from grassland to grassland, as we say. This is why the operation that CEA is carrying out jointly with EDF in Brennilis (next slide N5), in Brittany, is particularly important and must be conducted in an exemplary manner. CEA's position is that, in this context, the process must be carried out as speedily as possible up to IAEA level 3, in other words, precisely back to grassland.

This is also an opportunity for significant progress on very low level waste management, since dismantling operations, by nature, generate a large volume of this type of waste.

e) **Fifth challenge : Safety**

In order to master them, taking serious accidents into account in the design of second generation reactors is a major innovation in safety ; this underlies important research and development programs. We may mention, as examples, the control of the hydrogen risk (Mistra program), the development of efficient processes aimed at spreading and cooling corium (Vulcano program), the understanding and control of fission product release phenomena (Phébus PF program) (Next slide N6). These latest programs are carried out especially in collaboration with Japan which has become one of our main international partners for research on nuclear safety, with JAERI, NUPEC, and PNC.

Of course, above and beyond the very specific programs mentioned above, we can say that, by nature, all the innovative programs concerning nuclear topics must include some studies on safety, as safety is an integral part of the very design and of the sizing and operating rules for nuclear facilities, which also must result from an international consensus.

f) **Sixth Challenge : Radiobiology**

Scientific advances in the domain of radiobiology and, more generally of the detailed understanding of the interactions between radiation and living matter, are a necessity for promoting public acceptance of nuclear. It is necessary to achieve an understanding of the intimate mechanism of degradation and repair at the cellular and molecular levels and, in particular, of DNA. Only this understanding will allow an unbiased view of the risk, and hence of the basic norms and regulations for radiation protection to be achieved. CEA's effort in this domain has already been intensified in the past years. We are continuing to pilot this research in partnership with the other research establishments and universities, with many international cooperations.

g) **Last challenge : Controlled Fusion**

Indeed, (next slide please N7) controlled fusion is further away, but in the panorama of long term options concerning energy resources, this promising alternative must not be omitted. However, it concerns the very long term insofar as, today, nowhere does any laboratory have reached simultaneously all the conditions to sustain the fusion reactions. It is therefore essential to work out a strategy able to manage this program over an extended period of time, preserving the present international dynamics and the collaboration between Europe, the USA, Japan and Russia.

CEA obtains important scientific results on TORE SUPRA in Cadarache, especially for mastering long-term discharges and the gathering of solid experience in the operation of superconducting tokamaks. Other CEA teams are contributing to the advancement of various technological domains important for the future fusion reactors, such as materials, thermics and tritigen blankets.

And now I come to my conclusion:

So the 7 major challenges have been briefly exposed. In my view, they stand as fundamental scientific and technical challenges to be faced to keep the nuclear option open to 2010. Nuclear energy indeed remains an essential component to meet France's energy requirements while complying with the Kyoto Conference commitments, and the energy policy orientations set by the Government. Consequently, it is important to provide the Government and the public with all the demonstrations on the economic competitiveness of nuclear energy, on the safety of the facilities and on the management of radioactive wastes.

In this context, CEA is called upon to play a leading role to propose, when the time comes, a set of satisfactory alternatives for the decisions that the Government will take in 2006 concerning the back end of the cycle and in 2010 for the renewal of the nuclear power park. The clearly reasserted commitment of the French Government to nuclear energy opens up ambitious program prospects for CEA. Over all the research topics, CEA must prove its responsiveness, mobilize its expertise and test resources, and make the best advantage of synergies among its different sectors of science and technology.

But for many of these research topics, it is mandatory for CEA to strengthen its ties with the rest of the French and international scientific and technical community, and particularly Japanese, mainly with JAERI, PNC, NUPEC, CRIEPI and certain universities, in the framework of present and future collaboration agreements. Indeed, success shall result from the mobilization of all participants in the nuclear field in domains representing widely shared technical and political stakes such as safety and long-lived radioactive waste management and, for the long term, the development of common strategies.

I thank you for your attention.

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Nuclear Energy for Sustainable Development: the IAEA's Role

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International Atomic Energy Agency

1. Increasing energy demand

Recent studies by the International Institute for Applied System Analysis (IIASA) and the World Energy Council (WEC) project energy demand increases of between 50% in a low economic growth scenario to more than 150% for the high growth scenario by the year 2050. These demands are mostly driven by growing populations and growing economies in the developing world. The current global population of about 5.9 billion is increasing at a rate of 80 million per year. By the middle of the next century, global population is forecast to have increased by 50%.

Strong economic growth in many developing countries, particularly countries with very large populations such as China and India, will lead to a continuing sharp increase in per capita energy demand and consumption for a better quality of life. The potential increase in demand is illustrated in the following figures. At present, Bangladesh and Tanzania use less than 100 kWh per person per year; China uses nearly 1000 kWh and, by contrast, 12,000 kWh in USA. There are plans for a sharp expanded use of electricity not only in Asia but also in Turkey, Mexico and South America. The World Energy Council forecasts that by the year 2020, world consumption of electricity will increase by 50-100% from the level in 1990. The serious question is how to produce additional electricity in a sustainable way.

2. Energy supply system options

The criteria for choosing between different energy resources have become more complex. Environmental impact is becoming important in connection with global warming. Safety of operation, and reliability of fuel supply in view of national energy independence priorities are also factors. Economic competitiveness is a major commercial consideration but complex to determine accurately.

The IAEA has a particular role and the necessary expertise to assist Member States in making informed choices with regard to the energy mix they pursue by conducting objective comparative studies of nuclear power and other energy supply systems in terms of greenhouse gases emissions, risks and economic factors. The IAEA comparative studies programme includes: (1) energy demand analysis and supply options, (2) economic analysis, (3) health and environmental impact and risks of energy systems, and (4) sustainability of supply. The programme is being carried out in co-operation with eight international organizations: EC, ESCAP, EBRD, IIASA, NEA/OECD, OPEC, UNIDO, WMO.

3. Climate change concern due to heavy dependence on fossil energy

Today 87% of commercial global primary energy depends on fossil sources. These sources have a strong environmental impact through the release of noxious gases (SO_2 and No_x), toxic substances (heavy metals) and greenhouse gases (CO_2). Nuclear power and hydro-electric sources - with minimal environmental release - each contribute only 6% of global energy supply. At present one third of commercial primary energy is consumed in electricity generation - fossil fuels account for 63%; nuclear power 17%; hydroelectric 19%; and renewable systems less than 1% share. Most of the recently added global electricity generation capacity is fossil fuel and the expansion in the transportation sector is oil based. The WEC and IIASA middle economic growth scenario projection at the year 2050 is for more than a double increase in fossil fuel consumption and a continuing fossil dominance with 2/3 share of global energy, some 20% less than today.

The short term outlook is clearly for greater GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) reported that the atmospheric CO_2 concentration - which in pre-industrial times had a level of 280 ppmv - has risen to some 360 ppmv in 1995 and will reach 700 ppmv in 2100 in the mid-range emission scenario. This increase may cause an additional increase in surface temperature between 1° and 3.5° C . This climate change would be associated with a rise in sea levels of between 15-95 cm.

4. Kyoto Protocol

At the 3rd session of the Conference of the Parties to the UN Framework Convention on Climate Change (COP3, UNFCCC) in Kyoto, agreement was reached on an average cut in greenhouse gas emission by industrialized countries of 5.2% from 1990 levels between 2008 and 2012. The reduction targets are 8% for the EU, 7% for the US and 6% for Japan. There are similar targets for 21 other industrialized countries. These targets are legally binding for states that accede to the Protocol. The Protocol opened for signature in New York on 16 March. Seven countries have signed already including Argentina and Switzerland.

Past agreements show how difficult it is to achieve a reduction of CO_2 emissions. In 1988, the Toronto target was to reduce CO_2 emissions by 20% by the year 2005. However, since 1988, global CO_2 emissions have, in fact, increased by about 16%. In 1992 the Rio target for industrialized countries was to return to the 1990 level of CO_2 emission by the year 2000. In fact, between 1990 and 1995 US emissions increased by 6% and Japan's emissions rose by 12%, while Russia and Eastern Europe lowered their emissions by 30% due to industrial disruption. An IEA (International Energy Agency) study projects CO_2 emissions in 2010 to be in the range of a 36% to 50% increase above the 1990 level.

It was particularly disappointing that the Kyoto Conference did not make any explicit reference to nuclear power which currently produces 17% of electricity without emitting GHG. The Conference urged States to improve energy efficiency and to promote "new and renewable forms of energy" and "advanced and innovative environmentally sound technologies". While it may be assumed that many States view nuclear power as an indispensable part of their response, more work needs to be done to focus public attention on the serious issues involved.

5. The use of renewable energy sources to avoid GHG emissions

Clearly, greater efficiency and greater use of renewable energy sources such as solar, wind power, biomass and geothermal energy should be sought wherever feasible. Research and development is being carried out in industrialized countries on technological improvement of the application of renewable resources for electricity generation. However, solar photovoltaic and windpower are intermittent sources of electricity generation. They are not suitable for base-load electricity supply without the provision of expensive energy storage facilities or back-up supplier. Furthermore, the collection of energy from low energy density sources is inevitably expensive. The area needed by these sources for an electricity generation capacity of a 1000 MWe power plant is: 25-50 km^2 of solar cells, 50-150 km^2 of wind mills and 3000-5000 km^2 of biomass plantations. These figures give some indication of the high cost and the difficulties of utilising renewable resources for commercial electricity production, particularly when land values are high.

Firewood remains economically viable in many places to produce heat for cooking and home heating. Solar panels for hot water supply for families are used quite widely. Photovoltaic solar cells for electricity in distant places where building power lines is very expensive, is feasible. However, these growing "niche" roles for alternative energy resources will not significantly reduce the pressure for increased base-load energy production and it is difficult to imagine that these energy sources could be economically viable to meet the demand for such large-scale base-load electricity generation.

6. Environmental advantages of nuclear power in avoidance of GHG

Nuclear power with its low environmental impact can contribute substantially to the sustainable energy future. Nuclear power is a mature technology currently supplying 17% of the world's electricity to avoid emission of more than 2300 million tonnes of CO_2 annually (8% of global CO_2 emissions). CO_2 emissions per kWh produced by the full fuel chain of coal power technology is about 1300 g/kWh. By comparison, nuclear power fuel chain emissions are only 30 g/kWh (IAEA estimate). Burning natural gas produces less CO_2 than burning coal or oil. But leakages during extraction and pipeline transport, which are more than 5% in some areas, can offset much of this advantage since leaked methane is a more damaging GHG. Some natural gas chains, therefore, could have emissions similar to the coal energy chain. In Japan about 60% of electricity is generated by fossil fuel. In 1995, CO_2 emissions per kWh were 348 g/kWh. In France, more than 75% of electricity was generated by nuclear power and the emissions of CO_2 were 62 g/kWh in the same year (OECD).

A 1000 MWe coal power plant on average produces annually 6,000,000 tonnes of CO_2, 44,000 tonnes of sulphur dioxide, 22,000 tonnes of nitrogen oxides (noxious gases) and

320,000 tonnes of ash containing 400 tonnes of heavy metals. By comparison, a 1000 MWe nuclear power plant (NPP) in normal operation does not release noxious gases or other pollutants and produces annually only some 30 tonnes of high level radioactive spent fuel and 800 tonnes of low and medium level wastes.

These relatively small quantities and volumes permit an effective confinement strategy in which radioactive material and wastes are isolated from the environment. By contrast, the dispersion strategies for the disposal of large quantities of fossil fuel waste involve the environmental release of waste products and the shallow ground burial of solid waste containing toxic substances.

7. Economic competitiveness and energy security

The economic competitiveness of nuclear power is at present roughly on par with coal, and in some cases gas and oil, depending on fossil fuel prices in individual countries. Nuclear power has lost competitiveness with gas when used in a combined cycle in some countries. This competitiveness should be restored by better management, economy, engineering and operation in the whole nuclear fuel cycle.

However, the larger initial investments required for nuclear power plants are a drawback in capital-starved developing countries. But nuclear technology is relatively young and there is scope for rationalisation, standardization, modular construction, simplification and better fuel utilization which will bring higher efficiency and lower costs.

An important positive feature of nuclear power is the stability of supply of uranium fuel. Nuclear fuel can also be easily stored which offers a measure of energy independence to countries that do not have an abundance of energy resources, such as France, Japan, the Republic of Korea and others.

8. Future nuclear power strategies for better sustainability

The real limit to the operational life-span of a nuclear power plant is not technical but economic, since any component can be replaced. For newer reactors which became operational in the 1980s and later, economic operation for an average of 50 years is expected. Most plants now being ordered include an owner-specified operational time requirement of between 40 to 60 years. To meet the growing demand for electricity, advanced reactors will be introduced to replace retiring reactors and will probably dominate the market between 2015 and 2050.

The IAEA's International Symposium on "Nuclear Fuel Cycle and Reactor Strategies" (1997) projects that current known uranium resources are sufficient to cover nuclear power requirements for the medium economic growth variants up to the year 2050. However, these resources may not be sufficient to cover the years after 2050 for reactors existing in 2050. In this respect, recycling Pu in LWRs is a logical and prudent policy option.

In 1997, out of some 10,500 tons of spent fuel discharged from power reactors world-wide, 3,040 tons were reprocessed separating 23 tons of Pu, of which 9 tons were used for MOX fuel fabrication. The total civil-separated Pu inventory as of December 1997 is estimated to be 170 tons. In order to utilize this, Pu-thermal technology (Pu use as MOX fuel in thermal reactors) has become well-established and has been commercially used in Europe since the 1960s. There are 20 NPPs using MOX fuel mostly in Europe (Belgium, France, Germany and Switzerland). The total global number will increase to around 40 by the year 2000. The cost of electricity produced using MOX fuel is sufficiently competitive with that using uranium fuel. It is rational also for Japan to use Pu as MOX fuel as an interim measure to bring the recovery and recycling of Pu into better balance The use of Pu to reduce inventories is also desirable with respect to the non-proliferation of nuclear materials.

The development of fast reactor technology is expected to be continued for long-term energy security and global sustainable development by using Pu, particularly in countries where energy resources are limited such as Japan and France. Some important tasks for fast reactor development for commercial applications include the improvement of economic competitiveness and safety. The International Symposium on "Nuclear Fuel Cycle and Reactor Strategies" projected that the next 50 years will be dominated by thermal nuclear reactors (PWR, BWR and PHWR) and that these reactors will continue to play a significant role beyond the year 2050. Fast reactors are expected to be introduced gradually between 2030-2050. By

2050, it is likely that there will be a mixture comprising a large population of advanced thermal reactors with a small population of fast reactors which may grow steadily after 2050.

9. Non-electricity applications of nuclear energy

The utilization of nuclear energy for non-electrical purposes is an important part of a long-term energy strategy. The IAEA has been implementing a project on assessment of desalination of sea water by nuclear heat for Member States in arid and semi-arid regions. In Kazhakstan, a fast reactor plant has been safely used for desalination of sea water for quite a long time. Recent achievements of continuous hydrogen production by splitting at high temperatures (900°C) water at the laboratory scale in JAERI (Japan Atomic Energy Research Institute) may provide the technology for future economical production of H_2 by HTGR (high temperature gas cooled reactor). Hydrogen can be used for transportation such as hydrogen-fuelled automobiles and fuel cells. A high temperature test reactor of 30 MWt will be in operation this year at JAERI to make important milestones in the development of utilization of nuclear energy for non-electrical purposes.

10. Nuclear safety and enhancement of public acceptance

The nuclear power system - a mature and comparatively safe technology with an important contribution towards producing sustainable energy - is facing the risk of being undervalued or ignored. The future role of nuclear energy depends critically on improved public acceptance which requires, *inter alia*, a consistent, demonstrated record of safety in all nuclear applications and in the safe management of radioactive waste.

Safety is the responsibility of nuclear operators as regulated by national governments. The IAEA plays a fundamental role, but except in relation to our own Agency operations, we have no power to enforce - only to recommend, advise and assist. Our approach has been to seek to establish a global nuclear safety culture comprising: legally binding international agreements, non-binding safety standards and the provision of safety services.

In 1996 Member States adopted the Convention on Nuclear Safety which commits them to achieve and maintain high safety levels. They are obligated to meet international benchmarks in major areas of regulation, management and operation of nuclear power plants. An important feature is a peer review of national reports on steps which States have taken to fulfil their obligations. The final review meeting will be held in April 1999. As of the end of 1997, 41 countries are party to the Convention including nearly all States having nuclear power programmes. The IAEA also provides Member States extensive services for the application of safety standards through the Operational Safety Review Teams (OSARTs), the Assessment of Safety Significant Events Teams (ASSETs) and the Assessment of Safety Culture in Organizations Teams (ASCOTs). They are the best practical way for safety culture to penetrate borders.

The Joint Conventions on Safety of Spent Fuel Management and on Safety of Radioactive Waste Management was adopted in September 1997. This covers applications in the civilian sector and obliges parties to take appropriate steps for ensuring the safe and environmentally sound management of radioactive waste and spent fuel, and for preventing accidents. In 1997 26 States signed the Joint Convention. One State (Norway) ratified it.

The IAEA will strengthen nuclear safety assurance in Member States through: (1) the development of national safety profiles covering radiation protection, waste safety and safety of nuclear installations; (2) raising safety problems with relevant Member States for them to remedy shortcomings with possible agency assistance; (3) more actively promoting our safety services; (4) more effective use of the Annual Nuclear Safety Review; (5) strengthening of the interaction with the nuclear safety community.

In addition, it should be recognized that a quantum improvement in safety can be achieved through the upgrading of safety features of nuclear reactor and fuel cycle installations by improving technology and engineering within the framework of improved safety culture in Member States.

11. Waste disposal management

To date no long-term disposal site has been licensed in any country. Deep underground geological formations which have not been disturbed for many millions of years are being considered. Solid domes or graphite tunnels several hundred metres below the surface are impervious to water ingress, which is the potential mechanism for material transport to the surface environment. Several barriers prevent the release of radioactive disposal material: the canisters containing the vitrified waste; surrounding clay backfill, and; the solid host material. Even if radioactive material were to escape from man-made barriers, the long path through the host rock to the surface would most probably ensure sufficient dilution so as to pose little risk to human health. However, these disposal techniques are blocked not by technical, but by political obstacles.

12. Non-proliferation

It is of public concern that the wider use of nuclear power might increase the risk of the further spread of nuclear weapons. However, it should be recalled that nuclear weapons development consistently preceded - and did not follow from - the introduction of nuclear power reactors. The risk of further States acquiring nuclear weapons exists, but it is only marginally affected by an expanded use of nuclear power. Furthermore, the IAEA safeguards system has been strengthened to cover both declared and undeclared activities through Protocols Additional to Safeguards Agreements.

The priority now is to sustain and build on the present momentum towards the conclusion of Additional Protocols. Eight States have now signed, and there has been encouraging progress in recent consultations with key countries, including members of the European Union, Japan, Canada, as well as the United States. Agreement has been reached on the new Protocols with members of the European Union, Euratom and the IAEA which will be submitted to the IAEA Board of Governors for approval in June. The conclusion of all Additional Protocols by the end of the year 2000 is not an unrealistic goal.

13. Nuclear techniques for a better life and sustainable development

Application of isotopes and radiation technology has proven to have a large potential to contribute to sustainable development and basic human needs including, *inter alia,* food security, agriculture, water resources management, human health, environmental protection, and industry. One of the most important roles of the IAEA is to promote these applications and to transfer them to developing countries.

Recognizing that 850 million people suffer from chronic malnutrition, the IAEA's food and agriculture programmes, operated jointly with FAO are contributing to increasing food production in a sustainable way. The programmes encompass mutation breeding, soil fertility and crop production, animal production, food irradiation and insect pest control using nuclear technology. One example of the many success stories is the eradication of the tsetse fly in Zanzibar Island (Tanzania) in 1997 using the Sterile Insect Technique with radiation. The success of this programme will greatly improve livestock production.

Nuclear technologies are making considerable contributions in the field of human health. The IAEA's programmes cover radiotherapy of cancer, nuclear medicine for early diagnosis and monitoring nutritional status in developing countries. One recent successful example in Tunisia is early screening of neonatal hypothyroidism (thyroid disorder of new born babies) using radioimmunoassay to avoid cases of serious mental retardation.

Deterioration of the environment is a serious global concern. Nuclear based analytical techniques are used to monitor concentration and behaviour of pollutants. The IAEA Marine Environmental Laboratory is monitoring radioactivity and non-radioactive pollutants in the marine environment. Radiation technology can clean gaseous and liquid wastes. In Poland, for example, the IAEA has a large ongoing Model Project to clean flue gases from power stations burning coal which is the only major energy resource.

14. Transfer of beneficial nuclear techniques for development

A number of developing countries, currently 95, have benefited from IAEA technical support programmes amounting to some US$ 800 million over the past 40 years. These technical co-operation activities are now aimed at producing greater social and economic benefits in agriculture, human health, environmental protection and industry. Additional important support is to assist developing countries to build their research capacity through the IAEA's research contract programme.

The thrust of the IAEA technical co-operation programme is to becoming a partner in national development for connecting technology to end users. The IAEA is not a "development" organization, and it has no large pool of funds. Technical cooperation projects must meet certain criteria: they must respond to priority national and regional needs; produce sizeable economic and social impacts; employ nuclear technologies only where they have distinct advantages, and; attract strong government commitment.

Priority fields for the TC programme are applications in agriculture and food, health, water resource management and industrial development, and strengthening radiation protection and waste management infrastructure. Nuclear power application is not yet a high priority programme in the majority of developing countries. Only 19 countries out of 95 have NPPs in operation or under construction.

Conclusion

It should be recognized that the current and future use of nuclear power can make a major contribution to the reduction of greenhouse gases and that nuclear power is cost-competitive with fossil fuels, in particular coal. In addition, as a cost-free by-product, nuclear power curtails deterioration of local air quality and regional acidification problems due to sulphur dioxide and nitrogen oxides. Public concerns about nuclear safety, waste disposal and the risk of proliferation of nuclear weapons are important factors in the future of nuclear energy. They need to be fully addressed by the nuclear community and particular should be given to objectively informing the public of the realities of nuclear power- risks and results - compared to other energy options. Perhaps public opinion will eventually understand that the options are limited and the nuclear option is effective and feasible for sustainable development.

SESSION 1

GLOBAL WARMING AND GLOBAL ENERGY AFTER KYOTO

A Keynote Address to the 31st Conference of the Japan Atomic Industrial Forum, Inc. Tokyo, Japan - 20 April, 1998

by

Michael Jefferson
Deputy Secretary General
World Energy Council

Introduction

The timing of this talk could have been better. Twelve years on from Chernobyl, Japan's nuclear industry has had a troublesome couple of years. We are four months on from the Kyoto Conference, where the intellectual level of debate was heightened by demonstrators with placards declaiming "No Fossil Fuels; No Nuke". I am still not sure whether that message was aimed at the 34% of us in the world's population that have no commercial energy services, or the 6% of electricity derived from hydropower and new renewable sources.

Meanwhile, last month saw oil prices fall to their lowest level for 25 years. This is not the most propitious moment for the promotion of alternative fuels and measures to mitigate climate change - assuming that human activities are changing global climate.

According to the IPCC's Second Assessment Report, published in 1996, the balance of statistical evidence now points towards a discernible human influence on global climate. The UN Climate Convention of 1992 states, in Article 3 (Principles), that cost-effective precautionary measures should be taken, regardless of lack of full scientific certainty about the attribution of global climate change to human activities, so as to ensure global benefits at the lowest possible cost.

The Climate Convention also states that the developed country Parties to the Convention should take the lead in combating climate change and the adverse effects thereof. These Parties, the so-called Annex I Parties, committed themselves to the aim of returning their anthropogenic emissions of carbon dioxide and other greenhouse gases to their 1990 levels by the year 2000.

By the time of the Kyoto conference in December, 1997 the industrialised countries had done little to meet these commitments **(charts 1 and 2)**. Indeed, on their current trajectory not even the EU-15 Member Countries will achieve that aim in aggregate, so far as CO_2 emissions are concerned, by the year 2000 **(chart 3)**. Yet the EU-15 seem relatively better placed than the USA, Japan or the OECD as a whole in terms of anthropogenic CO_2 emissions out to 2000 and 2010 under recent trajectories **(chart 4)**.

At the Third Conference of the Parties to the UN Climate Convention most Annex I (or should we now call them Annex B?) Parties agreed to cuts (or claimed limitations) in their emissions out to 2008/2012 for six gases **(chart 5)**. Various provisions were also made for net changes in emissions due to land-use and forestry changes, which can make a huge difference to the position for some countries - such as Australia, New Zealand and Finland. Thus Kyoto complicated matters by introducing allowances for absorption of CO_2 by reversal of forest clearance and agricultural soil changes; and by the inclusion of methane, nitrous oxide, HFCs, PFCs, and SF_6. A wide range of activities outside the energy sector come into play - agricultural, industrial, waste handling and disposal, and the use of solvents and certain other products. The particular contribution that the energy sector will be expected to make towards reducing overall anthropogenic greenhouse gas emissions has become more difficult to discern. What the Kyoto protocol is clear about is that the countries forming its Annex B list are expected to reduce their emissions between 1990 and 2008/2012 by the carbon dioxide equivalent of 5.2% in aggregate. Variations within that aggregate range from +10% to -8%, although in fact the leeway granted to Australia is much greater than +8%. For the economies in transition, their commitments of 0 to -8% need to take account of reductions in CO_2 emissions amounting to over 30% between 1990 and 1996 - for reasons having nothing to do with seeking to mitigate climate change.

<u>The Results of Kyoto</u>

The Kyoto protocol is intended to place legally binding commitments on the Parties to it. No government delegation in Kyoto on 11 December, 1997 opposed the final passage of the protocol in the Committee of the Whole or in the Plenary Session. The protocol is open for signature from 16 March, 1998 until 15 March, 1999; and becomes open for accession the following day. The protocol will only enter into force 90 days after not less than 55

Convention Parties, incorporating Annex I Parties which accounted for at least 55% of total Annex I CO_2 emissions in 1990, have ratified.

Probably the biggest single question is: will the USA ratify? The USA contributes some 25% of the world's anthropogenic CO_2 and total greenhouse gas emissions; and, depending upon the basis of the calculation, around 38% - 42% of Annex I CO_2 emissions in 1990. The US Senate in June, 1997 submitted a Resolution stating that the USA should not be a signatory to any protocol which mandated new commitments for Annex I Parties without new, specific scheduled commitments to limit or reduce greenhouse gas emissions to developing country Parties within the same time - period; or which would result in serious harm to the US economy. That Resolution was passed 95 votes to 0 the following month. In Kyoto, the only Article which provided for non-Annex I Parties to take on additional emissions limitation undertakings was gavelled out. Thus the first ground of US Senatorial concern was rejected at Kyoto (arguably in compliance with the Berlin Mandate governing the Kyoto proceedings). The second ground was not addressed by governments in Kyoto, although it was a central focus for some US industry and trades union lobbyists.

The more innovative elements of the Kyoto protocol are:

- some rather general references to enhancing energy efficiency, promoting new and renewable forms of energy, phasing out fossil fuel subsidies, limiting aviation and marine transport emissions, etc. under Article 2. There is no reference to specific policies and measures, nor to nuclear power, in this Article;
- establishment in principle of Joint Implementation with credits between Annex I Parties under Article 6;
- establishment of "a clean development mechanism" through which projects between Annex I and non-Annex I Parties resulting in certified emissions limitations will hopefully occur, under Article 12; and
- provision for emissions trading between Annex B Parties under Article 17.

The widespread indifference of energy consumers towards global climate change, means it is difficult to introduce effective policy measures. This makes it extremely doubtful whether the generalities of Article 2 will be readily translated into action. Energy consumers are the customers of businesses, which in turn means that the ability of businesses to innovate in order to mitigate climate change is severely constrained. Furthermore, although Articles 6, 12 and

17 are potentially interesting and offer opportunities for business initiatives, they are and should remain subordinate to domestic actions. JI projects and trading should also be specifically linked to, and result in, emissions reductions.

There is concern that trading in "hot air" resulting from past emissions reductions - unrelated to climate change mitigation measures - would do little to reduce global emissions. Overall, there is concern that the Kyoto protocol does nothing directly to enable immediate mitigatory policies and measures to get under way, and yet it expects demonstrable progress to have been made by 2005.

The Kyoto protocol is also defective insofar as it prolongs an earlier failure of climate change negotiations, the short-term focus on targets and timetables, and both postpones important questions for later resolution and opens up potential loopholes. The WEC's Statement to the Kyoto Conference expressed once again our belief that: "The longer action is delayed the higher is likely to become the cost of abatement and adaptation".

A Modest Step Forward, Maybe

In terms of annual CO_2 equivalent emissions, atmospheric CO_2 concentration and implications for global mean surface temperature the outcome of Kyoto in itself is neither here nor there by 2100 **(charts 6-8)**. Even if Annex I Parties were to reduce their emissions 1% per annum between 2010 and 2100 the impact is modest. The Kyoto protocol is therefore, assuming it is ratified and successfully implemented, only a small first step.

If we compare the WEC/IIASA scenarios[1], noting that Annex I countries remain far adrift from the emissions trajectories of the Ecologically Driven Scenarios (C_1 and C_2), it will be seen that the Kyoto outcome is well below the current emissions trajectories of Annex I Parties (which have broadly followed the High Growth A Scenarios since 1990 - excepting the transitional economies and two or three EU-15 countries). Moreover, non-Annex I Parties' emissions are rising so rapidly as to make Kyoto scarcely relevant on the future global emissions scale **(chart 9)**.

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[1] World Energy Council/International Institute for Applied Systems Analysis: "Global Energy Perspectives to 2050 and beyond", 1995 and updates. A future report, published by Cambridge University Press, will be issued to coincide with the 17th WEC Congress in Houston, Texas, in September, 1998.

Even taking account of the scope for carbon offsets permitted under the Kyoto protocol, the net outcome has only modest impact by 2010 **(chart 10)**.

WEC/IIASA scenarios indicate that only the two Ecologically Driven scenarios and a High Growth "bio-nuc" scenario (A_3) produce relatively low annual CO_2 emissions out to 2100 **(chart 11)**. These are also the only scenarios which result in atmospheric CO_2 concentrations by 2100 less than double pre-industrial levels **(chart 12)**.

More Robust Routes Forward

Past analyses by WEC have pointed to:

- a continuing reliance on fossil fuels for many decades to come, with the current world's 76% reliance on the fossil fuels only gradually declining;
- the plentiful geological resources of fossil fuels, although in practice supply disruptions could occur - especially if vulnerabilities increase due to higher import dependency and lengthening supply lines;
- potential technology, financial and environmental constraints on the fossil fuels;
- price uncertainties;
- a clear need to expand non-fossil fuel supplies; and,
- the huge scope for raising the efficiency of supplying and using energy services.

What reliance the world will place upon individual fuel sources in future is clearly uncertain and, in our view, most usefully considered by developing internally consistent alternative scenarios. The lower the level of global energy consumption over the next century, perhaps largely due to successful efforts to raise efficiency and encourage conservation, the less the need to develop and use alternatives to the fossil fuels. In such an evolution it will also be easier for new renewable energy resources to contribute a large share of the primary energy supplies required.

If human-induced climate change is taken seriously, and it is believed that large volumes of carbon potentially emitted cannot satisfactorily be stored at acceptable cost (down depleted oil and natural gas wells, for instance), then only three of the WEC/IIASA scenarios meet the criteria required: A_3, C_1, and C_2. Two of these scenarios indicate that nuclear has an expanding future. **Tables 1** and **2** indicate the role nuclear power is assumed to play in the six WEC/IIASA scenarios.

However, there will be numerous challenges and hard choices ahead. It is not clear how and by which technologies the current problems facing nuclear energy may be resolved, and our scenarios reflect the wide span of possibilities.

Conclusions

Perhaps one of the greatest challenges over the next two or three decades is to avoid closing options and to open up new ones for achieving sustainable development. The danger is that because of public concerns about nuclear power's operational safety, waste disposal and proliferation, the nuclear option may get blocked off or wither on the vine.

The WEC's 16th Congress in Tokyo in 1995 concluded, so far as nuclear was concerned:

> **Further development of nuclear technology for the full energy cycle appears to be needed if nuclear power is to make a major contribution to longer-term energy needs. Without public confidence in this technology there must be doubts as to the role nuclear energy can play.**
>
> **Over the next 30 years a much wider range of energy forms will be required to satisfy the world's increasing global demand. In addition to fossil fuels, these will include publicly acceptable nuclear development and those forms of new renewable energy which can be made viable.**

But if nuclear is to play its full role then more than changes in technology will be required. The WEC's Message for 1997 referred to the need not only to secure high safety performance, good operating practices and the safe management of nuclear waste, but also the need to ensure that facts are communicated successfully and are comprehended by the general public. This in turn will require a transparency, and a readiness to admit past failures (and present ones whenever they arise), which sometimes seems alien to an industry born out of a military defence psychology where secrecy was a requirement. Each time news is released of past problems or present failures, the prospects for nuclear power suffer some setback. The greater the success in keeping such past events secret, the greater the damage done to nuclear's future credibility when such secrets are eventually revealed. The more often there is evidence that the industry, or its operators, remain less than open when mistakes or accidents occur the greater the public concern aroused.

Thus the desirability of keeping the nuclear option open needs to be set within a framework of transparency and the broadest perspective of requirements for sustainable development. The WEC's 1995 Congress recommended that:

> **governments, business decision makers and energy consumers be urged to start taking action now to adapt to the needs of our longer term future. It is not just in response to the risk of climate change that 'minimum regret' measures based on the precautionary principle are required.**

This is not the point in human history when nuclear power should be consigned to the white elephant's graveyard. There are many hard choices lying ahead, and premature closure of the nuclear option is liable to make them much harder still.

Changing global climate may prove to be the single biggest reason for facing up to the future and the decisions which need to be made. But in itself the Kyoto conference did not advance the world much along the path of decision-making.

We are now six years on from the adoption of the UN Climate Convention. Six years have almost passed since the Rio Earth Summit, where 154 country governments and the European Community signed up to the Convention. The lack of real progress since then in curbing anthropogenic greenhouse gas emissions must be deeply disturbing to anyone genuinely concerned that human-induced global climate change may be occurring.

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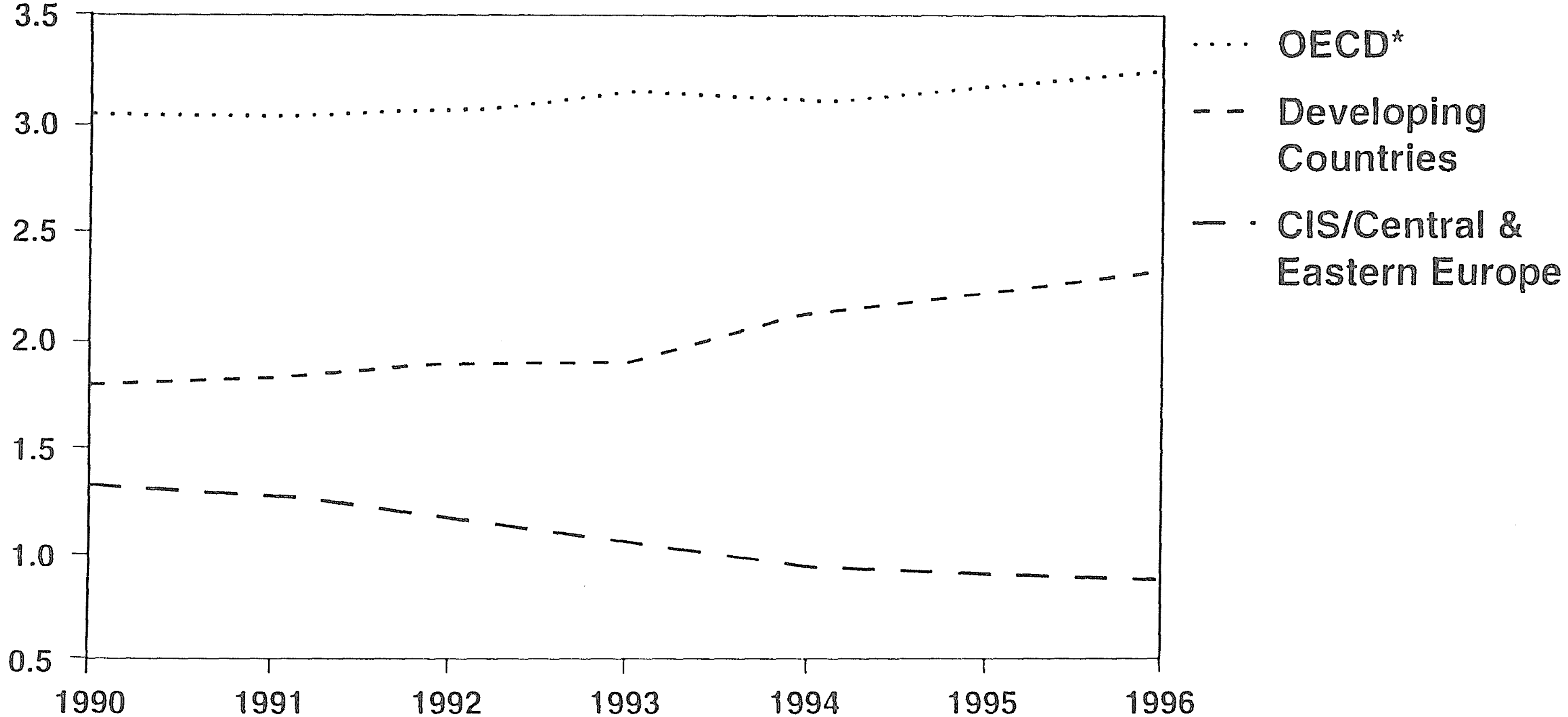
34/word/jmj/jmjspeec/JAIFconf.doc
JMJ/ddb:01.04.98

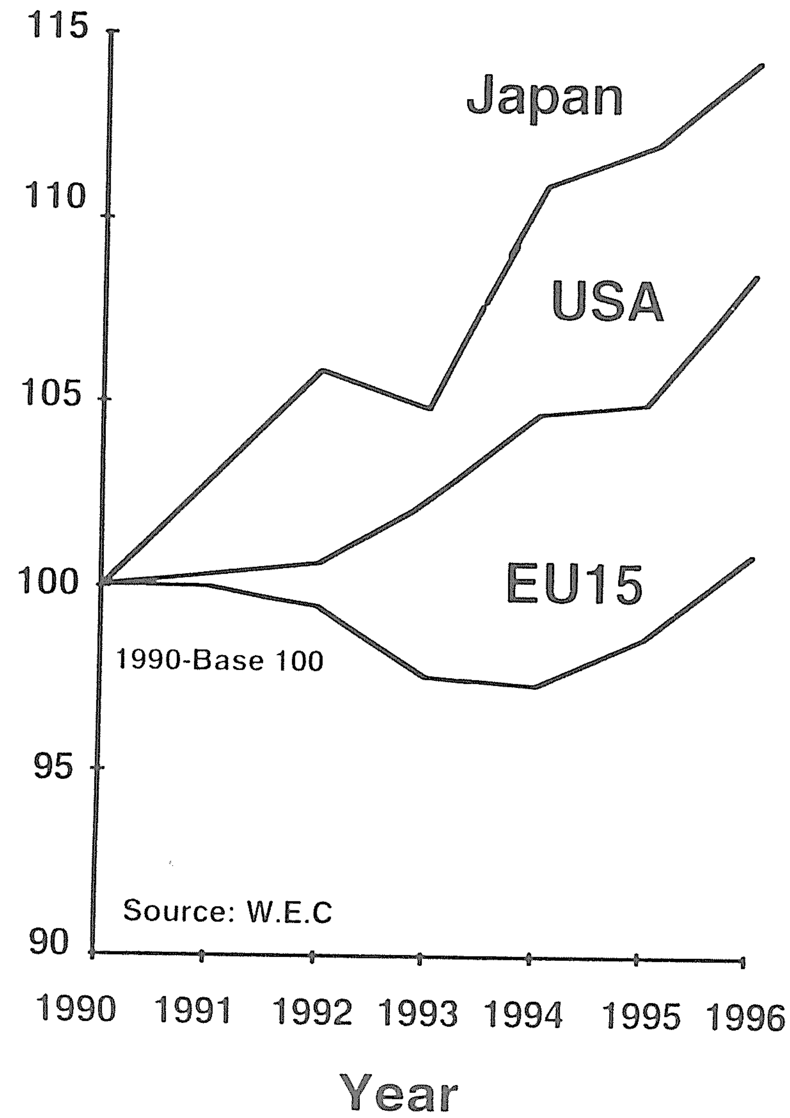
CO_2 EMISSIONS FROM FOSSIL FUEL COMBUSTION
(Gigatonnes of Carbon)



*Excluding Mexico, Korea, (Republic of), Hungary and Poland

CHART 2

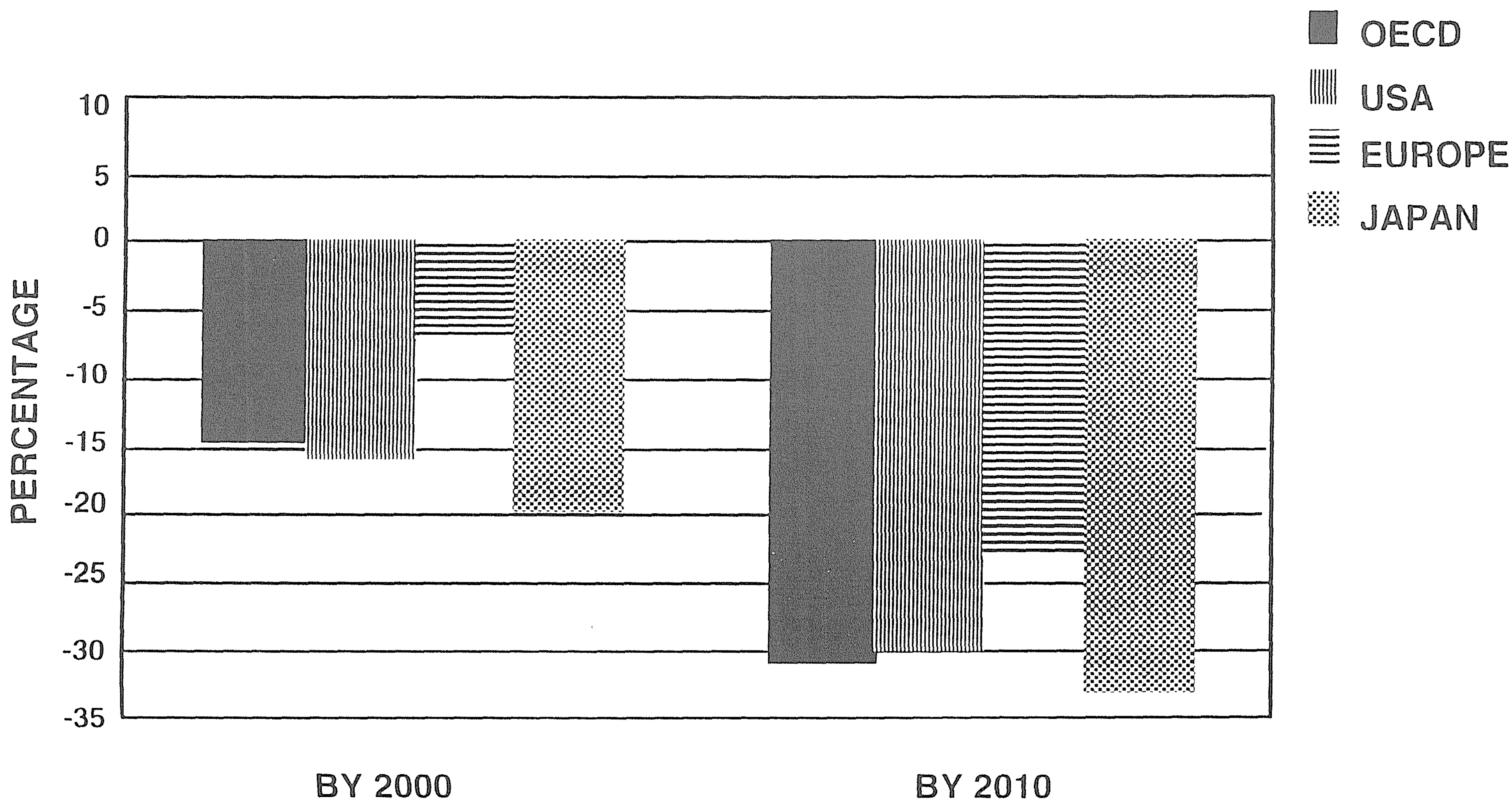
CARBON EMISSIONS



INCREASE IN EU-15 CO_2 EMISSIONS FROM FOSSIL FUEL COMBUSTION 1990-2000 ON RECENT TRAJECTORIES (%)

Austria	+	6
Belgium	+	20
Denmark	+	30
Finland	+	11
France	+	5
Germany		0
Greece	+	24
Ireland	+	15
Italy	+	5
Luxembourg	-	7
Netherlands	+	15
Portugal	+	50
Spain	+	18
Sweden	+	15
U.K.	+	3
Total	+	7

ANNEX 1 CO_2 EMISSIONS CHANGES REQUIRED TO RETURN TO 1990 ON RECENT TRAJECTORIES OF FOSSIL FUEL USE

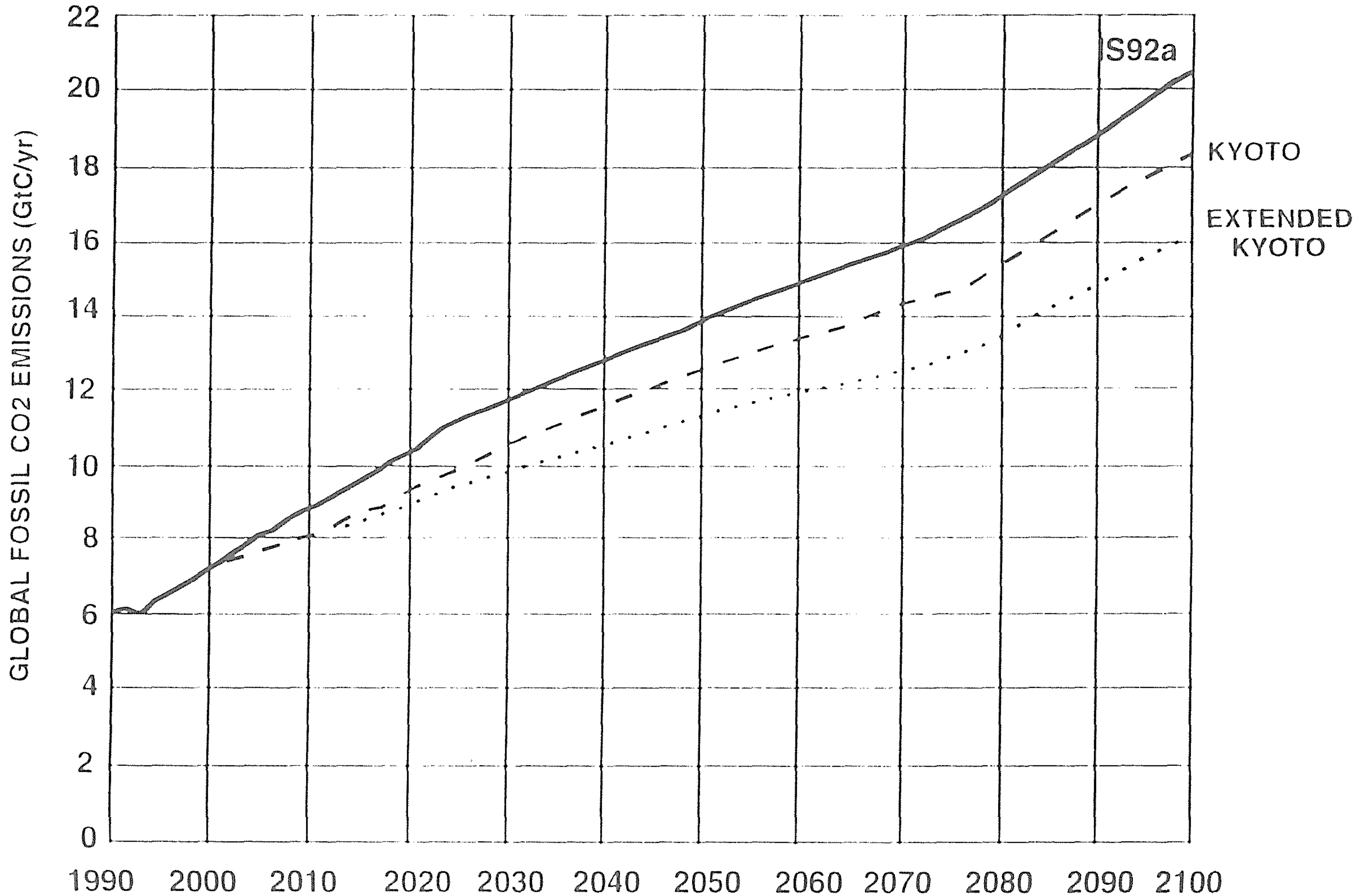


KYOTO EMISSIONS LIMITATION OR REDUCTION COMMITMENT BY 2008/2012 (%)

Australia	+ 8
EU-15	- 8
Canada	- 6
Japan	- 6
New Zealand	0
Norway	+ 1
Iceland	+ 10
USA	- 7
Russian Fed/Ukraine	0
Hungary/Poland	- 6
Croatia	- 5
Other C&E Europe	- 8

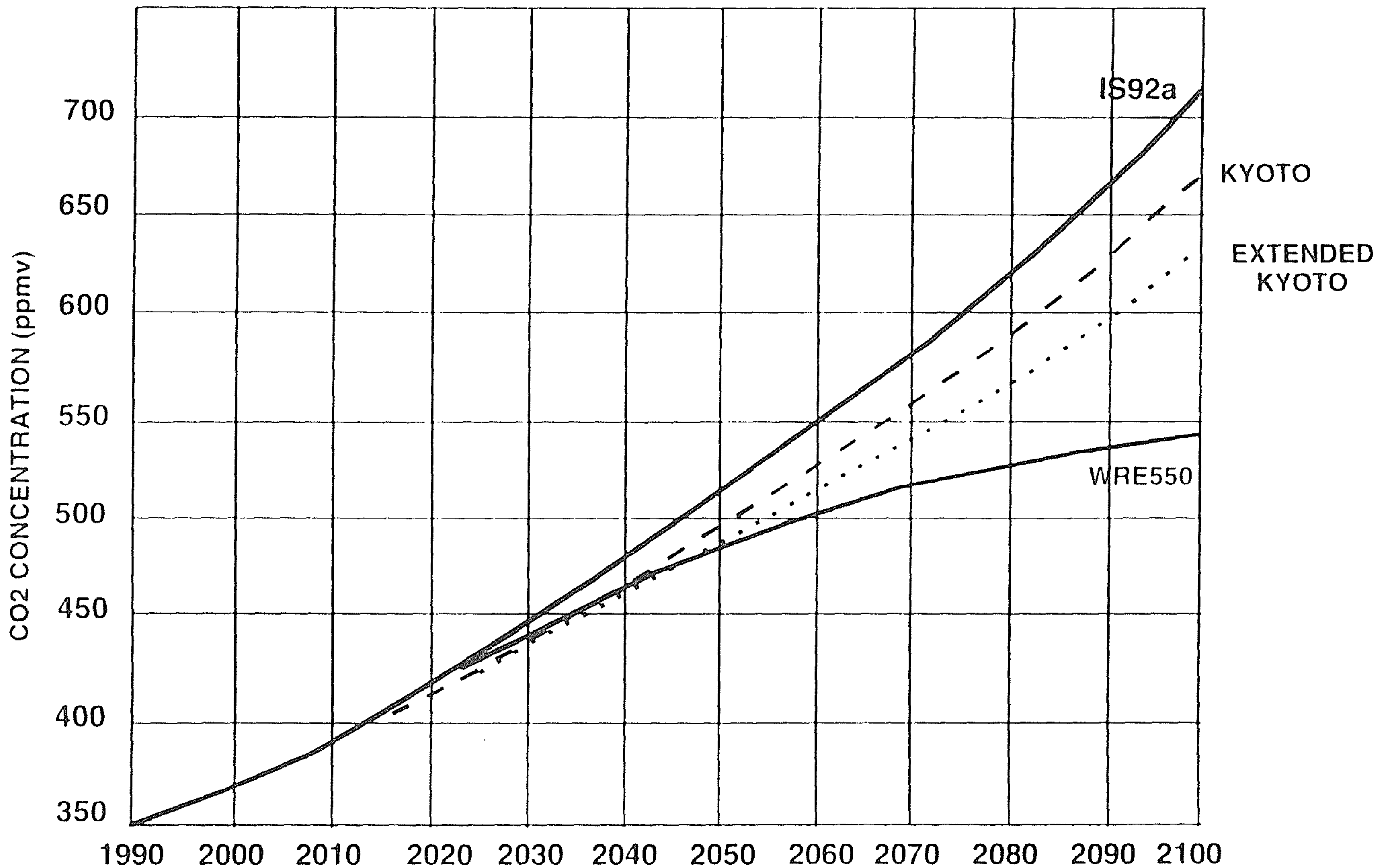
CHART 6

FOSSIL CO_2 EMISSIONS: IS92a, PROTOCOL & EXTENDED PROTOCOL



Source: T.M.L. Wigley
Note: Kyoto = Annex I Parties emissions constant after 2010
Extended Kyoto = Annex I emissions decline 1% p.a. compounded 2010-2100

FOSSIL CO_2 EMISSIONS: IS92a, PROTOCOL & EXTENDED PROTOCOL

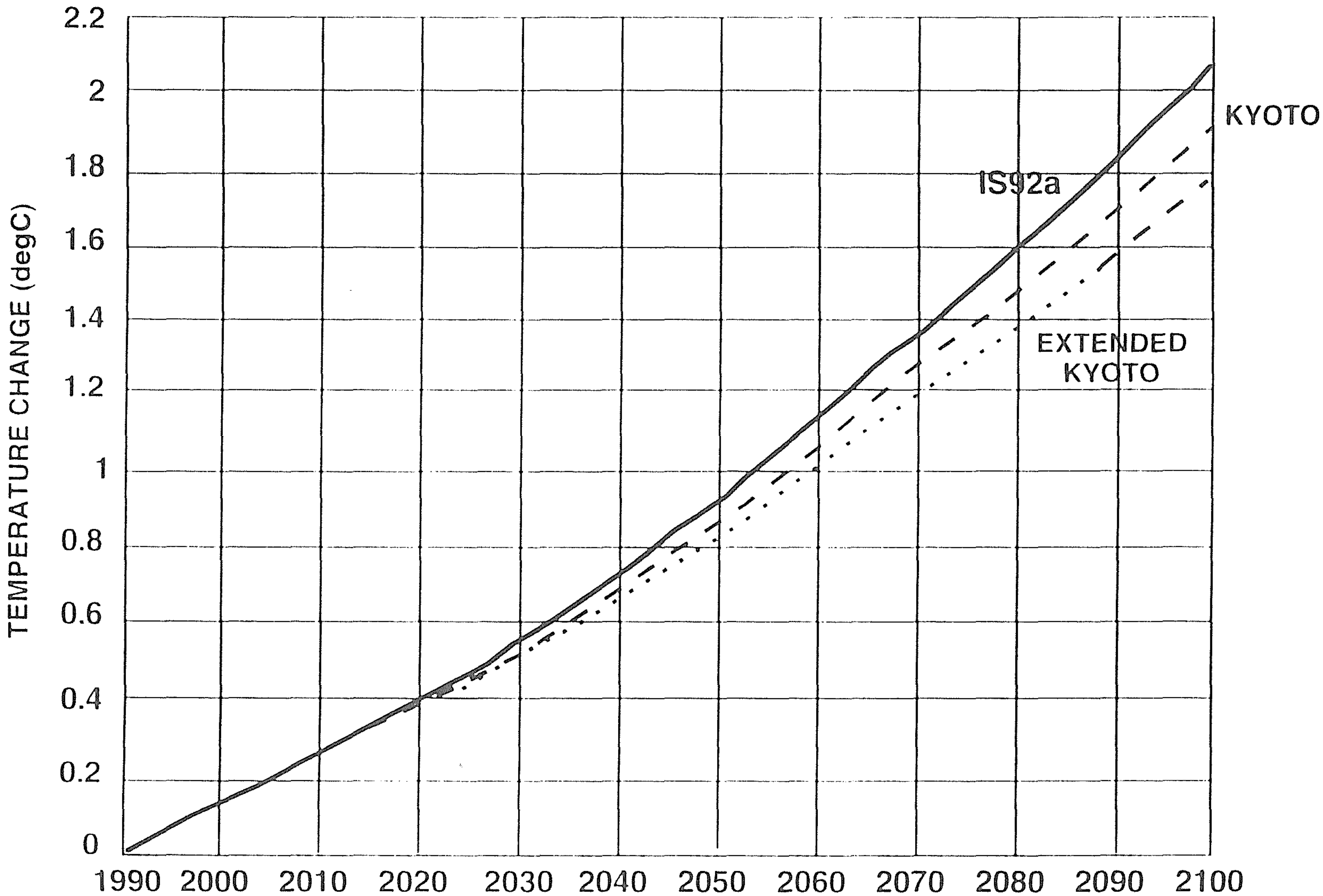


Source: T.M.L. Wigley

Note: Kyoto = Annex I Parties emissions constant after 2010

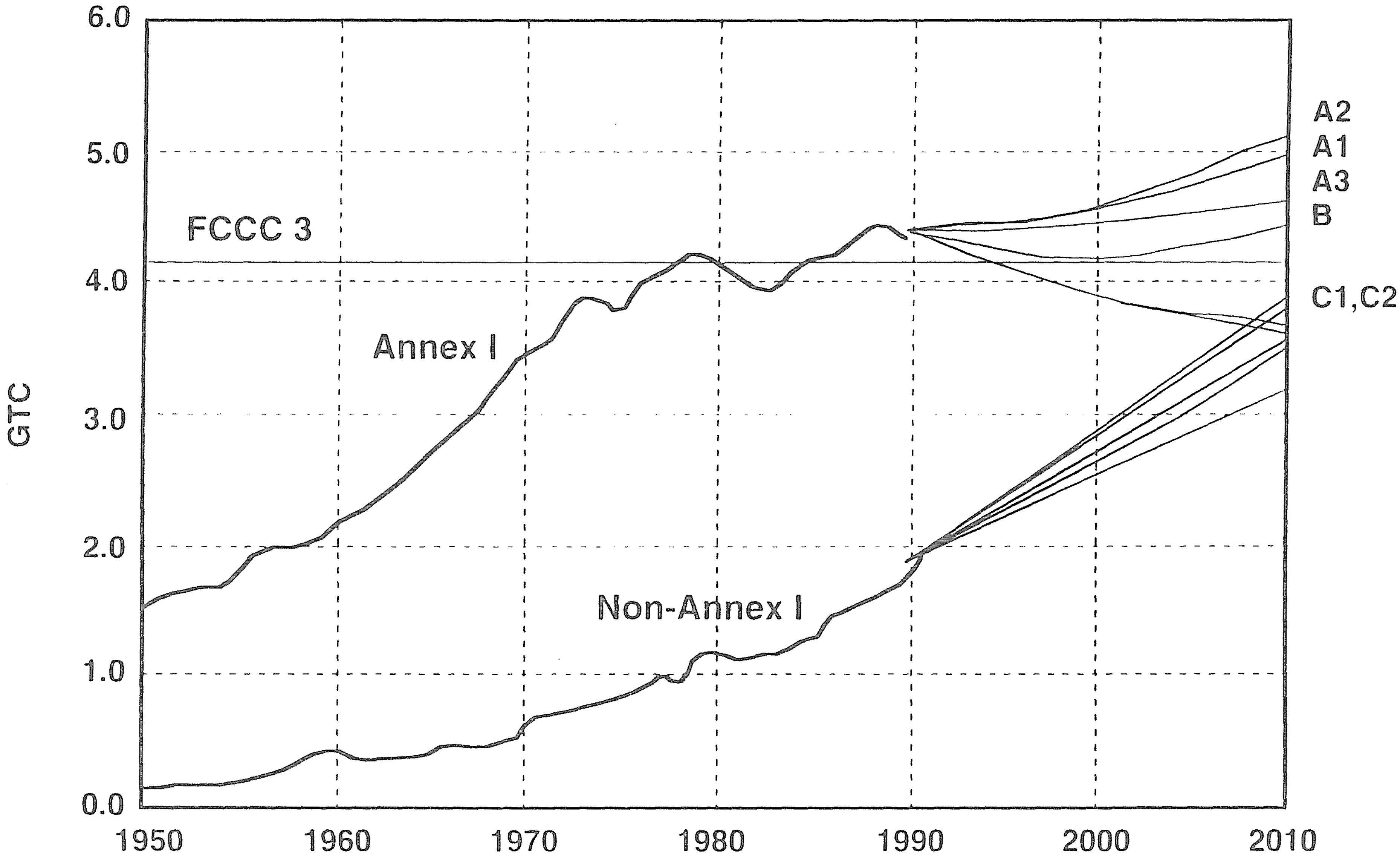
Extended Kyoto = Annex I emissions decline 1% p.a. compounded 2010-2100

GLOBAL MEAN TEMPERATURE: EFFECT OF PROTOCOL

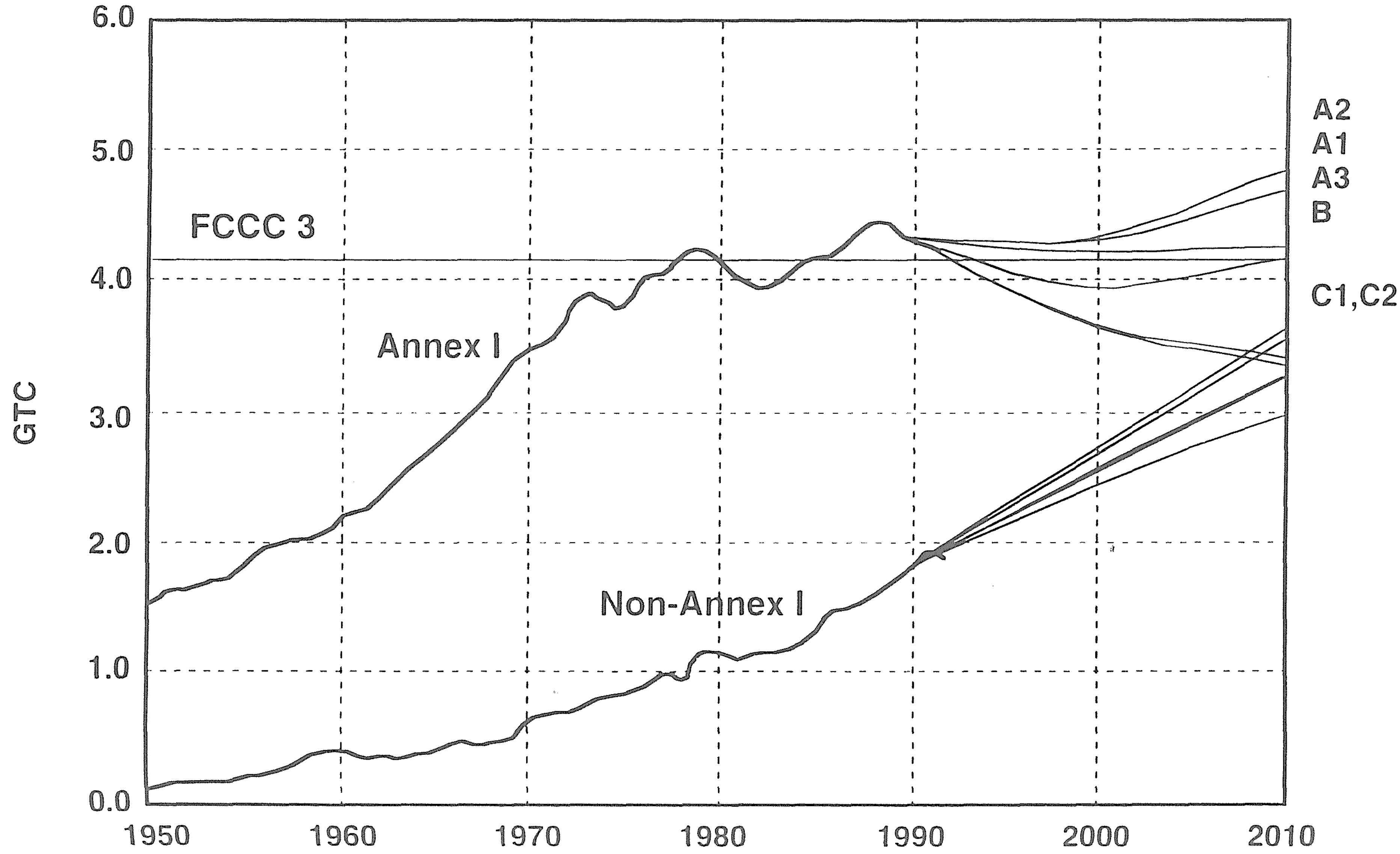


Source: T.M.L. Wigley
Note: Kyoto = Annex I Parties emissions constant after 2010
Extended Kyoto = Annex I emissions decline 1% p.a. compounded 2010-2100

ENERGY RELATED CO_2 EMISSIONS (Gross)



ENERGY RELATED CO_2 EMISSIONS (Net)



GLOBAL ENERGY-RELATED CARBON EMISSIONS, 1850 TO 1990, AND FOR THREE SCENARIO FAMILIES TO 2100, IN GtC

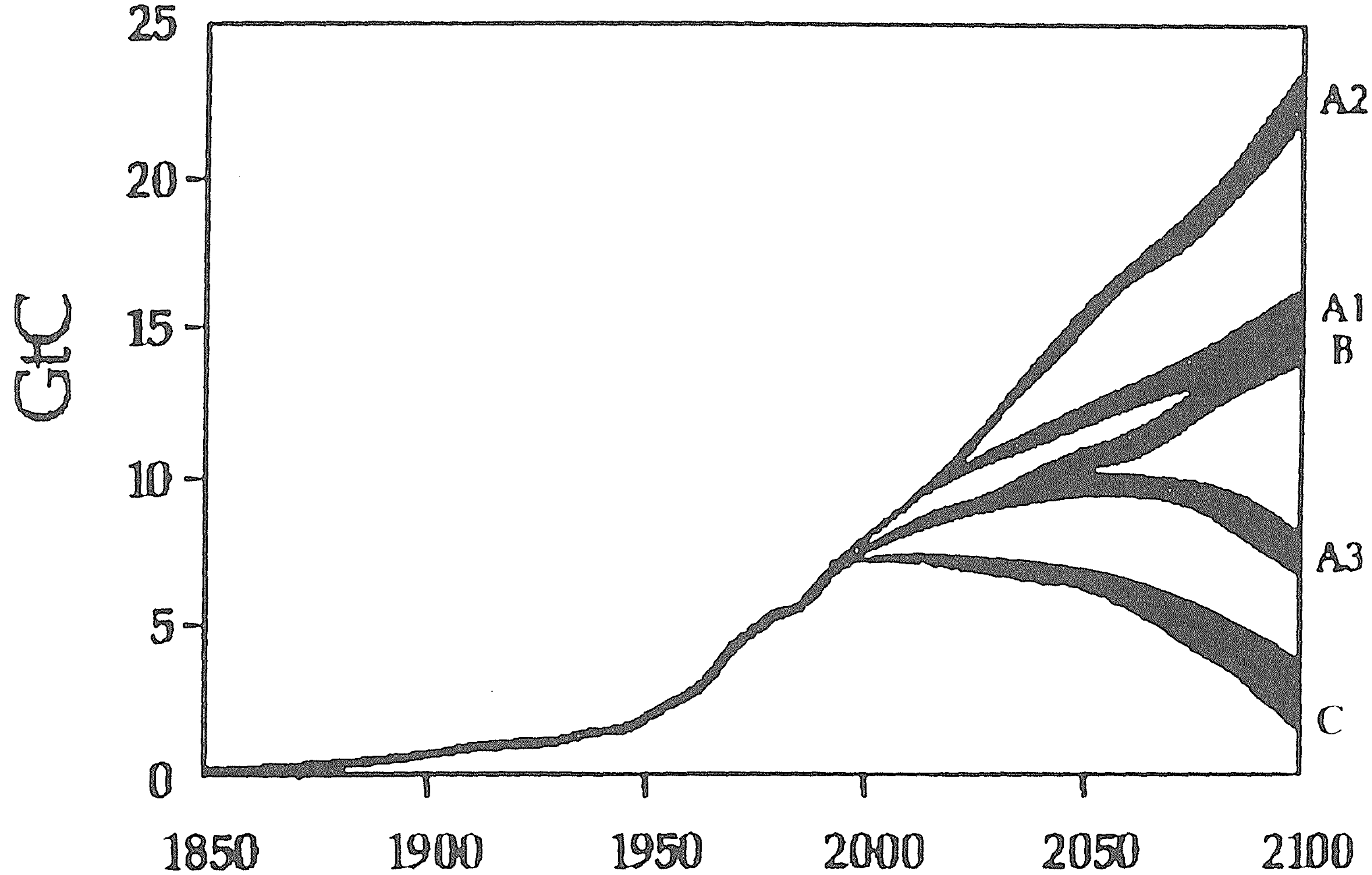
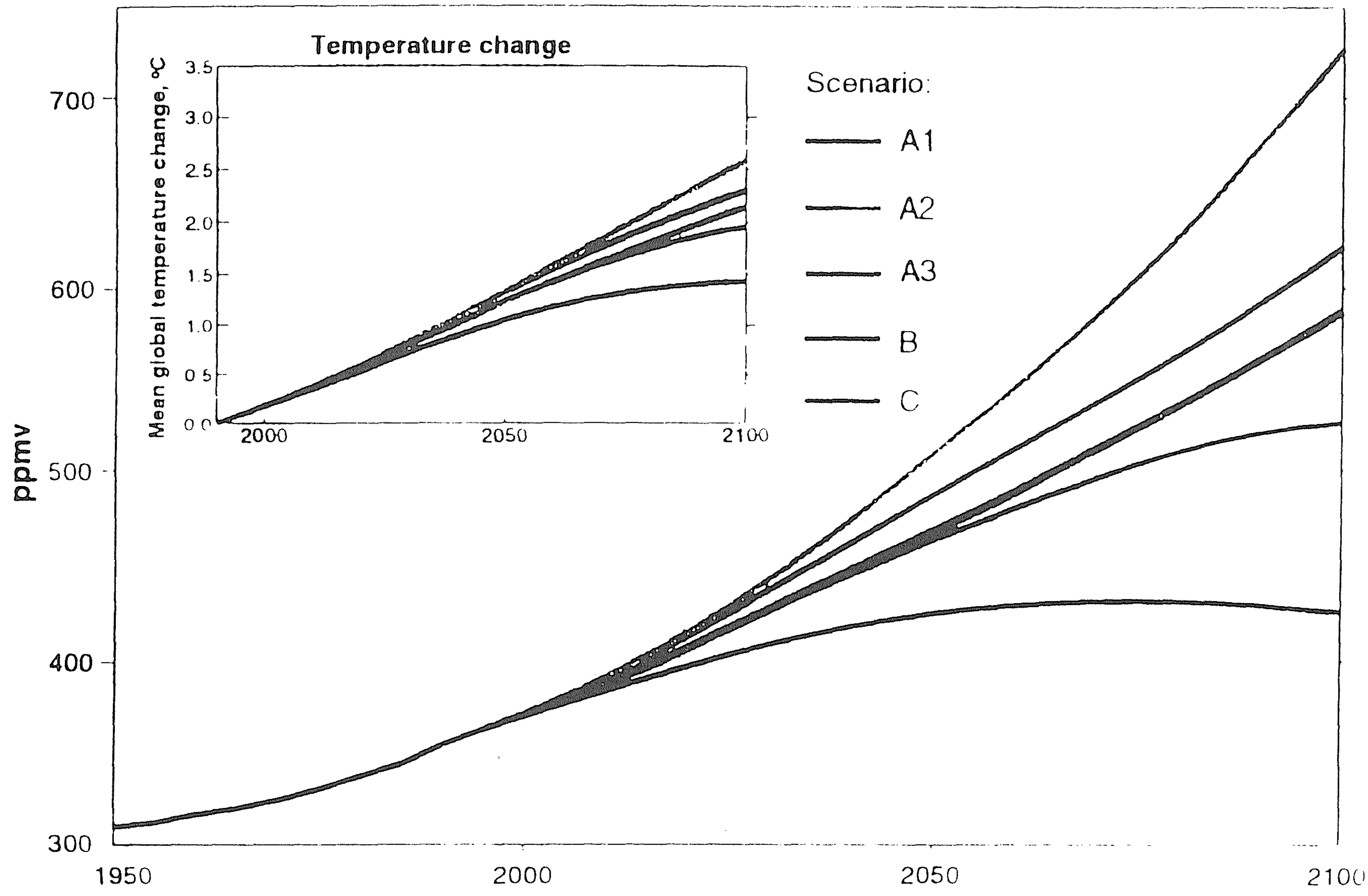


CHART 12

CO_2 CONCENTRATIONS (ppmv), 1950 TO 2100



Nuclear Capacity (1990 = 357 GWe)

	SCENARIO					
	A1	A2	A3	B	C1	C2
2020	646	417	732	645	480	605
2050	1875	782	1860	1915	380	1240
2100	3680	6415	6725	5700	-	2750

TABLE 2

Nuclear Capacity as % Global Electricity Generating Capacity

	SCENARIO					
	A1	A2	A3	B	C1	C2
2020	15	10	17	18	15	19
2050	25	10	23	31	7	25
2100	24	37	39	42	0	31

31st JAIF Annual Conference

20-22 april, 1998, Tokyo, Japan

NUCLEAR POWER AND GLOBAL WARMING

by

Luis Echavarri, Director-General, OECD Nuclear Energy Agency

Introduction

Environmental issues, and in particular global warming, are becoming more and more important factors in policy-making for the power sector. At the third meeting of the Conference of the Parties (COP-3) to the United Nations Framework Convention on Climate Change (UNFCCC), that was held in December 1997 in Kyoto, decision-makers agreed on provisions for reducing GHG emissions. A key provision of the Kyoto Protocol [1] is that Annex I countries (i.e., essentially OECD countries) shall, individually or jointly, reduce their emissions according to country-by-country targets with a view to reducing their overall emissions by 5.2 per cent below 1990 levels in the commitment period 2008 to 2012.

The energy sector, from primary energy extraction to end-use, is one of the main sources of greenhouse gas (GHG) emissions, in particular carbon dioxide (CO_2), that raise concerns because of the potential risk of their inducing global warming and climate change. The carbon dioxide emissions related to energy use are estimated to represent some 75 to 90 per cent of the anthropogenic CO_2 emissions. Therefore, another provision of the Kyoto Protocol is that Annex I countries shall undertake promotion, research, development and increased use of new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies.

Nuclear energy, which is essentially carbon-free, is one of the "advanced and innovative environmentally sound technologies" that can contribute to alleviating the risk of global climate change. However, at present, nuclear power is facing problems related to maintaining economic competitiveness in a deregulated market and enhancing public acceptance. In this context, the challenge for governments and nuclear industries is to keep the nuclear option open in the long term in spite of the likely short-term stagnation of nuclear power programmes in most countries.

This implies preservation of infrastructures, including research and development programmes and facilities that could support the development of new reactors and fuel cycle technologies adapted to future markets and meeting sustainability requirements. Intergovernmental organisations such as the Nuclear Energy Agency (NEA) can help in this process by providing cost-effective ways and means, through sharing information and experience, of keeping the nuclear option open for future generations.

Greenhouse gas emissions and nuclear power

The analysis of past experience illustrates the role of nuclear power in reducing carbon dioxide and other atmospheric emissions. A comparison of time series of electricity generation by source and atmospheric emissions in different countries shows a strong correlation between nuclear energy's share in electricity generation and the decrease of emissions [2]. Countries that have implemented large nuclear programmes have achieved simultaneously significant reductions of carbon dioxide and other atmospheric emissions, while countries which have little or no nuclear power in their energy mixes for electricity generation have experienced stable or increasing atmospheric emissions from the power sector.

In France, carbon dioxide, sulphur dioxide and particulate emissions from the power sector were reduced by factors of four, nine and ten, respectively, between 1980 and the mid-1990s, while electricity generation roughly doubled during the same period. This reduction resulted essentially from an increase in the nuclear share of total electricity generation from less than 25 per cent in 1980 to more than 75 per cent in 1995. In Sweden, energy related carbon dioxide emissions were reduced by more than 40 per cent between the early 1970s and the early 1990s, owing essentially to switching from oil to nuclear and hydro power for electricity generation. Sweden also reduced its domestic sulphur dioxide and nitrogen emissions significantly during the same period.

World-wide, as greenhouse gas emissions from the nuclear fuel cycle are of the order of 25 g/kWh compared with some 450 to 1250 g/kWh when using fossil fuel, replacing the whole of the nuclear generation capacity by a mix close to that of the current non-nuclear power capacity would entail increasing the world's energy sector's carbon dioxide emissions by some 8 per cent.

Future energy and electricity demand

Population growth is a driving factor in energy and electricity demand. By the middle of the twenty first century, the world population will roughly double, reaching some 10 billion inhabitants by 2050 [3]. Population growth will be concentrated in developing countries which will represent nearly 85 per cent of the world population by 2050. Historical trends towards urbanisation are expected to continue; by 2050 more than three quarters of the world population will live in urban areas and an increasing number of people will live in mega-cities exceeding 10 million inhabitants.

Technological progress, changes in life styles and a better recognition of the value of our natural environment will likely reduce the energy intensity of future development patterns. However, historical and recent trends in energy and electricity demand growth demonstrate the limits to conservation and savings. Consequently, there is little doubt that energy demand will continue to grow. Since electricity is a very versatile energy form which provides non-substitutable services, such as lighting, and is well adapted to the requirements of densely populated areas such as large cities, electricity demand is likely to grow faster than total primary energy demand.

During the last fifteen years, electricity consumption has grown at a steady pace of some 4 per cent per year world-wide. All the projections and scenarios developed by authoritative organisations indicate a continuing growth of electricity demand in the short, medium and long term. For example, the OECD International Energy Agency is projecting, up to 2010, electricity demand growth rates of some 3 per cent per year in the world and around 2 per cent per year in OECD countries [4]. In the longer term, the energy perspectives of the World Energy Council (WEC) indicate at least - in the "ecology driven case" - a doubling of electricity demand world-wide by 2050 [5]; other WEC scenarios lead to a nearly four-fold increase of electricity demand between 1990 and 2050. The "Low CO_2-Emitting Energy Supply System" scenario (LESS) of the Intergovernmental Panel on Climate Change (IPCC), which assumes drastic improvements in energy efficiency and dramatic technological progress, projects a nearly three-fold increase of electricity demand in the world by 2050 [6].

Potential nuclear power development

Nuclear power is, today, a commercially available source of electricity that contributes already to reducing anthropogenic greenhouse gas emissions. Some 17 per cent of the electricity consumed world-wide is generated by nuclear power plants and in OECD countries, nuclear power supplies 25 per cent of electricity consumption.

In order to meet increasing electricity demand, additional generating capacity will need to be built. Once social, economic and technical constraints have been taken into account, the number of realistic large-scale electricity supply options is fairly limited and nuclear power is undoubtedly one of them. During the next decades, the main alternatives for electricity generation is likely to continue to be coal-fired, gas-fired and nuclear power plants. Hydro power is not likely to expand in OECD countries and world-wide its contribution is unlikely to increase significantly. Other renewable sources, although they are expected to be developed steadily, will remain marginal contributors to total world energy supply.

In this context, nuclear power, while expected to be stagnant in the short term except in a few countries, is likely to be developed continuously in the long term, especially because it is one of the sustainable options commercially available. Recent studies on long-term nuclear power development provide a range of scenarios for possible nuclear capacity evolution in the world to 2050 and beyond. Most of them project that nuclear capacity will increase rather slowly to 2015 and, in ecologically driven scenarios, grow more steadily to 2050. For example, one of the Key Issue Papers produced for the International Symposium on Reactor and Fuel Cycle Strategies: Adjusting to New Realities [7], sponsored last year by the IAEA and the NEA, presents medium and high scenarios for nuclear power with world nuclear capacity in the year 2050 reaching around 1 100 and 1 800 GWe, respectively, as compared with some 350 GWe today. Other studies, such as the Global Nuclear Vision Project being carried out by the Los Alamos National Laboratory in the United States, project similar ranges of nuclear power capacity by 2050. The NEA is carrying out studies along the same lines. In a reference scenario developed by the Agency within its programme of work on nuclear power and sustainable development, it is projected that world nuclear capacity could be around 1 100 GWe [8] by 2050. Those studies show that the scenarios in which the share of nuclear power in energy supply increases substantially achieve low carbon dioxide emissions.

Necessary conditions for the sustainability of nuclear energy

While there is no doubt that nuclear power development would reduce GHG emissions from the energy sector, the challenge is to demonstrate that nuclear power is a sustainable option, i.e., to ensure that the outcome is not worse when using nuclear energy than when using other energy sources. Much of the NEA work supports the position that we can use nuclear energy safely and without environmental damage.

The key factors for ensuring that nuclear energy is sustainable are: adequate management of natural resources; control of radioactive emissions; safe operation of nuclear facilities; safe management and disposal of radioactive waste; economic competitiveness; and avoidance of the spread of nuclear weapons. The last point is not within the mandate of NEA and will not be dealt with in this paper. It is fair to stress, however, that the fears expressed in the 1960s that the number of nuclear weapon states would increase substantially with the development of nuclear power did not materialise. The nuclear non-proliferation and safeguards regime developed around the NPT, supplemented by regional nuclear-weapon-free zone agreements and complemented by the International Atomic Energy Agency (IAEA) inspection system, has gained the adherence of most of the world. This regime, which has gained in strength in recent years as a result, for example, of improved safeguards measures, has proved to be effective in providing the needed assurance that proliferation remains in check.

Natural resources

Natural resources and technologies existing or under development could support broad nuclear development in the 21st century. With current technologies, known uranium resources would not be sufficient to support significant development of nuclear power beyond the first half of the next century. However, additional uranium resources could be discovered and economically exploited in the long term. Furthermore, improved fuel design and management, and advanced reactors, offer ways to reduce significantly the amount of natural uranium required per unit of electricity generated. In the long term, thorium fuelled reactors and fusion could enlarge even further the nuclear resource base.

Safety

A general perception that there is a high level of safety in existing plants is vital to maintaining the sustainability of the nuclear power option. The safety record of nuclear power, particularly in the OED area, has generally been very satisfactory. In fact, an NEA collective opinion published two years ago reached just such a conclusion with respect to OECD facilities [9]. This high level of safety can be maintained in the longer term provided that the OECD Member countries are able to deal with emerging challenges, including: technical issues, such as ageing of existing plants and even more stringent safety requirements for new plants; socio-economic issues, such as deregulation and privatisation; and organisational issues, such as preserving and enhancing safety culture, and maintaining an adequate level of competence and capability. Safety standards in non-OECD countries have not always measured up to standards in OECD countries. However, international co-operation and assistance programmes put into place since the Chernobyl accident, the broad adoption of safety culture world-wide, and the entry into force and implementation of the Nuclear Safety Convention have improved the situation considerably.

Radiation protection

The small quantities of radioactive materials released by nuclear reactors and fuel cycle facilities in routine operation are monitored and limited to levels believed to cause insignificant environmental and health damage on the basis of the recommendations from the International Commission on Radiological Protection as interpreted by national regulations. The population doses resulting from nuclear industry emissions of radioactivity are monitored and assessed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). In its 1994 report [10], the UNSCEAR assessment showed that the collective effective dose committed to the world population by a 50-year period of operation of existing nuclear power facilities, i.e., power plants, uranium mining and other fuel cycle facilities, is 2 million man-Sieverts (man-Sv) as compared with 650 million man-Sv committed by natural background radiation. That is, the dose commitment from natural background radiation is 325 times higher than that from the world's entire nuclear power industry. Therefore, even if it is assumed that there would be no reduction in the nuclear industry's radioactive emissions per kWh (even though at present there is a trend towards decreasing emissions per kWh), nuclear electricity generation could reach 750 thousand TWh per year as compared to less than 2.5 thousand TWh per year in the late 90s without leading to a population dose higher than that from the natural background.

Radioactive waste disposal

Perhaps the biggest challenge for the sustainability of nuclear power is to demonstrate that radioactive waste can be disposed of in a way such that humans and the environment will not be harmed in the distant future. Nuclear fission, being a high density energy source, generates less solid waste than most alternatives. One kilogram of uranium produces more than 10 000 times more electricity than one kilogram of fossil fuels or biomass. Therefore, solid waste arising from the nuclear chain represents small volumes as compared with those produced by most alternative generation sources. A 1 GWe coal fired power plant generates some 350 000 tonnes of solid waste per year, including chemicals that remain toxic indefinitely. A nuclear power plant of the same capacity and its supporting fuel cycle facilities generate each year some 500 tonnes of low-level waste, 200 tonnes of intermediate-level waste and 25 tonnes of high-level waste when operated once through [11].

Owing to its small volume, nuclear waste can be isolated from the biosphere. Considerable experience has been gained in the past few years in the handling, treatment, storage and disposal of low- and intermediate-level waste, the conditioning of high-level waste, the storage of high-level waste and spent fuel, and the minimisation of operational waste. A collective opinion published by the NEA, the European Commission and the IAEA in 1991 [12] confirms that safety assessment methods are available to evaluate the potential long-term impact of radioactive waste disposal systems on humans and the environment, and that appropriate use of such safety assessment methods, coupled with sufficient information about proposed disposal sites, can provide the technical basis to decide whether specific systems offer a satisfactory level of safety for current and future generations. A second collective opinion published by NEA in 1995 [13] addresses, specifically, the strategy for the final disposal of long-lived wastes from both an environmental and ethical perspective, including considerations of equity and fairness within and between generations. It concludes that the geological disposal strategy can be implemented in a manner that is sensitive to fundamental ethical and environmental considerations, and that it is justified to continue development of geological repositories for such wastes. The bottom line is that, although experts agree that technical solutions exist for the safe handling and disposal of all types of radioactive waste, the implementation of high-level waste repositories is a prerequisite to demonstrating the sustainability of nuclear power.

Competitiveness

Economic factors will remain a touchstone for the deployment of alternative electricity generation sources and technologies and, therefore, competitiveness is a prerequisite for the commercial development of any energy supply option and, indeed, for sustainability. While in the mid-1980s the competitive margin of nuclear generated electricity as compared to coal was significant, and other generation sources were generally much more expensive [14], today, if direct costs only are considered, a nuclear power plant is seldom the least cost option for a new generation unit. In most countries, low coal, oil and gas prices prevailing on international markets, coupled with enhanced efficiency of coal and gas plants, allow fossil fuels to compete favourably with nuclear power for the plants to be built and connected to the grid in the coming decades.

However, there are some indications that nuclear power may regain competitiveness, even if only direct costs are to be considered. There is no reason to assume that nuclear technology, which is relatively young, cannot achieve additional performance improvements leading to further cost reduction. Cost reductions have occurred with regard to uranium and fuel cycle services as well as operation and maintenance costs. A number of nuclear units currently in operation have very low marginal electricity generation costs, and those costs tend to decrease as a result of additional feed-back from experience and enhanced efficiency achieved through operation. Another factor that could improve the competitiveness of existing nuclear plants is extension of their lifetimes. The technical lifetime of most operating reactors in OECD countries was initially expected to be 40 years. Today, many operators consider that these units will be operated for 50 years or more. The experience acquired in operating plants in France, Japan and the Republic of Korea shows that nuclear power plant investment costs, which represent the largest share of nuclear electricity generation costs, can be reduced by standardisation and efficient management of programme implementation. Also, new reactor designs are aimed at reducing plant capital costs.

The longer-term perspective for the competitiveness of nuclear power could also be improved dramatically if and when external costs are factored into decisions about new generating plants. As a matter of fact, there are no significant external costs associated with residual emissions from nuclear power systems. The early recognition of potential harmful impacts of nuclear facilities led to stringent standards and regulations and, therefore, the residual health and environmental costs are very small. In addition, back-end and decommissioning costs are included in direct nuclear electricity generation costs.

One important external cost associated with sources of producing electricity relates to security of supply. The analyses of the International Energy Agency (IEA) conclude that, in the absence of policy measures aiming specifically at alleviating dependence on OPEC oil, the share of the world oil supply supplied by OPEC will grow from the current 40 per cent to 50 per cent or more by 2010 [4]. Also, the sustainability of the "rush to gas" might be challenged on the grounds that presently known reserves of gas represent some sixty years of supply based on the present yearly rates of consumption. There have been many examples of policies aiming at reducing energy dependence which reinforced the competitiveness of domestic sources. Nuclear power, which is essentially a domestic resource and does not raise security of supply issues, would benefit from such policies.

Another significant external cost is the potential economic impact of greenhouse gases. There are no firm data but many widely varying estimates available on the costs of global climate change. Government commitments, such as those agreed upon in the context of the UNFCCC, might result in policy measures aimed at incorporating the impact of greenhouse gas emissions in the costs borne by electricity producers and consumers. Clearly, any measure that would lead to recognising the value of reducing GHG emissions would reinforce the competitiveness of nuclear power versus coal or even gas.

Concluding remarks

Increasing substantially the share of nuclear power in electricity generation is feasible and would contribute significantly to reducing GHG emissions from energy systems. Indeed, it is not clear that governments and industry could rely on electricity sources other than nuclear power to provide the desired range of economic, environmental and social benefits. Therefore, efforts to alleviate the present barriers to the implementation of nuclear programmes are worthwhile.

The challenge will be to maintain the nuclear option for the long term, which means keeping alive nuclear infrastructure, and, in particular, the ability to develop new reactors and fuel cycle technologies in spite of the short-term stagnation of nuclear power development programmes in most countries. Already there are signs of weakening in some aspects of infrastructure. Continuation of these trends, in particular in OECD countries, might well jeopardise the ability to expand nuclear energy in a timely manner when that becomes desirable. Strengthening research and development efforts aiming at the design and implementation of a new generation of reactors will be a prerequisite for adapting the nuclear industry to even more competitive electricity markets, while increasingly stringent safety standards are likely to be implemented. Continued education and training of highly qualified manpower will also be required.

Intergovernmental organisations like the Nuclear Energy Agency can help in this process by offering opportunities for exchanges of information and experience sharing. Some elements of infrastructure, notably research and facilities, may be preserved more cost-effectively by international action of the kind which the NEA and other international organisations exist to promote.

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日本の電気事業の地球温暖化問題への取り組み

電気事業連合会　原子力開発対策会議委員長　鷲見禎彦

《はじめに》

○昨年１２月に、気候変動に関する国際連合枠組条約第３回締約国会議（ＣＯＰ３）が、我が国の京都で開催された。
本会議で採択された議定書において、２０１０年までに先進国全体で温室効果ガスを１９９０年より少なくとも５％削減するという目標が合意された。我が国については、６％削減を目標としており、現在、国の委員会等でそのための方策を検討中である。

○日本の電気事業者の立場から、温室効果ガスの排出状況やその削減に向けての活動について紹介したい。

１．日本のエネルギー消費とCO_2排出量

○１９９０年から９５年にかけて、日本の最終エネルギー消費は１１％、CO_2排出量は８％増加した。

○１９９０年から９５年にかけての部門別最終エネルギー消費をみると、産業部門は５％の増加にとどまっているのに対し、民生部門、運輸部門はそれぞれ１９％、１６％と大きな増加を示している。そのため、CO_2排出量をみると、産業部門はほぼ横ばいであるのに対し、民生部門、運輸部門はいずれも１６％増加している。

○近年、利便性と快適性を求める国民のライフスタイルの変化に伴い、民生部門および運輸部門のエネルギー消費が大幅に増加している。

○例えば、民生部門では、大型化、多機能化や待機時消費電力を消費する製品の増加により、機器１台当たりのエネルギー消費が増大していることがあげられる。また、運輸部門では、自家用乗用車や貨物自動車のエネルギー消費が増加している。

○今後特段の対策を講じない場合、この傾向は継続し、最終エネルギー消費は２０１０年には１９９０年に比べて３１％増加し、これによるCO_2排出量の増加は２１％と想定される。

○１９９５年の日本の一次エネルギー供給のうち、電力用の占める割合は４１％であるのに対して、エネルギー起因のCO_2排出量における電力の割合は２８％にとどまっている。
これは主として、原子力を中心とするCO_2を排出しない非化石エネルギーが発電に導入されてきたことによる。

○日本の総排出量は、米国、旧ソ連、中国に次いで世界第４位であり、世界全体の５％を占めている。
日本の中で電力用の占める割合が約３割であることから、日本の電力の世界の総排出量に占める割合は約１．５％となる。

○日本の電気事業者の温室効果ガスの削減努力は、世界の総排出量の削減に少なからず影響を与える。

２．これまでの日本の電気事業の取り組み

○日本の電気事業者は、
電気の供給面では
原子力発電を中心とした電源のベストミックスの推進、
火力発電における熱効率向上や送配電ロス率の低減などエネルギー利用効率の向上、
新エネルギーの導入や普及拡大の推進に、
また、使用面では、エネルギー利用効率の高い機器・システムの開発や普及拡大などに積極的に取り組んできた。

○この結果、１９９５年には１９７０年に比べ、発電電力量あたりのCO_2排出量（CO_2排出原単位）で、３７％以上を低減出来た。

○このような取り組みが無かったと仮定した場合、１９９５年のCO_2排出量は実際よりも８７００万ｔ－Ｃ増えていたことになる。
このCO_2排出回避量８７００万ｔ－Ｃのうち、原子力発電によるものが約７割を占めており、他電源に比べてCO_2排出量が著しく少ない原子力発電の推進は、地球温暖化防止に大きく貢献するものである。

３．電気事業の環境行動計画

○日本の電気事業は１９９６年１１月に『電気事業における環境行動計画』を策定し、その努力目標として『２０１０年における電力業界全体のCO_2排出原単位を、１９９０年の実績（０．１０４ kg－C /kWh ）から２０％程度低減するよう努めていく。』　ことを公表した。

○この行動計画では、電気の供給面・使用面から各種の対策に取り組んでいくこととしているが、その中でも、CO_2削減効果の大きい原子力発電の開発の推進および原子力発電の利用率の向上については、今後とも安全性の確保を大前提に、積極的に取り組むこととしている。

４．CO_2削減シナリオ

○日本のCO_2排出量を、例えば、２０１０年に１９９０年レベルに抑制するためには、新エネルギーを最大限導入（１９１０万ｋｌ）、省エネルギーを最大限推進

（５６００万ｋｌ）したうえで、さらに原子力発電が７０５０万ｋＷ必要（新設２０基程度、２５００万ｋＷ）とされている。

○ＣＯＰ３で国際的に合意された温室効果ガスの排出量に関する削減目標を達成するためには、これに加えて、共同実施や排出権取引等を適切に組み合わせることも必要となる可能性がある。

○原子力発電の開発、新エネルギー・省エネルギーの推進等については、現在、国の委員会等において検討が進められており、６月頃とりまとめられる予定である。

５．今後の課題

○CO_2排出量を削減するためには、少なくとも原子力発電が７０５０万ｋＷ必要であり、原子力発電の重要性がこれまで以上に高まっている。

○しかしながら、原子力発電の新規電源開発は、昨今大変厳しい状況にある。

○そのような中で、原子力発電の開発を進めるためには、国民の理解と信頼の確保が重要であり、そのためには、安全・安定運転の実績を積み重ねるとともに、電力自主保安活動に関するＰＡや電力消費地への理解促進活動を強化する必要があると考えている。

○立地地域での理解を促進するためには、当該地域の振興を図る必要がある。既存の立地地域の発展を図ることは、新規立地予定地点での理解を深めることにもつながる。そのため、電気事業者としても、国と連携して地域振興の拡充に努力していきたい。

○また、一方、原子力発電の利用率向上も、CO_2削減に貢献するものであり、これまでも進めている定期検査期間の短縮のさらなる追求、長期サイクル運転ならびに定格熱出力運転を検討していきたい。

○さらに、原子力発電の開発や利用率の向上を図るためには、理解促進活動や地域振興制度の整備等において、国と電気事業者の緊密な連携が必要と考えている。

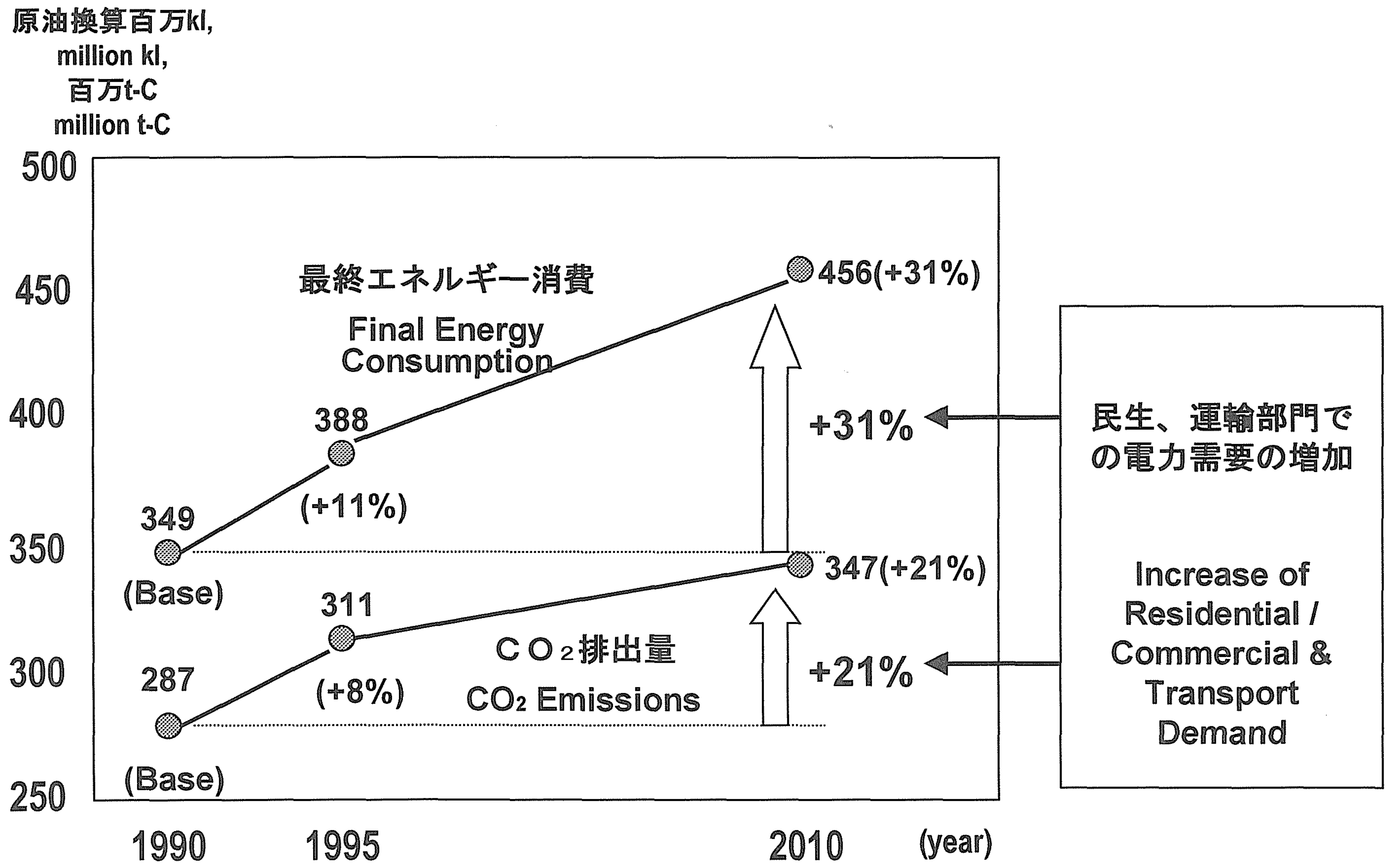
以　上

日本の電気事業の地球温暖化問題への取組
Efforts to Counter Global Warming Problems by the Japanese Electric Power Industry

鷲見 禎彦
Yoshihiko Sumi

1

日本の最終エネルギー消費とＣＯ２排出量
Japan's Final Energy Consumption and CO_2 Emissions

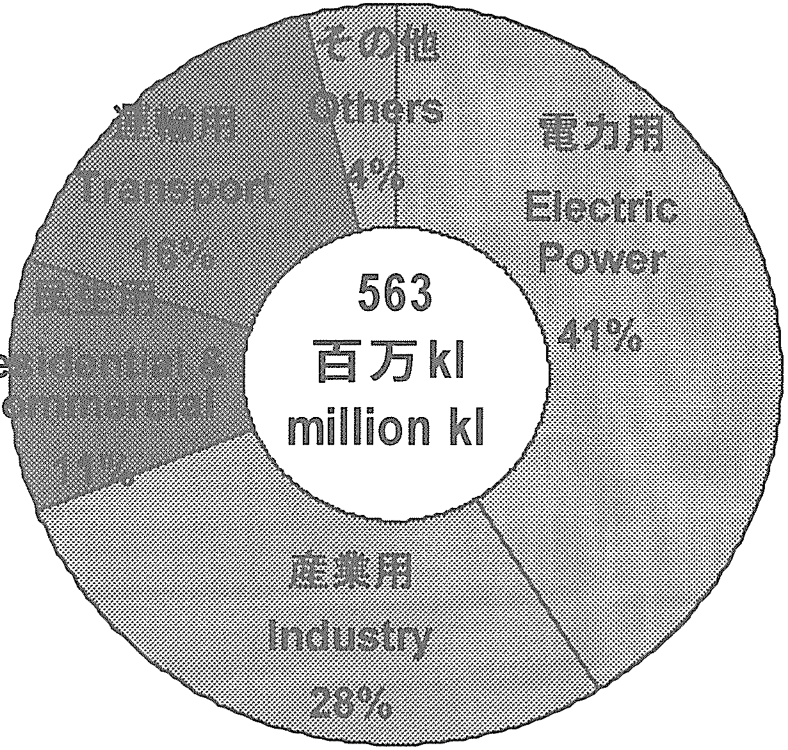


日本の１次エネルギー国内供給量とＣＯ₂排出量（１９９５年度実績）

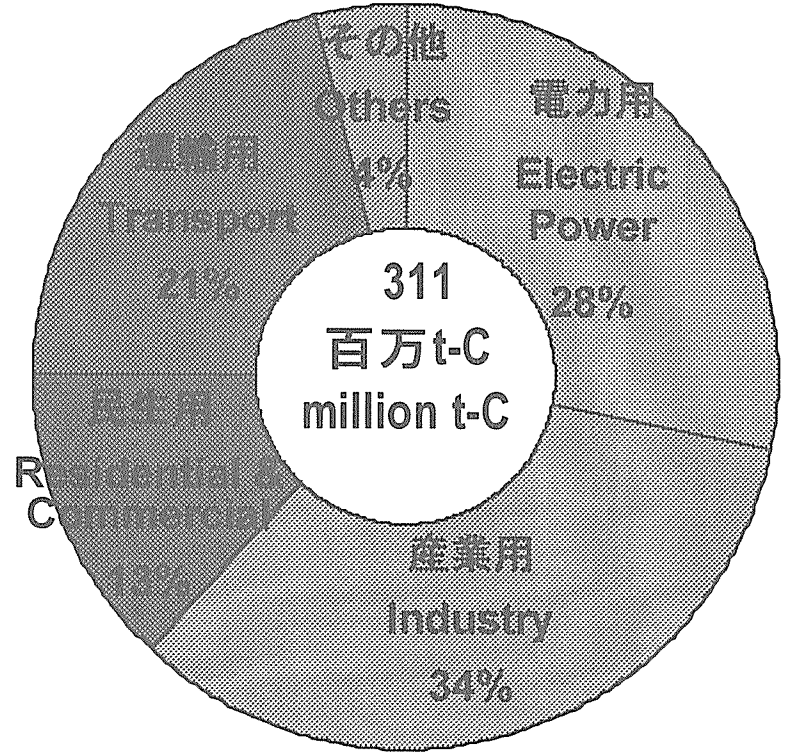
Japan's Domestic Primary Energy Supply and CO_2 Emissions(1995)

2

１次エネルギーの国内供給量
Domestic Primary Energy Supply



エネルギー起因のＣＯ₂排出量
CO_2 Emissions from Energy Use



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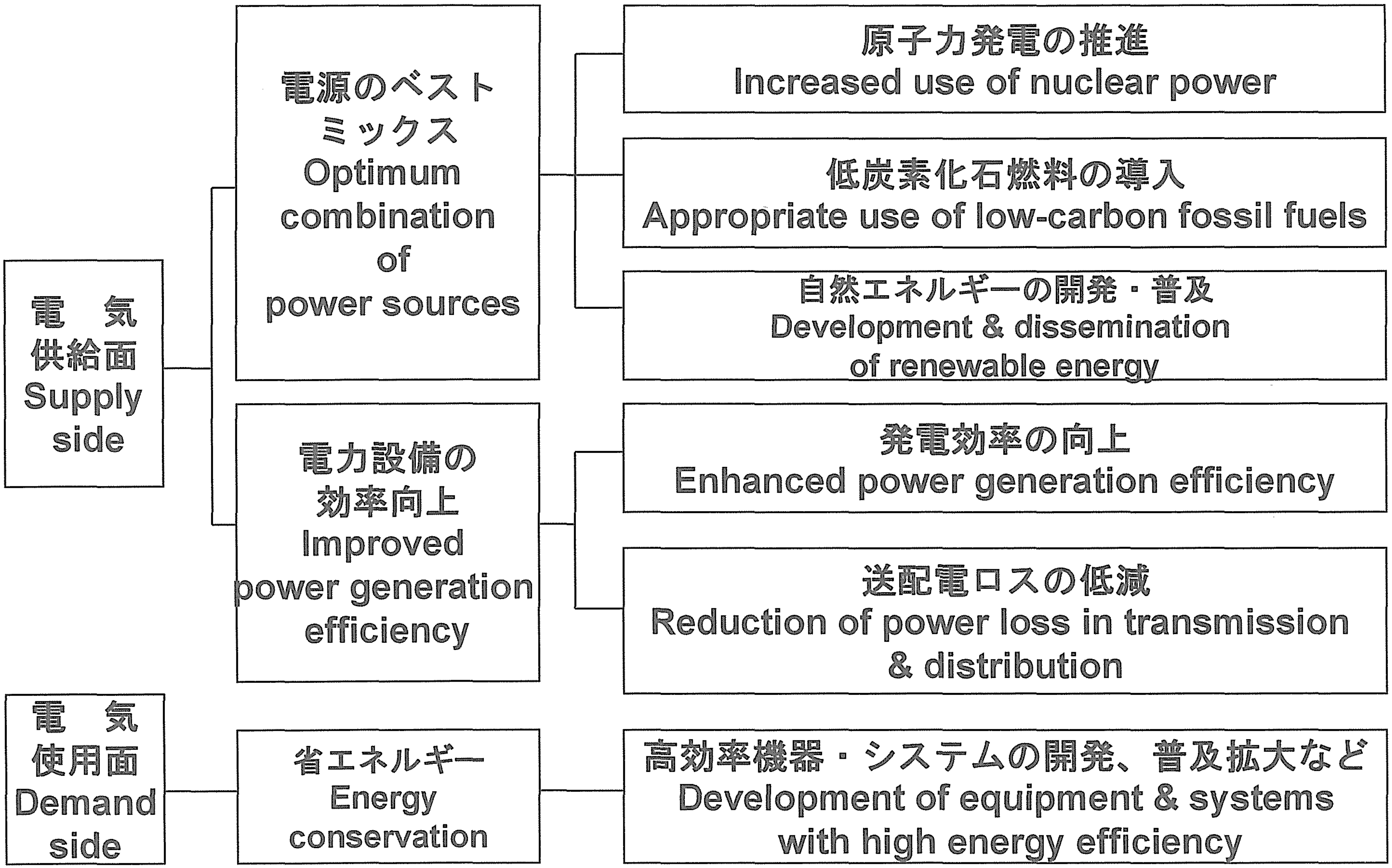
日本の電気事業のＣＯ$_2$削減への取り組み
Measures for CO_2 Reduction by the Japanese Electric Power Industry



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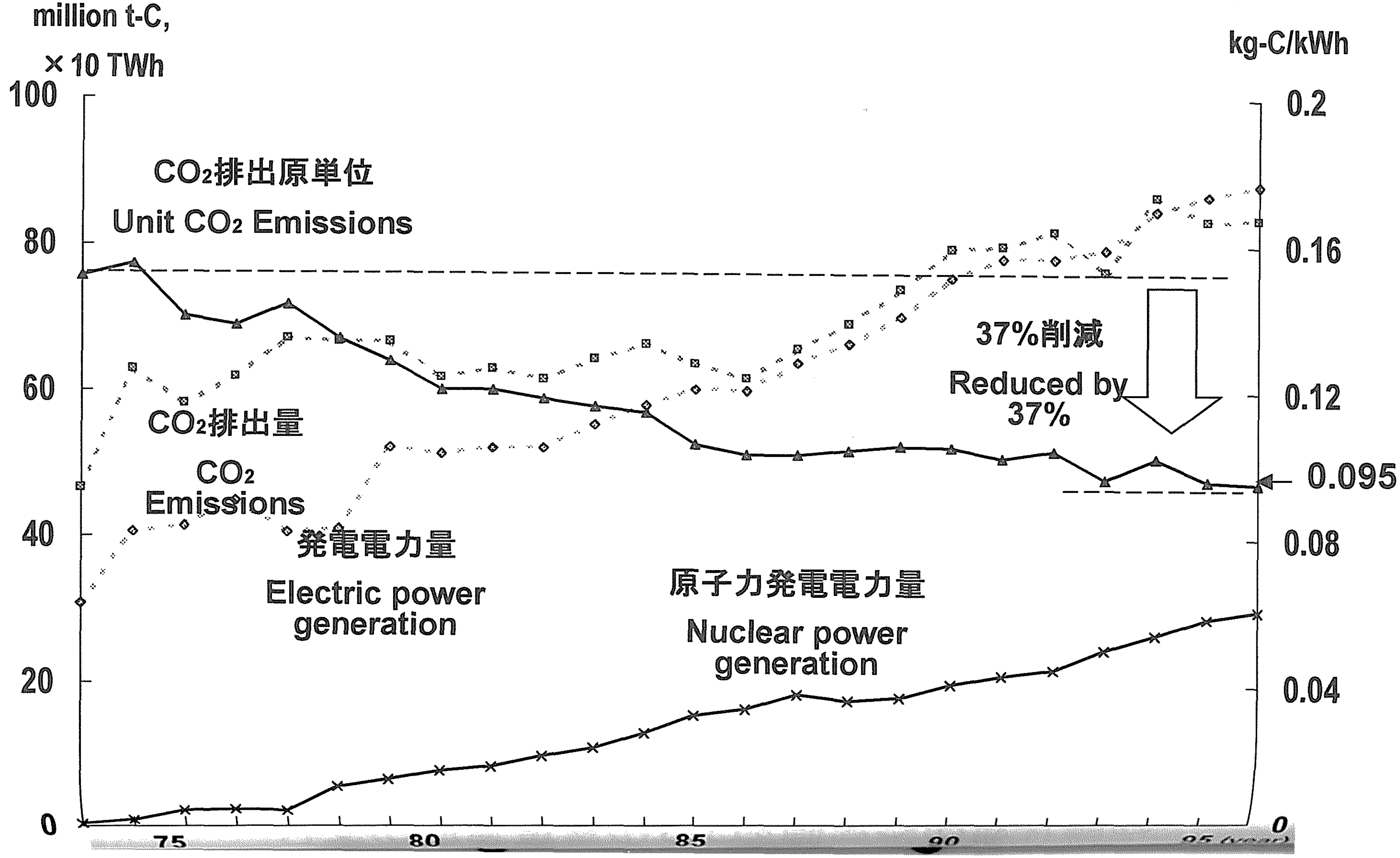
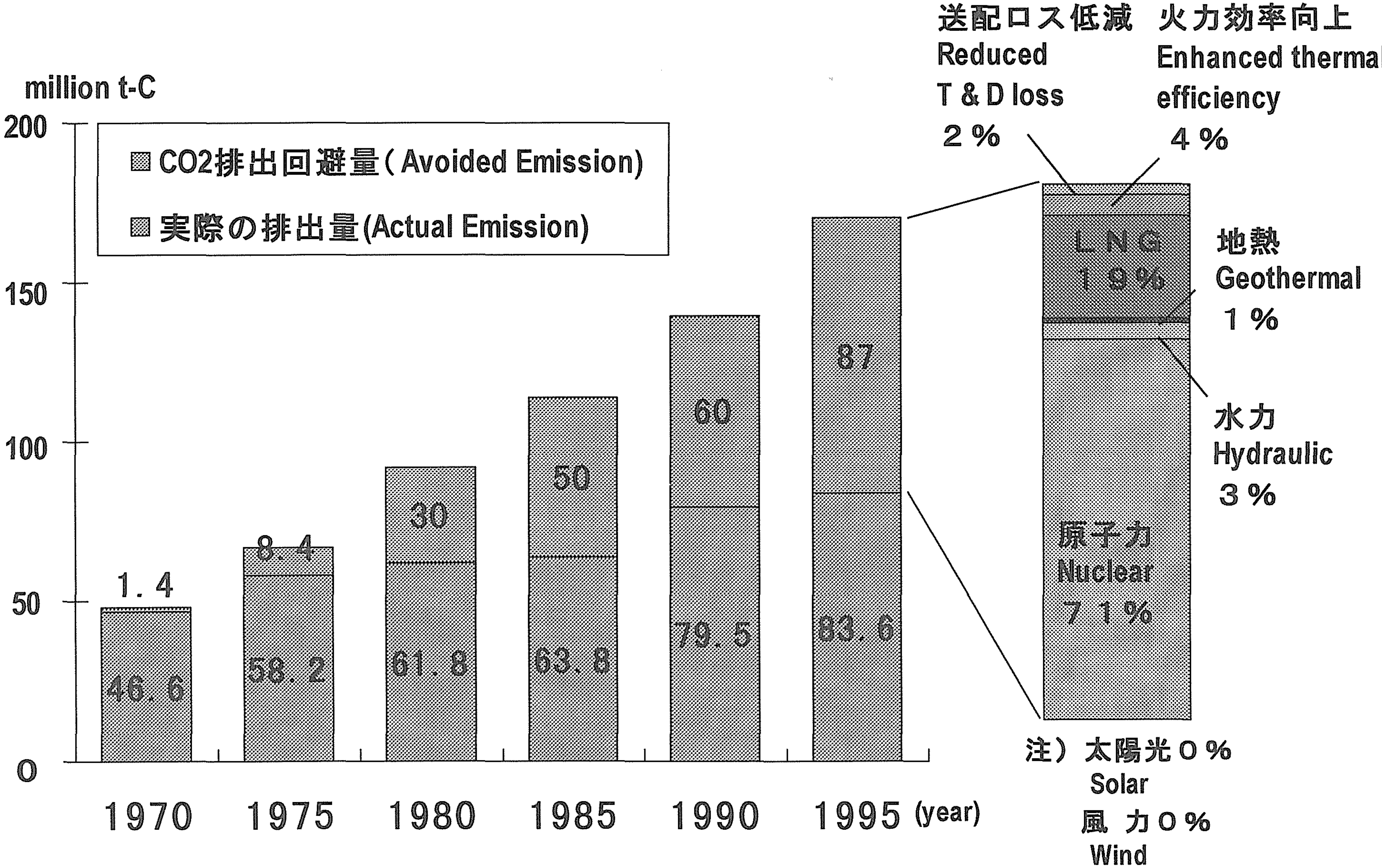
日本の電気事業のＣＯ２排出原単位
Unit CO_2 Emissions of the Japanese Electric Power Industry



原子力発電のＣＯ₂問題への効果
Effectiveness of Nuclear Power to CO_2 Problems



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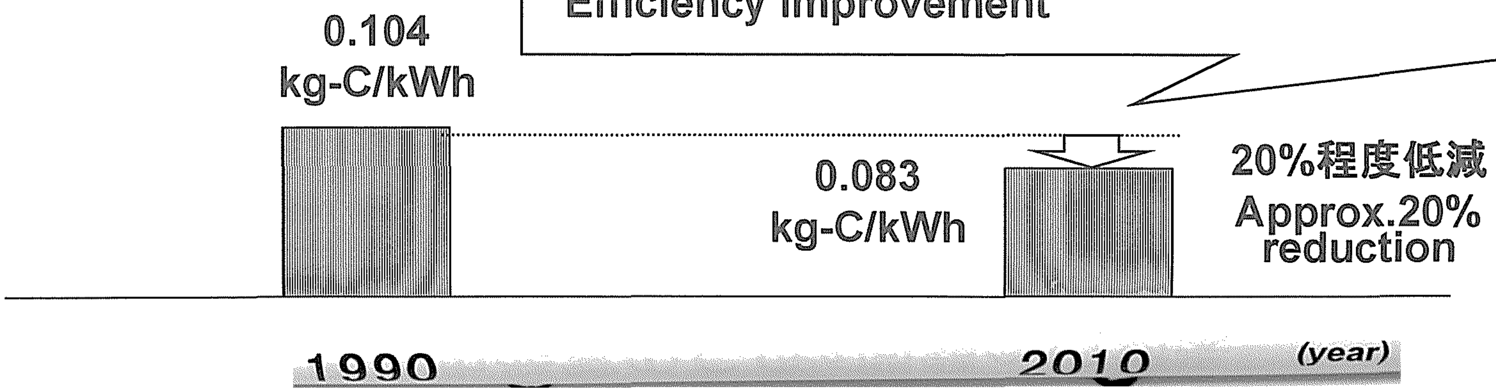
日本の電気事業における環境行動計画（1996年11月）
Environmental Action Plan by the Japanese Electric Power Industry(November 1996)

目標：２０１０年にCO_2排出原単位を１９９０年の実績（0.104kg-C/kWh）から２０%程度低減

Goal： Reduce unit CO_2 emissions by 20% by the year 2010 from 1990 level

- 原子力の開発推進
  Promotion of nuclear power
- 原子力の利用率の向上
  Improvement of capacity factors at nuclear power plants
- ＬＮＧ、新エネの導入
  LNG, new (renewable) energy
- 効率の改善
  Efficiency improvement



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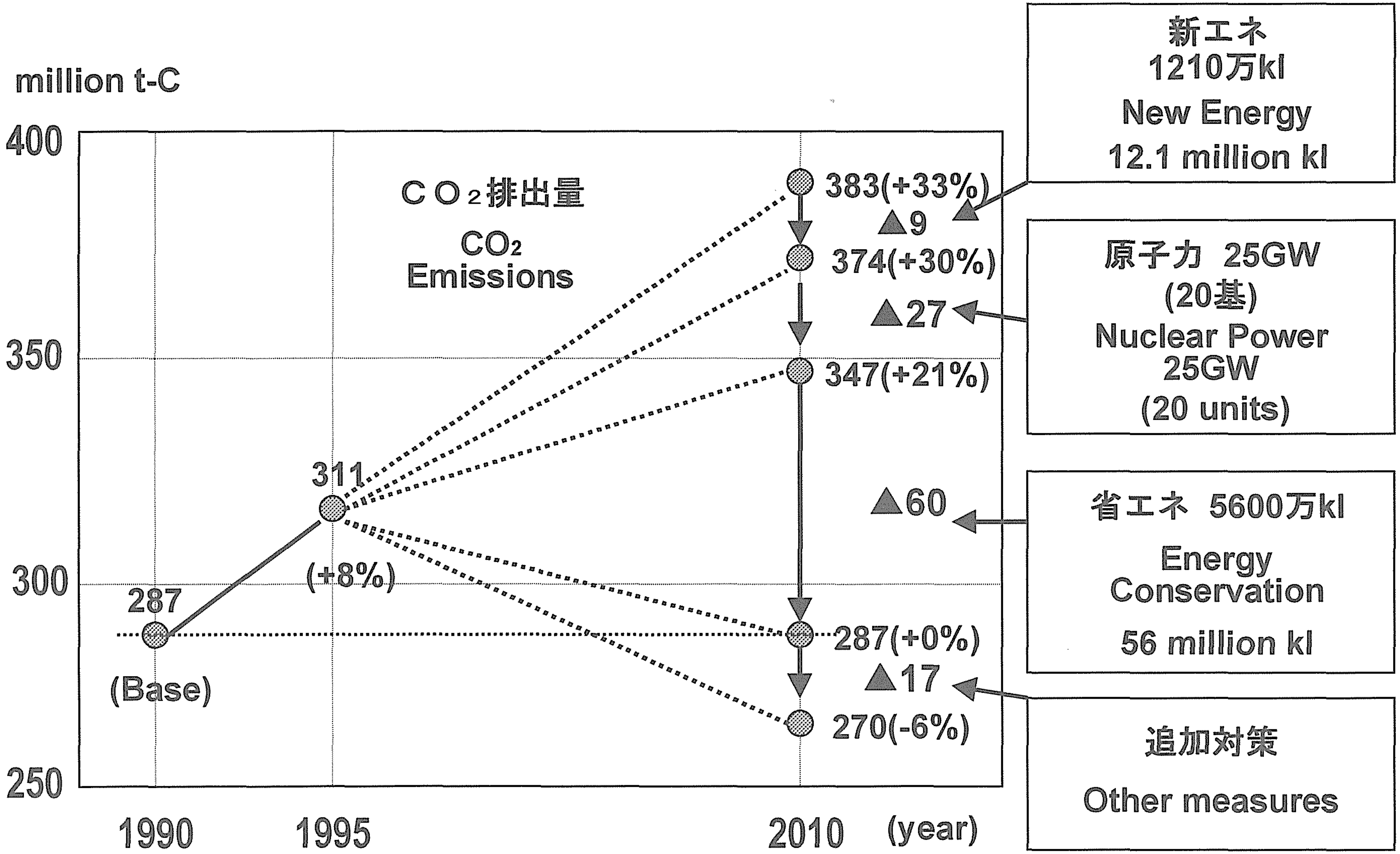
ＣＯ$_2$排出量削減シナリオ例
Example of CO_2 Reduction Scenarios



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原子力発電開発・利用に向けての課題
Problems in Development & Use of Nuclear Power

- 原子力発電の開発（2010年時点で7050万kW）
  Nuclear power development (70.5 GW in 2010)
  → 国民の理解
  Public acceptance
  → 地域振興
  Vitality in areas
- 原子力発電の利用率向上
  Improved capacity factor of nuclear power

⇩

国と電気事業者の連携
Collaboration between government & *utilities*

むすび
Closing Remarks

原子力発電開発の目的
Purposes of nuclear power development

↓

地球温暖化問題への対応
Global warming problems
エネルギーセキュリティの確保
Energy security

↓

世界的な課題
Global problems

↓

世界的な原子力発電の開発
Global nuclear power development

For the 31st JAIF
Annual Conference
only

April 19-22,1998, Tokyo

Energy Consumption and Carbondioxide Emission in China (outline)

Qu Shiyuan
Energy Research Institute
State Planning commission
Beijing, China

Content

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(1) The Present Situation.
(2) The Estimation of Economic Growth in Future.

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(3) China's Energy Intensity.
(4) China's Energy Demand in Future.
(5) China's Electricity Consumption Mix.
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3. Carbon dioxide emission stem from energy consumption.
(1)The emission of carbon dioxide.
(2) The percent of carbon dioxide emission from coal.
(3) The growth rate of The carbondioxide emission.

4. The strategics of energy development and environment protection.
(1) To improve energy utilization efficiency--to save energy.
(2) To improve energy structure.
(3) To make proper economic policies.
(4) To make proper regulates and laws.

1.Chian's Economic Growth.

(1)The Present Situation(see Table1-1).

The characteristics are as follows:

The average growth rate per year was 12.01% .

The primary industry rose by 4.15% each year, it's percent went down from 27.1% in 1990 to 18.8% in 1995.

The Industry rose by 17.68%,very fast. It's percent went up from 37% in 1990 to 47.33%.

The construction increased by 15.49%, also fast. It's percent rose from 4.6% in 1990 to 5.4% in 1995.

Transportation increased by 10.61%, commerce by 9.69%, so the tertiary industry increased only by 9.88%. The percent not rose, but decreased from 31.3% in 1990 to 28.47% in 1995.

The growth rate of population was 1.16% a year.

Table1-1. The Economic growth during 1990 ~ 1995

Unit: 100 million Yuan; %

	1990		1995		
	Amount	%	Amount	%	Growth rate
GDP	18548	100	32704	100	12.01
Primary Ind.	5017	27.1	6148	18.80	4.15
Secondary Ind.	7717	41.6	17244	52.73	17.45
of which: Ind.	6858	37.0	15479	47.33	17.68
Cons.	859	4.6	1765	5.40	15.49
Tertiary Ind.	5814	31.3	9312	28.47	9.88
of which: Tran.	1148	6.2	1901	5.81	10.61
Commerce	4666	25.1	7411	22.66	9.69
Population	11.43		12.11		1.16

Note: price in 1990 (as The same below)

(2) The Estimation of Economic Growth in Future(see Table1-2).

GDP will increase by 9.0% each year during 1995-2000. by 7.2% during 2000-2010.

The primary industry will rise by 5.28% every year during 1995-2000, by 4.55% during 2000-2010. It's percent will change from 18.8% in 1995 to 5.28% in 2000 and 4.55% in 2010.

The industry will rise by 8.32% annually during 1995-2000, by 6.35% during 2000-2010. It's percent will decrease from 47.3% in 1995 to 46% in 2000 and 42.5% in 2010.

The construction will rise by 7.89% per year during 1995-2000, by 3.44% during 2000-2010. It's percent will change from 5.4% in 1995 to 5.0% in 2000 and 3.5% in 2010.

Because of quick growth of commercial sector, the tertiary industry will increase fast, the growth rate will be 12.49% annually during 1995-2000 and 67% during 2000-2010.

The population will increase slowly further. But population in city will increase quickly than in rural area.

Table1-2 Economic Development in China

Unit: 100 million Yuan; %

	1995		2000			2010		
	Am.	%	Am.	%	G.Rate	Am.	%	G.rate
GDP	32704	100	50319	100	9.00	100851	100	7.20
Prim. Ind.	6148	18.8	7950	15.8	5.28	12405	12.3	4.55
Second. Ind	17244	52.7	25663	51.0	8.28	46391	46.0	6.10
of which :								
Ind.	15479	47.3	23147	46.0	8.32	42862	42.5	6.35
Cons.	1765	5.4	2516	5.0	7.89	3530	3.5	3.44
Tertiary Ind.	9312	28.5	16706	33.2	12.40	42055	41.7	9.67
of Which:	1901	5.8	2919	5.8	8.96	5850	5.8	7.20
Trans. Commerce	7411	22.7	13832	27.4	13.29	36205	35.9	10.10
Po.(100 M.)	12.11	100	13.0	100	1.43	14.0	100	0.74
of which:								
City	3.52	29.1	4.16	32.0	3.40	5.6	40.0	3.02
Rural	8.59	70.9	8.84	68.0	0.58	8.4	60.0	-0.51

2.China's Energy Consumption and Demand.

(1) Energy Consumption in past years(see Table 2-1).

Coal was taken as major energy in primary energy consumption, accounting for about 75%.

In the electricity consumption the coal-electricity accounted a large percent, about 77%, and it was going up during 1990-1995.

The biological energy was playing important role in China.

The nuclear power was very smaller.

Table2-1 Energy Consumption During 1990 ~ 1995

unit: million Tce; %

	1990		1995		
	Amount	%	Amount	%	Growth rate
Total	1250.03	100	1533.15	100	4.18
of which: conv.En.	987.03	78.96	1311.76	85.56	5.85
coal	752.11	76.2	978.57	74.6	5.41
oil	163.85	16.6	229.56	17.5	6.98
natural gas	20.73	2.1	23.61	1.8	2.64
hydropower	50.34	5.1	76.22	5.8	8.65
nuclerpower			3.80	0.3	
renewable energy ※	263.00	21.04	221.39	14.44	-3.39
Total Elec.Cons.	6230.4	100	10023.4	100	9.98
of which:coal ele.	4706.4	75.54	7798	77.80	10.63
hyd.pow.	1267	20.34	1906	19.01	8.51
nuc.pow.			100	1.00	
oil-gas pow.	250	4.01	211.4	2.11	3.30
other※	7	0.10	8	0.08	2.71

notes: (1) The calorific capacity is as follows: 1kgce is 7000 Kcal., 1kg coal is 5000 Kcal., 1kg oil is 10000 Kcal, 100 million M^3 natural gas is 93100 Kcal.

(2) Coal Consumption of 1kwh are as follows: 3.92 gce in 1990, 3.78gce in 1995,3.60gce in 200, 3.30gce in 2010.(as the same below).

(3)※ including new and biological energies(as the same below).

(4)The percents of coal oil natural gas hydropower and nuclear power are for conventional energy.

(2) China's Energy-Economy During 1990-1995(see Table 2-2).

The growth rate of energy consumption was smaller than economy. The elasticity of energy consumption was less than 0.5.

The energy intensity and electricity intensity were becoming smaller, energy saving and electricity saving were remarkable.

Electricity will increase quickly, the elasticity of electricity consumption will be nearing 1.0.

Table 2-2 China's Energy-Economy during 1990-1995

	1990	1995
GDP(100 million)	18548	32704
Growth rate of GDP (%)		12.01
Energy Cons. (MTce)	987.03	1311.76
Grow.rate of Energy Cons.(%)		5.85
En. Intensity (Tce/10000Y.)	5.32	4.01
The rate of Energy Saving (%)		5.50
Elasticity of EnergyConsumption		0.487
Energy Saving (MTce)		428.42
Electricity Cons.(100 Mkwh)	6230.4	10023.4
Growth rate of elc. cons. (%)		9.98
Elasticity of elc. cons.		0.831
Elec.Intensity (kwh/yuan)	0.336	0.306
The rate of electricity saving (%)		1.85
Electricity Saving (100 Mkwh)		981

(3) China's Energy Intensity(see Table 2-3).

Energy and electricity intensity will becoming smaller.

Energy saving and electricity saving will be remarkable.

Table2-3 China's Energy Intensity and Energy Saving Rate in Future

Unit: Tce/10000 yuan; kwh/100 MYuan; %

	1990	1995		2000		2010	
	Inten.	Inten.	S.Rate	Inten.	S.Rate	Inten.	S.Rate
En.Inten.	5.32	4.01	5.49	2.90	6.28	2.05	3.41
Ele.Inten.	0.336	0.306	1.85	0.278	1.90	0.248	1.14

Note: Only including conventional energy here.

(4) China's Energy Demand in Future(see Table 2-4).

The percent of Coal will still be larger, but will becoming smaller.

The increase of oil will be slowly.

Natural gas, hydropower and nuclerpower will increase fast, but their percent will still smaller.

Although hydropower and nuclearpower will increase quickly , thermal power will account for a larger percent than others.

Table2-4 China's Energy Demand in Future

Unit: Mtce; %

	2000		2010	
	Amount	%	Amount	%
Total (Mtce)	1709.89	100	2360.21	100
of which: Renewable(Mtce)	250	14.62	297.7	12.61
Conventional (MTce)	1459.89	85.38	2062.51	87.39
of which: Coal (MT)	1450	70.91	1850	64.10
Oil (MT)	210	20.56	280	19.40
Natural gas (Billion M^3)	30	2.73	80	5.10
Hydropower (Billion Kwh)	220	5.43	480.8	9.40
Nuclerpower (Billion Kwh)	15	0.37	100	2.00
Total Electricity(Billion Kwh)	1400	100	2500	100
of which: Thermal power	1165	83.2	2125	85.0
Hydropower	220	15.7	345	13.8
Nuclerpower	15	1.1	30	1.2

(5) China's Electricity Consumption Mix(see Table 2-5).

The percent of coal-electricity will be becoming larger from 1995 to 2010 and reach 83.3% in 2010.

The percent of hydropower and oil-electricity will be decreasing.

although nuclearpower and new energy electricity will develop fast in future their percents will be very small.

Table2-5 Electricity Consumption and Demand in China

Unit: 100 million kwh; %

	1990		1995		2000		2010	
	Amount	%	Amount	%	Amount	%	Amount	%
Total	6230.4	100	10023.4	100	14000	100	25000	100
coal ele.	4706.4	75.54	7798	77.80	11356	81.1	20825	83.3
hyd.pow.	1267	20.34	1906	19.01	2200	15.7	3450	13.8
nuc.pow.			100	1.00	150	1.1	300	1.2
oil gas pow.	250	4.01	211.4	2.11	280	2.0	375	1.5
other※	7	0.10	8	0.08	14	0.1	50	0.2

※ Including new and biological energies.

(6) China's Energy-Economy in Future(see Table 2-6).

The growth rate of energy consumption will be smaller than economy and the elasticity will be less 0.5.

Energy intensity will become smaller and energy saving will be remarkable.

The growth rate of electricity will be larger than energy consumption and the elasticity will be nearing 1.0.

The electricity intensity will become smaller and electricity saving will be remarkable.

Table2-6 The Present Situation and Forecast of Energy Consumption in China※

	1995	2000	2010
GDP(100 million)	32704	50319	100851
Growth rate of GDP (%)	12.01	9.0	7.2
Energy Consumption(millionTce)	1311.76	1459.89	2062.51
Grow.rate of Energy Cons.(%)	5.85	2.16	3.52
Elasticity of EnergyConsumption	0.487	0.240	0.489
Energy Intensity(Tce/10000Y.)	4.01	2.90	2.05
The rate of Energy Saving(%)	5.50	6.28	3.41
Energy Saving(million Tce)	428.42	508.54	857.23
Ele. Cons.(100 million kwh)	10023.4	14000	25000
Growth rate of Ele. cons. (%)	9.98	6.80	5.97
Elasticity of Ele. cons.	0.831	0.756	0.829
Ele.Intensity(kwh/yuan)	0.306	0.278	0.248
The rate of electricity saving (%)	1.85	1.90	1.14
Ele. Saving(100 million kwh)	981	1409	3026

※Only including conventional energy here.

3. Carbondioxide emission stem from energy consumption(see Table 3-1).

(1) The emission of carbon dioxide is large and will increase in the future.

(2) The percent of carbon dioxide emission from coal is and will be more than 75%. But it will become smaller gradually in future.

(3) The growth rate of emission from coal will rise during the next ten years. But the growth rates of emission from oil and natural gas will decrease.

Table 3-1 Carbondioxide Emission Estimation

Unit:Tc/Tce; %

	1995		2000			2010		
	Am.	Pc.	Am.	Pc.	G.R.	Am.	Pc.	G.P.
coal	64194	81.58	67916	77.83	1.13	86651	75.48	2.47
oil	13452	17.09	17585	20.15	5.50	23447	20.42	2.92
natural gas	1044	1.33	1764	2.02	11.06	4703	4.10	10.30
Total	78690	100	87265	100	2.09	114801	100	2.78

Note: The emission factors are as follows: o.656 for coal; o.586 for oil; o.442 for natural gas.

4. The strategies of energy development and environment protection.

(1) To improve energy utilization efficiency--to save energy.
---to develop advantage technology.
--- to improve economic structure.
--- to improve energy management.

(2) To improve energy structure.
--- to develop hydropower.
--- to develop nuclear power.
--- to increase consumption of oil and natural gas.
--- to rise the percent of coal transforming and processing.

(3) To make proper economic policies.

(4) To make proper regulates and laws.

第31回原産年次大会(1998年4月20～22,東京国際ﾌｫｰﾗﾑ)

中国におけるエネルギー需給と地球温暖化問題

長岡技術科学大学 助教授　李 志東

１．渠時遠先生の原稿の要旨

①経済発展の現状と見通し

高度経済成長が維持されている．1990-1995年の年平均成長率が12%．工業化が進行中．第二次産業の比率が90年の42%から95年の53%へ上昇，その他が低下．

将来に関しては，2000年まで9%，2000年～2010年7.2%，15年平均7.8%を維持，GDP規模は95年の3.08倍．第三次産業の比率が上昇，その他が低下．

②エネルギー消費の現状と見通し（IEAベースとは比較不可能）

エネルギー消費が堅調に増加．90-95年5.9%，GDP原単位ベースの省エネ率は5.5%(90年より25%低下)．石炭中心だが，比率が低下．石炭76.2→74.6%,石油16.6→17.5%．

将来に関しては，2010年は95年の1.57倍，平均伸び率3.06%．省エネ率は4.37%(95年より50%低下)．石炭中心だが，比率が低下．石炭74.6→64.1%，石油17.5→19.4%，天然ガス1.8→5.1%，水力5.8→9.4%，原子力0.3→2.0%．

③二酸化炭素排出の現状と見通し

2010年のCO_2排出量は95年の1.46倍，平均伸び率2.5%．

④エネルギーと環境保護戦略（箇条下記）

1)省エネ：技術進歩，経済構造，管理

2)エネルギー構造の調整：水力，原子力の開発促進，石油天然ガスの利用促進，石炭加工度の向上

3)経済政策　　　　4)規制強化と法制化の促進

２．脱石炭化について

①渠先生原稿に対するコメント：

高度成長を前提とする場合，エネルギー需要が増大し，環境問題が深刻化．省エネ率が4.4%と高く仮定するにしても，消費が３%以上で増大．

しかし，もっと増える可能性が大きい．理由は省エネ率が過大ではないか？

購買力平価(ppp)評価の原単位は現在日本の1.5倍，4.4%で低下すると，2010年に0.75倍．日本が年率1.9%の省エネをしないと，2010に，中国の効率が日本より高くなる？！

②省エネを促進するために，また，環境問題を解決するために，脱石炭化を実行するしかない． 石炭は効率が低く，しかも，環境問題を誘発する．

大気汚染，酸性雨，温暖化などの国内環境問題と地球環境問題の主因は，高い石炭依存度にある．粉じんの70%，二酸化炭素の80%，二酸化硫黄の90%以上が石炭に起因．

③脱石炭化は短期的には石油天然ガスを中心に展開される．

現状：中国は豊富な石炭資源を背景に，建国初期から石炭中心の自給自足型エネルギー需給構造を形成したが，それを揺さぶる動きは今回を含め二回あった．

1952年95% →	1976年72% →	1990年78% →	1995年77.4%(74.6%).
原油開発成功	低迷	さらに低迷	
石炭→石油	石油→石炭	多様化	
自給自足	自給自足	石油純輸入	

しかし，90年代初期から進展中の今回の構造変化は前回とは異なる様相を見せている．

一方，石油，天然ガスの輸入確保，航路安全と経済負担能力の問題は何れも解決できないものではない．CNPC（中国石油天然ガス総公司）とSINOPEC（中国石油化工総公司）の元社長が３月の内閣改造で入閣した．これは脱石炭化の流れを加速させる要因となろう．

④中長期的には，原子力，水力，風力等の自然エネルギーが期待される．

⑤中国の脱石炭化はCO_2削減の共同実施のチャンス．

地球温暖化問題とエネルギー

（財）日本エネルギー経済研究所
理事　十市　勉

1．京都会議の意義とその評価

近代工業文明の見直しを迫る第１歩
エネルギー資源利用のグローバル管理の時代へ
南北間および世代間の公平性と世界の人口問題
温暖化防止対策と実効性、効率性、公平性の原則
不可欠なグローバルかつ長期的視点からの対応策

2．ＣＯ2排出削減策と世界のエネルギー需給システムへの影響

確実な開発途上国を中心とする世界のエネルギー需要の増加
化石燃料のクリーンな利用と発電効率の向上
必要なﾗｲﾌｻｲｸﾙ･ｱｾｽﾒﾝﾄ（LCA）手法による温室効果ガスの影響評価
原子力や自然エネルギー等の非化石エネルギーの利用促進
技術革新によるエネルギー消費効率の飛躍的な向上
一段と重要性を増す先進国から開発途上国への技術移転

3．地球温暖化問題とわが国エネルギー政策の課題

グローバリゼーションとエネルギー問題のパラダイム・シフト
エネルギー安全保障－一国主義からアジアを視野に入れた国際主義へ
経済のグローバル化で強まるエネルギー市場効率化の要請
地球温暖化問題－市場原理を最大限活用した解決策の追求
排出権取引、共同実施、ｸﾘｰﾝ開発ﾒｶﾆｽﾞﾑの活用

エネルギー・ゼロ成長社会に向けてのわが国の課題と問題点
長期エネルギー需給見通しと原子力、新エネ、省エネの将来
経済・社会システムの省エネ型への転換と国民意識の変革
重要な政策手段の「ﾍﾞｽﾄ･ﾐｯｸｽ」－自主努力、規制策、経済的手法

SESSION 2

日本社会の変革と原子力開発

三菱マテリアル株式会社
取締役社長　秋元　勇巳

１．はじめに

１９７３年の石油危機以降、日本は省エネルギーとエネルギー源の多様化に取り組み、一定の成果を上げてきた。原子力発電は石油代替エネルギーの中核として、一次エネルギー源の約1/6、総発電量の1/3強を占めるに至っている。このような長年の努力にも拘わらず、日本のエネルギー供給構造は未だ十分とは言えない。 1994年現在、日本はエネルギーの57.4%を石油に頼っており、また、エネルギー全体の８割強は輸入である。これは、日本と同じようにエネルギー資源に乏しいフランスの輸入依存度が50%以下であるのと比べると著しく見劣りがする。

近年、探査や掘削技術の進歩により、石油の供給は安定しており、また最近はアジアの経済混乱による需要の低下もあって価格も低迷しているが、中長期的に見ればエネルギー危機はいずれ訪れるものと覚悟しなければならない。２１世紀を前に、日本のエネルギー・セキュリティについてもう一度見直してみる必要があろう。

従来のエネルギー・セキュリティの議論は、日本についての、それもせいぜい20～30年程度の期間を対象にした場合が多かった。しかし経済活動の規模の拡大に伴い、そのような狭い範囲の議論だけでは不十分になってきている。時間および空間の双方について範囲を広げて俯瞰する必要がある。

２．時間についての視点

時間に関し、短・中期的な視点と（超）長期的な視点がある。

短・中期的には、資源の量的な制約よりも経済、政治、社会あるいは環境影響の面からの制約が問題になると考えられる。日本が消費している石油の約80

％は、政情が不安定な中東からの輸入である。これは、石油への依存度が大きいことと併せて、日本のエネルギー供給基盤の脆弱さを示している。石油依存、中東依存からの脱却が大きな課題である。社会的には中央政府の指導力の低下と地域エゴを容認する傾向がＮＩＭＢＹ現象を生み、立地に多大の労力と時間がかかるようになって来た。着手から発電まで２０～３０年を要するケースも多くなっている。また、環境問題、特に地球温暖化問題がエネルギー供給の上での大きな制約要因になりつつある。昨年12月のＣＯＰ３京都会議では、二酸化炭素等の温室効果ガスの排出を先進国全体で5.2％、内日本は６％を削減することが決められた。長期的な二酸化炭素ガスの蓄積の影響が、科学的にかつ確実性を以って予見されている訳ではないが、手後れになっては取り返しがつかないとの理由で、「後悔しないための政策」が採用された。二酸化炭素ガスを大量に排出する化石エネルギーの使用を抑制しつつ、持続的な成長を今後も維持していくためには、原子力や再生可能エネルギー等のクリーンなエネルギーの割合を拡大させなければならない。短・中期的には太陽光発電等の新エネルギーは供給の主役にはなり得ないことが明らかであり、原子力の拡大が、エネルギーと環境との両立を図ることのできる唯一の道となろう。

長期的には、資源の量的な制約－化石燃料の枯渇－が現実の問題として浮上してくる。もちろん、化石エネルギー資源が突然枯渇するのではなく、エネルギー危機が何度か繰り返されるうちに、ちょうど波が繰り返し押し寄せるうちに潮が満ちてくるように、量的な限界が近づいて来る。振り返ると、７０年代の２回の石油危機は、波打ち際で遊んでいるところに突然大きな波が来たので驚いている子供の様子に喩えられるかも知れない。今は、波は全く無いが潮は腰の下まで満ちてきており、来世紀中頃には、潮は胸まで満ちているであろう。そして、その状態で受ける波（エネルギー危機）はずっと厳しいものとなるのに違いない。現在のように、廉価な石油が豊富に、事実上無制限に入手できる時には、将来のエネルギー資源の開発に消極的になるのはあるいはやむを得ないかもしれない。しかし、まだ余裕のある今のうちから、将来のエネルギー源の開発に取り組むべきである。新エネルギーの導入も積極的に行う必要があ

ろう。原子力においても、ウランの使い捨て（ワンススルー・サイクル）ではエネルギー資源の枯渇に対する解決策にならず、高速炉によるプルトニウム・リサイクルが必須のものとなる。高速炉およびその燃料サイクルについて、開発のリードタイムを考慮して早期に準備していくことが重要であり、エネルギー危機が発生してからでは間に合わない。ここでも、「後悔しないための政策」を採るべきである。

３．空間についての視点

従来のエネルギー・セキュリティーは、日本という国レベルの空間を想定していた。しかし、今後は国レベルだけでなく、グローバルな視点とローカルな視点とを併せて持つ必要がある。

昔と異なり、各国の経済は密接な関連を持っており、１国の都合だけでエネルギー供給を考えることはできなくなっている。アジアの経済発展は同地域のエネルギー需要の急増をもたらし、1995年には日本を除くアジアの石油輸入量は日本の輸入量を越えるに至っている。しかも、アジアのエネルギーの中東依存は極めて高く、日本と同様脆弱なエネルギー供給構造をしている。アジア全体としてエネルギー・セキュリティを考えないと、１国のエネルギー危機が地域全体を危機に陥れる危険性がある。地球温暖化や酸性雨等の化石エネルギー使用に伴う環境影響は地球規模での対策を必要とするが、このこともグローバルな視点を持たなければならない理由である。

日本だけが石油を一人占めできないのと同様、日本だけが温室効果ガスの排出を減らしても効果が無いのである。エネルギーの問題は、一国のレベルで解決できる問題では無くなっている。既に述べたように、原子力は地球環境とエネルギー供給を両立させ得る現実的な唯一の道であるが、日本自身が原子力発電所を増設するだけではなく、積極的な原子力開発が計画されているアジア諸国を、技術（原子力安全、核物質管理）および経済面で援助してゆくことが大切である。そしてそれが、アジア諸国にとっての利益だけでなく、日本のエネルギー・セキュリティーと環境にとっての利益に繋がってゆく。

グローバルな視点とは逆に、ローカルな視点、すなわち国内の地域毎にその特性に合せたエネルギー供給を考えていくことも重要となってきている。風力、太陽光、地熱等の再生可能エネルギーは地域の特性に依存するところが多く、地域毎の産業基盤を活用したＩＰＰや、地域内で行われるリサイクルと関連したＲＤＦと併せて、その地域に適したエネルギー供給を選択してゆく必要がある。これらのエネルギー源は、エネルギー供給の主役にはなれそうもないが、分散型の補助エネルギー源として、また将来目指すべき循環型社会の基盤として重要である。硬直的な、原子力と再生可能エネルギーの二者択一の論争ではなく、両者の最適な組み合わせ－ベストミックス－が要求されている。これは同時に、集中と分散のベストミックスの要求であり、また、環境負荷の低減化と持続的な成長の達成を両立させようという要求でもある。

４．おわりに

現在、日本は明らかに変革期にある。それはパラダイムシフトとでも呼ばれるべきもので、今世紀前半の半導体の発明に起源を持つ情報化革命が、社会的な変革を巻き込んで、ようやく集大成されようとしている。現在は、来世紀初頭にも予想される本格的な情報化社会の到来を待つ夜明け前に喩えられよう。来世紀にはまた、循環型社会が実現されていなければならない。地球環境の包容力と資源は有限であり、その制約の下で爆発的に増加していく地球の人口を支えるためには、物質資源のリサイクルと環境を護るための廃棄物処理がきちんとなされなければならない。一方、エネルギー消費を切り詰めることは巷間に言われているほど容易なことではない。情報化にも、省資源のためのリサイクルにも、環境を護るための廃棄物処理にもエネルギーが必要である。エントロピーが一方的に増大し、エネルギーが散逸していくのは熱力学の教えるところである。省エネルギー化を進めたとしても、文明の進歩と共にエネルギー消費が増加することは避けられそうもない。また情報化社会の到来で、エネルギー使用形態は化石燃料から電気エネルギーへと大きく重点を移してゆくだろう。持続的な発展を支えるため、安定供給が可能なエネルギー源－原子力－が絶

対に必要である。

現在のような変革期において、今何をなすべきか、方針を決定することは必ずしも容易ではないかも知れない。しかし、視野を広げれば自ずと道は見えてくる。広く、グローバルに俯瞰する視点が要求されている。グローバルな視点に立って初めてエネルギー資源の偏在と地政学的問題、あるいは地球環境の問題が見えてくる。そして同時に足元を見つめる必要がある。個々の人々のエネルギー消費行動が地球環境に直結しているのである。時間についても、遠く来世紀後半以降、化石燃料資源の枯渇までを視野に入れる必要がある。そして、いつ来るか分からないエネルギー危機に備えて、そしてその時後悔しないよう、代替エネルギー源の開発に真剣に取り組むべきである。最後に、地球環境とエネルギー安定供給を両立させ得るのは原子力しかないこと、将来のエネルギー資源に備えるには高速炉によるプルトニウム・リサイクルが必須であることを、もう一度強調しておきたい。

以　上

JAPAN'S SOCIAL REFORMS AND NUCLEAR ENERGY

Dr. Yumi Akimoto
President and CEO
Mitsubishi Materials Corporation

1. FOREWORD

In the wake of the 1973 Oil Crisis, Japan embarked on a program of energy conservation and diversification that, to a certain extent, has succeeded. Nuclear energy is now a leading alternative source of energy, accounting for about one-sixth of all primary energy sources and generating more than one-third of all electric power. Despite these long-term efforts, however, Japan's energy supply system remains insufficient. As of 1994, Japan still relied on fossil fuel for 57.4% of its energy needs and continued to import more than 80% of its energy from abroad. By comparison, France (a nation which, like Japan, has few natural resources of its own) was importing less than 50%.

The supply of petroleum has stabilized in recent years, thanks to advances in exploration and excavation technology. Asia's ongoing economic troubles have resulted in declining demands and lower prices, but another energy crisis is only a matter of time. Japan needs to reassess its energy security as it enters the 21st century.

Most discussions of energy security tend to focus on periods of only 20-30 years, but this scope is much too narrow to include our nation's expanding economic activities. We need to approach the problem from a much broader perspective, in terms of both time and space.

2. FROM THE PERSPECTIVE OF TIME

There are two viewpoints we can take here: the short-term and the long-term. In the short-term view, economic, political, social and environmental restrictions play a much bigger role than resource limitations. Japan imports about 80% of its petroleum from the politically unstable Middle East, a fact which demonstrates not only our enormous dependence on fossil fuel but also the fragility of our energy supply structure. Breaking our reliance on oil and the Middle East is a major priority for us. The waning power of Japan's central government and the growing autonomy of regional communities have given rise to an NIMBY phenomenon. It now takes an incredible amount of time and effort to get a nuclear plant built. In many cases, 20-30 years pass between starting construction and opening day. Environmental problems (especially global warming) put ever-increasing restrictions on our energy supply. At last December's COP3 conference in Kyoto, advanced nations agreed to reduce emissions of carbon dioxide and other greenhouse gases by 5.2% overall. Japan agreed to reductions of 6%. There is, as yet, no sure scientific way to predict the long-term effects of carbon dioxide gas accumulation, but any effects will be hard to erase after the fact and so we have decided to adopt certain policies "just in case." We shall have to increase our use of nuclear power, renewable energy and other clean energy sources in order to reduce consumption of fossil fuels while maintaining steady growth. New energy sources like solar power are clearly not going to meet our major energy demands, at least not in the short-term. Indeed, expanded use of nuclear power seems to be the only way we can obtain the energy we need while protecting the environment.

In the long-term, we are faced with a major resource limitation: the drying up of our fossil fuel reserves. This won't happen all at once, of course. Instead, we are likely to undergo a series of energy crises as we approach the end of our fossil fuel resources, like waves sweeping higher and higher onto a beach as the tide comes in.

The two oil crunches that hit Japan in the 1970's left us squealing like small children who'd been hit by a big wave while playing in the sand. There are no big waves today - but we're standing in water up to our waists, and the tide is likely to have risen to our chests by the middle of the coming century. Under these circumstances, the inevitable energy crisis - when it comes - will be a very powerful wave indeed. Today, when we have access to a seemingly limitless supply of reasonably-priced petroleum, we are naturally less than enthusiastic about developing new sources of energy for the future. Nevertheless, now is the time we must begin planning for tomorrow, while we still have the wherewithal to do so. We need to introduce new energy sources today. In the field of nuclear energy, the once-through cycle of uranium is far from being a solution to our resource limitations. We are going to have to start recycling plutonium in fast reactors. Developing such reactors and a suitable fuel cycle is going to take considerable lead time. We must begin today; after the energy crisis occurs, it will be too late. Here, as in other areas, we must adopt certain policies "just in case."

3. FROM THE PERSPECTIVE OF SPACE

Conventional notions of energy security have always been based on the national level. From now on, however, we need to combine with a global and a local perspective.

The economies of various nations are intertwined as never before, making it impossible to consider the energy supply of any one nation alone. Asia's economic expansion, for example, has led to a corresponding rise in this region's demand for energy. In 1995, oil imports to other countries in this part of the world exceeded those to Japan. What's more, those countries are even more dependent on the Middle East than Japan is; their energy structures are as fragile as - if not more fragile than - our own. If we fail to consider the needs of Asia as a whole, the energy crisis of a single nation may very well put the entire region at risk. The environmental side-effects of fossil fuel consumption (global warming, acid rain, etc.) are likewise global in nature and therefore demand a global perspective. Just as Japan cannot monopolize the world's supply of petroleum, we cannot significantly improve the world's environment if we are the only nation to reduce greenhouse gas emissions. Energy problems can no longer be solved by one nation alone. Nuclear power, as I have said before, is the only realistic solution to the problem of energy and environment. Along with building more nuclear power plants in Japan, it is important for us to extend financial and technological assistance (for matters like operational safety and management of nuclear materials) to other Asian nations that are planning to develop nuclear energy programs. Providing this support would do more than serve the interests of our Asian neighbors. It would also contribute to Japan's own energy security and the world's environment.

We must also think about specific energy needs at the local level. Wind power, solar power, geothermal power and other forms of renewable energy rely on local climatic or geological characteristics. We need to choose local energy supply fitting to the regional characteristics between these renewable energies and other localized forms of energies, such as IPPs (which make full use of local industries) and RDFs (which participate in local recycling efforts).

Of course, none of these localized forms of energy is likely to become a major source of power, but they play an important role in helping to decentralize energy generation and promote recycling. We don't have to choose between nuclear energy and renewable energy. Instead, we need to develop the right mix of both. We must strike a balance between localized and centralized power generation, diminishing environmental impact while achieving sustainable growth.

4. CONCLUSION

Japan is clearly on the brink of a revolution or paradigm shift. The informational and social changes that began with the invention of the semi-conductor in the first half of this century are now coming together. We stand at the dawn of a true Information Age that could start as early as the beginning of the 21st century. The coming century must also be an Age of Recycling. The earth's capacity to accommodate change is, like its natural resources, limited. To sustain our exploding population under these conditions, we've got to recycle materials and protect the environment by disposing of waste products with great care. Reducing our consumption of energy is not as easy as it sounds. Energy is required to sustain our growing information technology, to recycle materials and to dispose of waste products. The law of thermodynamics states that entropy increases and energy dissipates. No matter how successful we are in conserving energy, the fact is that advance of civilization inevitably leads to greater consumption of energy. Our growing reliance on information technology, too, will contribute greatly to the shift from fossil fuels to electric energy. Nuclear power is an absolute necessity because it provides the steady supply of energy required to sustain growth.

It's not easy to determine what must be done during a period of transition like this. If we broaden our perspective, however, the way becomes clear, because what's needed is an expansive, global perspective. Only when we look at the world as a whole, we can see the uneven distribution of natural resources and geopolitical issues, and also see global environmental problems. At the same time, we must also take a long, hard look at the ground around our own feet. The manner of energy consumption of each individual have a direct impact on the global environment. We need to keep in mind that our supply of fossil fuels is going to dry sometime after the second half of the 21st century. There's no telling when the next energy crisis will occur, so we must begin developing alternative sources of energy now.

Finally, I would like to return to two essential points: nuclear power is the only way we can protect the environment while generating a stable supply of energy, and recycling plutonium through fast reactors is the only way we can ensure a supply of energy for the future.

グレゴリー・クラーク

いま日本の社会が直面している問題を説明するのは、そう難しいことではない。日本はこれまで伝統的な、ということは封建時代終了以来の、価値観に基づいて今日あるまでに発展してきた。その意味では、日本の発展は北ヨーロッパ諸国—とくにイギリス、ドイツ—の発展と似ているといえる。けれどもこれらの価値観は必然的に、大規模な近代的産業国家を営んでいく上で必要な価値観と対立する。イギリスとドイツはもう百年以上かけてゆっくりとこの変身をとげてきた。だが日本はほんの１０年やそこらでそれをやろうとしている。

なお悪いことに、日本はいまひどい不況の中でそれをやろうとしている。しかも日本は、その過程で、北ヨーロッパ社会が犯したと同じまちがいを犯そうとしている。というのは、不況の時は、自然な本能として、人々は消費を控え、政府は支出を削ろうとする。だが以前ケインズという経済学者がいったように、不況の時はまさにその逆のことをするべきなのだ。ひとびとがもっと消費をするように励まし、政府はあらゆる手段を講じて景気を刺激しなければならない。

日本がこのまちがいを犯している原因は、ひとつには１９８０年代のイギリスとアメリカの例を見ていることにある。この二国はたしかにこの時期に大改革をやった—企業再編成、自由化、民営化、小さな政府、等々。しかしながらこれらの改革の直接の産物はひどい経済不況だった。この経済不況を救ったのは、きびしい通貨切り下げである。日本もやがてはこういう措置をとるべきなのだ。ただしそれは日本の経済が回復の兆しを見せてからのことだ。

回復の兆しが現れるためのポイントは、新しい産業、新しい技術、そして新しいタイプの投資だ。そうした新産業のひとつとして、当然、原子力関連産業が発展しつつある。日本でも他の国でも、原子力をめぐる危険に対する不安が大きい。とはいえ歴史的に見て、人間はいつも新技術に対して不安をいだいてきた。昔は鉄道、航空機、自動車輸送などが危険で、環境を破壊するものだと恐れられていた。また電力というものも恐れられていた。そんな例は枚挙にいとまがない。人類の歴史とは、こうした恐怖心を克服し、新技術のフロンティアを切り開いていった歴史でもある。

こう言ったからといって、原子力に危険が伴わないと言っているわけではない。だがすべての新技術についていえるように、経験を積むことで危険は次第に減っていくものだ。そしてつねに、「それがなかったらどうなるか」ということを考えてみる必要がある。もしいまでも馬と帆船に頼っていたとしたら、果たしてより安全だといえるだろうか。原子力の事故は人に危害を与えることもある。だが石炭や石油によるエネルギーも無傷ではない。その場合は、大気汚染がある。資源も限られている。毎年世界中で炭鉱事故による死者が数千人にのぼることもたしかだ。これらの人の命や、またたいてい幼い子供のいるかれらの残された家族の悲劇は、原子力発電で起こる可能性のある事故による被害に比べて、軽微だと考えてよいのだろうか。原子力という新技術に反対する人々は、この問いに答えなければならない。またかれらは、とりわけ、世界が火力発電に依存し続ける場合に地球全体の温暖化をどうするか、明らかにしなければならない。

原子力発電所をめぐる「近親憎悪」と「相思相愛」

柏崎市長　西（さい）川（かわ）　正純（まさずみ）

１．２０世紀は人類を幸福にしたか

２．２１世紀、人類はそして日本はどこに向かうか

３．人類と原子力発電所、その近親憎悪

４．にもかかわらず、相思相愛をめざす原子力発電所立地自治体の努力、そして訴え

セッション2:「日本社会の変革と原子力開発」

東京電力㈱取締役原子力本部副本部長
宅間正夫

日本社会の変革と原子力開発について・・・・・3点に絞ってのべる。

１．　我が国は明治維新以来、つい今日まで物不足解消のために経済社会全体に生産者論理が支配したきたといえる。生産の効率性のためには、限られた専門集団に権限を集中させて中央集権的にことを行うのがよかった。産官の護送船団方式がその一例であろう。原子力開発もその例外ではなかった、といえよう。また、電力消費地域と生産地域の問題も、こうした社会を背景に生じてきたのではないか。

技術の語源は古代ギリシャ語の「アテレイア」で、「かくれたるものを現すこと」を意味するといわれる。「自然」のなかに隠れたものを明らかにし、花開かせる哲学や芸術にも通じるが、「技術」は自然を挑発しむりやり立ち上がらせる創造的プロセスであり、その過程で「技術」は自律的な運動をはじめるようになる、この時に「技術」は地球環境や人間の精神におおきな影響を及ぼすようになる、という。

生産者論理の世界の中で、技術を扱う専門集団が技術の自律的発展のおもむくままに社会や自然から離れてしまうと、その技術が如何に有用なものであっても社会から拒絶されることになるであろう。原子力は今、その一つの典型となってしまっていないか。

そし今日のグローバル化した市場原理の自由主義経済社会では、コストとサービス、お客様第一という消費者論理の時代である。利便性のみならずそれを超えたところで「技術」の社会的受容性が求められている。

この意味で原子力技術とそれを扱う専門集団の「社会性」が今、厳しく問われている。

現在のモノ不足の状態は一応解消されたようにみえるが、それと同時にある意味での皆の共通の目標であったモノの豊かさを追って、より良く、より多く、より大きいものを求める心も一段落して、なんとなく目標を見失ったように見える。

こうした折から、チェルノブイル事故の記憶の残る中での動燃の一連の事故は、それまでは増加する電力需要を背景に「必要性」が「安全性への不安感」を押さえ込ん

でいたようにも見える原子力に対して、一気に「安全性への不安感」が高まった。

かっては、「鉄腕アトム」に象徴される夢の技術であり、現在地球温暖化問題への対策の一つとして期待されてしかるべき特性を持ち、我が国の電力供給の３分の１を超えるほどに電力供給に重要な実績を上げている技術がなぜこうなってしまったのか。

これは、前述したように、従来、成長経済の中で、国，電力，メーカーに委ねていた原子力開発が「気がついたら知らないうちに事が進んでいた」ということへの不信感が、消費者原理の時代になってクローズアップされてきたのではないだろうか。本来、社会としてきちんとすべきだった色々な課題がなおざりにされてきた事のツケに直面しているのではないだろうか。例を挙げれば、ひとつは、原子力当事者が社会の声を自らの耳で聞き、社会に自らの声で語り、理解と支援を得る確固たる姿勢に欠けていたこと、ひとつはエネルギー，環境，原子力について教育現場で必ずしも十分に取り上げられてこなかったこと、さらにこれらが国のエネルギー政策として国会など公の場で十分に論じられず、国民に見えてなかったこと、である。

強調したいことは、市場原理の自由経済社会は言うまでもなく一人一人の個人が自主性、主体性を持って自己責任の原則のもとで市場に参加し、社会を作っていくような世の中であると思う。そうなると、自分の価値観や健全な社会常識をしっかり持った個人が企業や集団を形成していくこと、その中で官と民の社会的役割をしっかり踏まえてそれぞれがなすべき事をなすこと、という当たり前のことが、これからの社会では今一度根本から問われることになるであろう。

効率性を追求した結果の中央集権や首都圏集中が見直されつつあり、個人，分権，地方の時代となっていく今後は、いわゆるＮＩＭＢＹ（Not In My Back Yard）について市民レベル，国民レベルで真剣に考え、議論すべきであるし、このなかで生産者論理の時代を背景として顕在化した生産地・消費地の問題も論じられるべきであろう。

２．　生産者論理の世界はいわば男性原理・父性原理の社会である。これに対して、消費者原理の社会は女性原理・母性原理の社会といえよう。今日大きな価値と認められている多様性を許容する共生、人間と人間との信頼、自然環境への思い、生産地と消費地の相互理解等は、母性的な包容力と女性的な優しさなしには実現しえない。

こうしたなかで男性的なハードな技術の典型と思われている原子力をどうご理解・ご支援いただくか。再生可能エネルギーなどソフトなエネルギーでその効用を代替することが容易でないとすれば、ハードな技術を社会に訴える方法をソフト化していく

こと、しかないであろう。

最近の情報公開の徹底からインフォームドコンセント、さらには政策・方針決定への一般市民の参加など、今までとは違ったアプローチが既に進められつつある。

要は専門集団が社会や自然に対して、どのような心でのぞむか、ということである。

人間が自然と関わり合いながら時の流れの中で作り上げてきた諸々のモノや心が文化である、と私なりに定義すると、技術もその一つに過ぎないが、しかしきわめて重要な一つである。有限な生態系である地球に、人間をはじめとするいろいろな生物が共生していく上で、その重要性はますます増大するであろうし、使い方によって不可欠の有用性を持つであろう。原子力について言えば、技術を扱う当事者が自然や社会に対して謙虚さを失うことなく技術の夢とすばらしさをもう一度人々に理解され、感じてもらう努力を惜しんではならないと考える。

自然や社会に対して、技術に責任を持つ当事者は、技術の持つ長所も短所も社会に示して議論を深め選択肢を示していくことである。そして、今後ますます重要になってくるのは情報の発信者と仲介者と受信者の３者がバランスのとれた関係にあることであろう。生産者論理の社会では、発信者側の選択で開示されていた情報は、今後は受信者側すなわち社会が必要な情報を要求し、選択し、評価して、発信者即ち当事者の信頼性を判断する社会になってくる。ということは、発信者側の情報公開は当然のこととして、受信者側に必要な情報が必要な領、誤り無く伝えられ、やりとりされるための仲介者、そして情報を要求し、受け取り、判断する受信者の責任も重くなる。

原子力の「安全」を「安心」して社会に受け取っていただくためには、当事者の技術や技術力に対する「信用」のレベルから更に一歩進んで当事者の人間性への「信頼」のレベルにまで進まなければならない。

３．　殆どの天然資源を輸入にたよる我が国の現状は、時代的に社会がどう変化しようとも変わらないし今後も変わりえないであろう。さらに、地球環境問題など新たな国際規模での制約は国内でのエネルギー供給手段の選択の幅をいっそう狭める可能性を示している。

第２次大戦後、一億の日本国民が生存していくための産業復興とそのためのエネルギー供給に、電気事業者が必死の努力を傾けるさ中、１９５３年、原子力の平和利用と原子力発電の可能性が開けた。資源のほとんどない我が国がこの時、いち早く、英

国などとともに準国産エネルギー資源として原子力を選択し、「熱中性子炉——再処理とウラン資源リサイクル——高速増殖炉」のシステムの開発を進めてきたバックグラウンドは今いささかも変わっていない。そして我が国の原子力開発とその産業化のプロセスの中で、技術・人材・設備そして高い安全文化と高品質を作りこむシステムは、世界的にも貴重なインフラとして存在していることは看過できない。２１世紀に向けて発展途上の国々にとって我が国の有するこのインフラのもつ意義は、環境とエネルギーの両立を考えるとき、大きな意義をもつものと考える。しかし、時の流れの中で、事に当たる当事者は「不易流行」をも常に念頭におかなければならない。

市場原理の自由経済は、基本的には、市場に資源が豊富に供給され誰でも機会均等に市場で手に入れられるとともに、起業家精神（アントレプレヌールシップ）を持った者が、それでつくった製品を自己責任で機会均等に市場に売り出せる、という社会のように思える。そこで資源の必ずしも豊富でない国や海外から資源を容易に入手できない国がグローバル化していく市場経済を導入しようとすれば、必要な資源についてそのベースになる部分の供給を国や責任ある当事者が計画的、戦略的、長期的に保障することによって、その残りの部分、フリンジの部分に市場原理を導入できるようにする事が不可欠である、と思う。電力供給で言えば、資源のない日本にとって原子力はまさにベース部分にあたる。単にベース電源というに止まらず、発電市場の競争原理の導入を可能とするという意味である。我が国の最近のＩＰＰ導入は原子力がベースとして定着したことが、それを可能としたひとつの条件、と考えられないであろうか。

公共事業者である電気事業者は、２つの社会的使命を持っている、と考える。
一つは、いまのお客様に安価で安全で良質な電気を過不足無く供給すること、であり、もう一つは、そういう電気を後の世代のお客様に送り続ける、ということである。ウラン資源の再処理、リサイクルはこのためのインフラ整備であり、今の世代が少しでも進めておくべきもの、と言えるのである。

従来、日本の原子力は「国策民営」とでも言うべきやり方をとってきて、この背景には国のエネルギーの安全保障と電気事業者の供給責任を全うするためのエネルギー安全保障は一致している、という了解があったと思う。電力自由化が叫ばれる現在、これをどう考えるか。

前述のように、日本の資源や環境事情は社会構造如何によらず、基本的には変わら

ない。従って、上記の二つの安全保障は将来とも極めて重要であることには変わりない。国のエネルギー安全保障はどちらかと言えば長期スパンであり、かつ必ずしも柔軟性があるとは言い難いが、電気事業者のそれは長期，短期いずれも視野におかなければならないし、民営事業者であるからいずれの状況に応じて柔軟に力点をかえた経営が可能である。欧米で進む電力自由化の中で、短期的，近視眼的経営の傾向があり得るとしても、電気事業の長い、様々な歴史の上に育った日本の電気事業者は、短期的な状況に対応しつつ長期の供給の安全保障を着実に進めていく。このためには原子力の開発は重要な決め手である。変わりゆく社会の中で、変わるべきものと変わってはならないものとをしっかり見つめていくべき、と考える。

以上

Session 2 :

Revolution of Society and Nuclear Power Development in Japan

Masao Takuma
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I want to focus on following three viewpoints:

1. We can reasonably deduce that since the Meiji Restoration until quite recently "producer logic" has governed the conditions of the whole of economic society in Japan in order to overcome our disadvantage of having virtually no resources. For improving production efficiency, a centralized operation of industries, by concentrating authority on selected elite groups, must have been the most effective means. The system of the business world being divided into industries and protected and controlled by bureaucracy (the so-called "convoy system") is a typical arrangement designed with such intention, and the development of nuclear energy was not an exception. The problems existing between electricity consuming and producing districts have probably resulted from this system in the background.

The origin of the word "technology" is said to be the ancient Greek word *"atireia"*, which means "to reveal what is concealed". "Technology" has something in common with philosophy and art in that they reveal what is concealed in nature and bring it to blossom. However, "technology" is also a creative process through challenging nature to force it to reveal what is concealed, and "technology", in that process, begins to assume autonomous movements, inflicting serious impacts on the global environment and human spirit, it is said.

Once the elite group in control of some kind of technology begins to act as an autonomous force in a society operating under producer logic, such technology could eventually turn out to be unacceptable to society, however useful the technology. Maybe we need to ask ourselves if nuclear energy has not developed into a type of such technology.

Furthermore, we are living today in an age where "consumer logic" prevails which requires priority be given to costs and services and the satisfaction of customers and in a globalized liberal economy where market principles rule. In such an environment, what is required of "technology" is the social acceptability of the technology rather than its usefulness.

In this context, "the social performance" of nuclear technology and the elite group managing the technology is now being seriously questioned.

The state of the scarcity of goods seems to be eliminated provisionally, which, however, seems to have deprived people, lulled in by the disappearance of scarcity, of their target of seeking a better living surrounded by better, more and large wares.

In these circumstances, a series of accidents of PNC occurred while the memory of the Chernobyl accident still had not faded away, heightening directly "the concern on safety" of nuclear energy of which "the necessity" seemed to have been restrained "the concern" due to increasing demands for electricity in the background.

What happened to the technology which once was looked upon as a technology of dream symbolized as "TETSUWAN-ATOM (the Cannonball Atom)", which is a hero in Japanese famous cartoon, and has characteristics worth our expectation as an effective means of mitigating the global warning effects and is boasting a significant record of supplying electricity exceeding one third of our total electricity demands?

I believe the fact is that the distrust of the people was highlighted in the age of consumerism when they realized that things have developed in undesirable directions in nuclear energy development entrusted to the government, utility companies and manufacturers. Maybe, we are facing a situation of paying off the debt of our negligence of not having properly dealt with the issues which should have been essentially resolved orderly by the society. To name some examples, the people in the nuclear industry lacked a confident attitude in gaining the understanding and support of people through listening to voices of society with their own ears and talking to the society with their own voices. Or, the subjects of energy, environment and nuclear energy were not properly dealt with in the curriculum of schools and further, these matters have not been fully debated in public forums, such as the Diet, as the government's energy policy so as to draw people's attention.

What I should like to emphasize is that a society of a free economy, under the working of the market principle, naturally should be where each individual participates in the market independently and accountably with their own initiative to structure the society. There, individuals, firmly holding an values and sound social common sense, should constitute enterprises and groups and do their duty with good understanding of their tasks charged by the society whether they be part of public sector or the private sector. This rightful proposition will have to be questioned again thoroughly in future society.

The centralized administrative power and the concentration of activities in the metropolitan district, a mechanism necessary for the pursuit of efficiency, are under re-examination now. Problems with the so-called NIMBY (Not in My Back Yard) attitude of people should be seriously reconsidered and discussed at citizen's or national levels in the coming age of individual, decentralized authority and local societies, and through this process the problems between producing and consuming districts which surfaced during the age of the working of producer's logic should also be discussed.

2. The world under the workings of producer logic is in a way a society of masculine or paternal logic, whereas the world of consumer logic may be contrasted as a society of feminine or maternal logic. Qualities such as symbiosis to allow diversity, trust between people, valuation of nature as environment, mutual understanding between producing and consuming societies are regarded as highly valuable today, but they cannot be fostered without a maternal toleration capacity.

In this situation, the only way to successfully win the understanding and support of people for nuclear power, which may be a typical masculine and hard technology, is to moderate the manner of appealing for the introduction of a hard technology to society, because it is not easily practicable to replace a hard technology with some soft technology, like that for a renewable energy, in terms of its usefulness. New approaches different from those used in the past have recently been introduced. They include thoroughgoing information disclosure, creating informed consent and the participation of the general public in the determination process for policies and plans.

What is important is that the minds of the people in the elite group be directed sympathetically toward society and nature.

My interpretation of the culture is it includes all kinds of things and the spirit people developed with the long lapse of time under the influence of nature. In this context, technology is merely one of them, but an extremely important one. Its importance will increase more and more to support symbiotic existence of every kind of life including mankind on the earth of a finite ecologic system. And it will have an indispensable usefulness, which depends upon how it is used. As for nuclear energy, I believe the people in this business should not spare their efforts to renew understanding and consciousness of people on superior and dreamful nature of the technology by keeping in mind the importance of modest attitude toward nature and society. What is required of the people responsible to our nature and society in development of technology is to show and discuss in detail its advantages and disadvantages and to explain available options for us to society. And what is increasingly important now is a well-balanced relationship between the three parties of the dispatchers, intermediaries and receivers of information. Information which was used to be disclosed at dispatcher's option in the society of the producer's logic will have to be disclosed so receivers, or society who demand, select and evaluate it to judge the trustworthiness of the dispatchers, or the parties in industries, in the society of future. This means that the responsibility of intermediaries who collect a necessary amount of required information and correctly transmit it to receivers and the responsibility of receivers who demand receive and evaluate the information will increase. Of course it is needless to emphasize the importance of information disclosure.

In order to win acceptance of society for "safety" of nuclear energy comfortably, the people in the industry must advance one step further from a level of "confidence" in the technology and their technical capability to a level of "trust" in their own humanity.

3. The present condition of our country which requires us to rely on imports for most of our natural resources should not change in future; however, society undergoes change with time. Furthermore, new restrictions being imposed on a global scale, such as those addressing global environmental problems could possibly further narrow down the range of options available for our domestic energy supply.

When utility companies were making strenuous efforts in support of the industrial rehabilitation and assurance of required energy supply for the survival of the 100 millions of our people after the last world war, an opportunity for the peaceful use of nuclear energy and nuclear power generation emerged in 1953. Our country promptly joined with England and others in accepting nuclear energy as a quasi-domestic energy resource and undertook to develop a system of "thermal neutron reactor—reprocessing and recycling of uranium resources—fast breeder reactor". This background has not changed as of today. Also, we should not fail to notice the fact that we hold, as a globally valuable infrastructure, technology, human resources, and facilities and systems capable of instilling superior safety culture and high quality into products, which we have fostered in the process of our development and industrial application of nuclear energy. I believe the importance of this infrastructure of ours for developing countries is very significant when we consider the need for the resolution of the problems of environment and energy compatibility as we enter the 21st century. However, in this changing world we must always keep in their mind the proverb; "Substance does not change with the passing of time".

I consider a society of free economy under the working of the market principle basically is where resources are abundantly available in markets, anybody can obtain them at the markets with equal opportunity and the people with entrepreneurship can sell their products at the markets but at their own risk. Now, it seems important for countries which do not have sufficient resources or an easy means to obtain resources from abroad to secure systematically, strategically and in a long term the basic portion of necessary resources and to apply market principle only for their remaining fringe portion in order to introduce the globalizing market economy into them. For electricity supply, nuclear energy is that basic portion for Japan not favored with resources. Nuclear energy is not only important as the base of its electricity supply but also important in introducing the rule of competition in the power generation market. For the recent introduction of IIP in our country, the stable development of nuclear power may have been one of the conditions that has made that introduction possible.

Electric utility companies have two missions socially as a kind of public utility operation. One is to supply economical, safe and quality electricity in an adequate amount to customers of today and the other is to continue supplying electricity to customers of future generations. Reprocessing and recycling uranium resources are necessary for preparation of infrastructure to carry out these missions and are the things we should advance for the sake of our next generations. Up to today, the nuclear energy program of Japan has been undertaken under a system which may be called "private operation under the national policy" and there has been understanding in the background that the national security of energy supply and the energy security required to fulfill electric utility business's responsibility for supplying electricity are in accord. This is a question we should consider now when the freeing of the electricity business is crying out.

As I just mentioned, the resource and environmental conditions do not change basically with changes in the social structure, and the two kinds of the security will still remain extremely important in the future. The national security of energy is a long-span issue rather without flexibility and that of electric utility business has to be examined from both the long-term and the short-term point of view and it can be managed flexibly by changing its emphasis in response to changes in the situations because it is a private enterprise. While there is a possibility that short-term and short-sighted management will gather strength in the U.S. and European electricity business as the freeing of the business progresses, electric utility business in Japan which has a long and difficult history will steadily advance the long-term security in supplying electricity with properly dealing with short-term changes in conditions. In doing so, the development of nuclear energy is an important key for us. We should distinguish clearly what should be changed from what should not be changed in this society.

memo

memo

世間社会から市民社会への転換期における産業政策の課題

日本ＮＰＯセンター
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世間社会から市民社会への転換期における産業政策の課題

現代の日本は，世間社会から市民社会への転換途上にある。もう少しはっきり言えば，日本型世間社会から地球市民社会への転換と言ってよい。

この変化の始まりは１９８５年のプラザ合意とそれに伴う円高の急進，そして自動車や電気製品をはじめとするメーカー企業のアメリカを始めとする海外への進出である。ここでこれまで世間社会に守られてきた企業は市民社会の厳しさに直面する。その中で市民社会型の経営を身につける。

しかし国内市場を対象とする産業は，この間，依然として世間社会に守られ，バブル経済の中で結局は足腰を弱くした。昨年から今年にかけての一連の倒産騒ぎ，官民の癒着騒ぎは，まさにこの分野における市民社会型経営への転換を余儀なくされつつある姿を示している。そして産業界だけでなく社会全体が，今，その本格的な転換に迫られていると言っているのだ。

それを象徴するのが，この３月１９日のＮＰＯ法すなわち特定非営利活動促進法の成立だ。市民の力を背景に議員立法でできたこの法律は，もとの名を市民活動促進法と言っていたように，市民活動団体に主務官庁制度によらないで簡便に法人格を与える仕組みを実現したものである。ただそれだけのものには過ぎないが，ちょうど１００年前に施行された民法による公益法人制度に，ささやかながらも風穴をあけた意味は大きい。また法人制度で初めて情報公開を義務付けた意味も大きい。それは官から自由な透明性のある民間非営利活動の普及と発展に寄与し，世間社会から市民社会への転換を推し進める大きな力ともなろう。

私自信は原子力産業に関しては全くの素人ではあるが，そのような転換の中で新たな挑戦を受けているかにみえる。その課題を他のパネリストと論議できればと思う。

SESSION 3

Downstream Side of the Nuclear Cycle
Review of the Situation in France

Mr. Claude Mandil, Director General of Energy and Raw Materials
At the French Ministry of Economics, Finance, and Industry

Mister President, Ladies and Gentlemen,

It is an honor and great pleasure for me to take part in the JAIF for the first time this year, and to say something about a very important theme : the downstream side of the nuclear cycle.

First, I would like to say just a few general words about French energy policy. The goal of this policy, adopted on the heels of the first oil crisis, was mainly to achieve long-term supply security, and was based largely on the use of nuclear energy with the concomitant active energy savings and diversification of our foreign fossil energy resources. In twenty years' time, France accomplished a very ambitious investment program that now places the country in a unique position worldwide, in terms of the use of nuclear power for the generation of electricity.

The nuclear option allows France to enhance its independence, to avail itself of competitive energy, and to reduce the level of greenhouse gas emissions, which is indispensable for honoring the Kyoto commitments of December 1997. One feature of French nuclear policy is therefore its marked continuity.

With EDF, Framatome, and Cogema, France has world-class competitive industries and research of unanimously recognized quality at the CEA and Andra, of which the CEA's Administrator General, Mr. D'Escatha, gave a brief description on Monday.

The downstream side of the cycle is one of the major questions in the nuclear field today, and the rest of my discussion will be centered around this theme.

French industry downstream of the nuclear cycle has leveled off. Industrial investments have been made and are operational today. At the same time, major research programs are continuing to lay the groundwork for the future, especially for the decisions expected in 2006 concerning long-lived radioactive wastes.

I will first be talking to you briefly of these two aspects – industry and research – and try to show you the continuity of French policy, particularly in light of recent governmental decisions.

Then I will lay out the various strategies concerning the downstream side of the cycle seen in the long term, showing you all the flexibility that exists today.

1) A Consistent, High-Performance Industrial Tool

The French nuclear power plant population operated by the French power company, EDF, today includes 57 reactors in operation and one under construction. On the downstream side of the cycle, France has opted for reprocessing-recycling and has acquired the corresponding industrial tools operated by Cogema:

- × the Hague reprocessing plant, which also works for the requirements of Japanese, German, Belgian, Dutch, and Swiss electricity producers;
- × the MOX manufacturing plants of Cadarache, Dessel in Belgium, and the very modern Melox plant in Marcoule. This system is operated both for France and for export.
- × the number of French reactors loaded with MOX is increasing. Technically, up to 28 reactors can be charged with MOX. As of today, 16 are authorized to be charged, and this number should increase in the coming years as EDF applies for new authorizations and these are examined by the Nuclear Safety Agency.

France has decided to opt for reprocessing-recycling for two reasons:

1) Environmental

The plutonium contained in the spent fuel is essentially what constitutes its long-term toxicity (95 % at 10,000 years), so that its long-term environmental impact can be reduced considerably by reprocessing and recycling. These processes also isolate the only true ultimate wastes, which are the products of fission and minor actinides, so they can be given proper conditioning.

2) Long-term Economics

Reprocessing is a way of recycling uranium and, while this may certainly be an abundant natural resource today, it will necessarily be less so in the future.

We are aware that the increasing stock of separated plutonium poses a political problem. This is why, in order to avoid increasing its stock of separated plutonium, EDF has its irradiated fuel reprocessed as the need for the plutonium extracted from it arises. So the quantity of reprocessed fuel depends on the capacity of the MOX manufacturing plants and on the authorizations given to reactors to use the substance.

Currently, a little more than two-thirds of the irradiated fuel discharged from EDF reactors is reprocessed. The rest is stored, and what will become of it depends mainly on decisions that will be made in the coming years, especially the irradiated MOX fuel. A number of options are possible in these two fields, and the decisions will be made in light of the results of current research.

Hearing this, you doubtless wonder if there is not a contradiction, not to reprocess all the irradiated fuels, whereas I just told you that reprocessing is very useful on the environmental level. In answer, I can say that these fuels may someday be reprocessed anyway, but moreover any reduction in the stock of plutonium by recycling is a step in the right direction.

2) Research Programs to Prepare for the Future

In accordance with the law of December 30, 1991, there are three lines of research on the management of highly active radioactive wastes. This law defined a certain number of rules concerning the management of radioactive wastes, thus allowing for a transparent and democratic process. One of these rules prohibits the storage of imported radioactive wastes in France, even if reprocessed in France, beyond the time technically necessary for the reprocessing. The law therefore requires the wastes to be returned after reprocessing.

The three research themes provided for by the law are:

- separation-transmutation;

- reversible and irreversible disposal in deep geological layers, particularly with the construction of underground laboratories;

- surface conditioning and storage.

The purpose of this research is to provide the Parliament with the means of making decisions on the future of these wastes in 2006. The studies are being monitored and evaluated by a scientific "National Evaluation Commission" of 12 independent scientists. This commission writes a research evaluation report each year, and will generate a global report in 2006 to serve as a decision-making basis for the Government and Parliament.

The Government is determined to continue research along these three lines. This has been clearly restated by the Prime Minister, who made the decisions presented at the press conference of February 2, 1998, by the Minister of the Economy, Finance, and Industry, Mr. Strauss-Kahn making the following points :

Concerning the *first theme* of investigation, research on transmutation will continue despite the final decision to shut down the Superphénix fast neutron reactor (FNR), which is possible mainly due to the full resumption of Phénix operation and international cooperation.

In this respect, I would like to state the reasons why the government, in line with its political commitments, decided to abandon Superphénix. It was in fact felt that this prototype, launched in the seventies in a context of energy shortage and an estimated scarcity of uranium resources, is ill-suited to the current context. Today's population of conventional nuclear power plants is fully sufficient to meet our needs. There is no tension in energy prices, nor a supply shortage of uranium. The breeder reactor does not seem to have any short-term industrial perspective. Furthermore, this was a considerable technological advance to master, and was costing much more than planned. In its current state, it cannot be considered to be a model to be replicated in any breeder reactor development program.

So the government decided to drop Superphénix for technical and economic reasons,

and not for security-related reasons.
I also stress the fact that this step should not be taken as a disavowal of the fast neutron reactor idea. The acquired experience will be used, and research on fast neutron reactors will be continued in the long term, so that if someday it turns out that fast neutron reactors would be of use, there will be no obstacles to prevent this. In the short term, the research conducted in the Superphénix framework will be reoriented toward Phénix, a reactor of about the same size as Monju, especially for experimental purposes. Lastly, other avenues of transmutation research will be explored, with innovative concepts like hybrid systems, namely the projects of Professor Rubbia. France is anxious to see these programs conducted in an international framework, especially with countries that are still interested in the development of FNRs: Japan and Russia.

The *second theme* is storage in deep geological layers. The underground laboratory project – laboratories in which storage is explicitly prohibited by law – has sparked a very broad debate among officials and the population since the beginning. In 1993, the government put Representative Christian Bataille in charge of a mediation mission, after which he proposed four candidate sites for laboratories.

After two years of detailed reconnaissance work, the government authorized applications by the Andra agency to install and operate underground research laboratories on three sites: two in clay and one in granite beds.

These applications were subjected to a very detailed investigation in 1997, including a broad dialogue with the local communities and authorities.

On February 2, 1998, the Prime Minister announced his decision to retain at least two sites, in accordance with the law. He asked the National Evaluation Commission to continue its study of reversibility and the means of achieving it, and to report on its work by mid-year. The choice of sites for building and operating underground laboratories will be made known at that time.

Lastly, the research on the *third theme*, which is the study of the conditioning and long-term storage, will be intensified. Funding will be increased 15 % for this in 1998, and 20 % in 1999, reaching FRF 300 million per year. The priority here is a census of existing storage sites, an inventory of wastes to be stored, a functional analysis of a very long-term storage facility, the definition of containers, the long-term properties of the depots, containers, and packages. I will say again that we are of course only in the research phase on this theme, as on the other two. This will continue until 2006, so that no decision has yet been made to build a very long-term interim storage facility.

It would be useful for France to pursue all these research programs in a cooperative international framework, especially with Japan.

3) Flexible Strategy

The government wanted all the decisions affecting the downstream side of the cycle to be consistent, and asked me to act jointly with Mr. Vesseron, who is director at the Ministry of the Environment, to straighten out any conflicts in the strategies of the various players.
To this end, we organized a workgroup comprising the government agencies concerned, and asked the industries to do a great deal of analysis and thinking.

This work led to the writing of an intermediate report that was submitted to the Ministries of Industry and the Environment in the summer of 1997. This report is currently being examined by the parliamentary office of scientific and technological assessment, which is the body that has jurisdiction over these questions in the French Parliament. Once this office has made its comments known, a final report will be written.

To fulfill the mission entrusted to us by the Ministries, the committee's first step was to review the decisions already made concerning the downstream side of the cycle, which affect the strategy that is currently being followed by the various players in the nuclear sector. Whether or not this strategy will be followed beyond 2006 as provided by the law of December 30, 1991, depends on the decisions that will be made at that time, principally as concerns a possible authorization for an underground storage center.

The committee's second step was to define a number of possible post-2006 scenarios, attempting to cover as much territory as possible, with no preconceived ideas. We generated ten such scenarios, ranging from "all directly to store" to "all reprocessed".

I would like to tell you how we constructed these scenarios.

Several principles were followed. We used the time horizon of the year 2050 – neither too close nor too far off – and an annual nuclear electricity generation level of 400 TWh equivalent to today's level, which will still come to about 70 % of the total. The purpose was not to make energy forecasts. Furthermore, some of these scenarios assume that new industrial tools will be developed at more or less remote points in time, depending on their technical maturity and industrial requirements: blast lasers for reprocessing uranium or plutonium, hybrid systems, incinerators, new-generation FNRs, and so forth.

From there, we developed a decision tree consisting of answering the following four questions in succession.

The first is whether a deep storage center will be created or not. If this option is not retained, long-term surface storage of indeterminate duration would become unavoidable. We felt that this could not be considered a full-fledged strategy, but only a stop-gap measure that was not worth studying in depth.

The second question concerned the more or less large quantity of plutonium that could be placed in deep storage.

The third question is whether or not FNRs will be present – for energy reasons – in the nuclear power plant population. Of course this involves long-term strategies on the horizon of 2050, so I would like to make it very clear that there is no reason to discard those scenarios that include FNRs out of hand. Once again, the decision to drop the prototype Superphénix reactor was in no way a decision to abandon the FNR process altogether.

The fourth question is whether or not plutonium will be recycled in pressurized water reactors.

On the basis of the various possible answers to these questions, ten post-2006 scenarios were developed, grouped into five main paths. I will very briefly describe each of these paths, which should give you a good idea of how our thinking is going.

Path A. This is the open cycle, that is, with storage of irradiated fuels without recycling, with or without reprocessing for conditioning.

Path B. This is a partially closed cycle. Reprocessing is simplified, *i.e.* it becomes authorized to separate plutonium in the reprocessing operations with less efficiency than the current 99.9 %, and this plutonium is recycled. Moreover, certain irradiated fuels can be stored directly. This is a continuation of today's policy, with the fast neutron reactors.

Path C. This is a closed cycle with recycling of plutonium in pressurized water reactors or fast neutron reactors. Reprocessing is simplified.

Path D. This is a closed cycle with recycling of plutonium in pressurized water reactors or fast neutron reactors, and transmutation of minor actinides and long-lived fission products in one of the two scenarios.

Path E. This is a totally closed cycle only for plutonium in pressurized water reactors.

Of course, it would have been possible to develop an infinite number of scenarios; but it seemed to us that any scenario could be a combination of the ten scenarios retained.

The committee's third and last step was to evaluate each of these ten scenarios by different criteria: the flexibility needed to go from one scenario to another, the R&D effort needed, the financial effort, positioning in the international context, the quantities of material to be stored at surface or at depth, and the environmental aspects.

We felt it was no use trying to decide today which would be the best post-2006 scenario, but we rather tried to determine which of the scenarios studied were actually stop-gaps or dead-ends.

The main conclusion from this evaluation is that none of the scenarios studied would constitute a stop-gap or a dead-end. Nevertheless, while all of them are possible, not all of them will be pertinent with respect to the economic or technical environment at the time they come into play. And yet there is no clear-cut trend in this environment, so it would be careless to eliminate any one of the scenarios now at the outset.

From this point of view, we felt that the current strategy, as I have described it, offers many degrees of freedom and makes a move toward any one of the ten scenarios possible after the 2006 date set by the law of December 30,1991, or more probably toward a combination of several of the scenarios studied. The main conclusion is that it would be best to maintain the current flexibility to its utmost, in order to avoid jeopardizing certain options now that could be of use after 2006. This particularly applies to the continued research on the three themes of the law of December 30, 1991, which the government is determined to sustain, as I have said, and which enhances the flexibility of the current strategy. This leaves all possible avenues open for the future, so that the decision-makers of the second or third decade of the coming century will not be confronted with a dead-end situation.

Thank you for your attention. I am ready to answer your questions.

Spent Fuel Management

by
Dr William L Wilkinson
President, British Nuclear Industry Forum

ABSTRACT

The two options for managing spent nuclear fuel, namely, **reprocessing** with recycle of plutonium and uranium and **direct disposal** are discussed based on experience in the UK.

The reprocessing option is well proven. It is available now and operating well under international safeguards. Direct disposal may prove to be technically feasible in the future. The economic differences between the two are likely to be small and likewise the environmental impact. So far as public acceptability is concerned the main issue is the geological disposal of radioactive waste and this is common to both options. Long term sustainability is a key issue and only recycling can achieve this.

The choice between the two will depend on many factors and utilities may come to different conclusions depending on the individual circumstances at the time. Both options are likely to be pursued in parallel over the coming years. It us unlikely that new developments will have a significant impact on spent fuel management policy, at least in the medium term.

Introduction

There are two options for dealing with spent nuclear fuel:

- the once through fuel cycle with no separation of plutonium and direct disposal of spent fuel
- the separation of plutonium and uranium by reprocessing and recycle as MOX initially in thermal reactors and, possibly, later in fast reactors.

Both are viable but opinion is divided. Some countries prefer direct disposal and others recycling. The choice of the preferred strategy is specific to each country and depends on both economics and resources as well as political considerations.

Some countries, notably the USA, believe that plutonium should not be separated from spent fuel and that storage of spent fuel followed by direct disposal is the preferred strategy, especially from a proliferation point of view.

Others notably the European countries (UK, France, Belgium, Germany, Switzerland) along with Japan and Russia regard plutonium as a valuable resource and favour reprocessing and recycling within a strict safeguards regime.

National strategies were in the main decided 20 or more years ago and once the commitment has been made it is difficult to change in spite of the great changes which have taken place in the nuclear scene in the meantime, notably:

- nuclear power is growing fast in the Far East but it is static in Europe and the USA and has not fulfilled its early promise.
- uranium which was expected to be scarce and expensive is now cheap and plentiful and enrichment is also cheaper than expected
- whereas great technical progress has been made in reprocessing and plutonium recycling as MOX, the economic case for recycling in thermal reactors is not clear and the future for fast reactors is uncertain
- there is growing public concern about the proliferation dangers of stockpiling plutonium in spite of the excellent record of storing under international safeguards

This paper will discuss the various options for managing spent fuel bearing in mind these various considerations.

Reprocessing and Recycling of plutonium and uranium

It has been claimed that reprocessing can be justified, at least in part, as a proven way of dealing with spent fuel, ie as a waste management policy. This is because it allows plutonium and uranium to be removed from the high-level waste and vitrification then converts this waste into a form in which it can be safely stored and eventually disposed of.

However, the real justification for reprocessing is based on the recycling of the plutonium and uranium into the fuel cycle to make maximum use of uranium resources.

There is extensive experience in the UK on recycling reprocessed uranium back into the fuel cycle. As for plutonium European reactors started using MOX fuel in 1963 and America first used MOX in 1965. Over 400 tonnes of MOX fuel has been burnt in commercial LWRs and 34 reactors world-wide are licensed to load MOX fuel. Some 40 other reactors world-wide are considering submitting a MOX licence. MOX fuel has performed at least as well as enriched uranium fuel and no operational difficulties have been experienced. France, Germany and Japan plan to burn about 100 tes of MOX fuel per year.

In the UK, Sizewell B, the LWR operated by British Energy, could utilise MOX, although it is not presently licensed to do so. On a standard fuel cycle, Sizewell B could incorporate around 16 tonnes of plutonium over the remainder of its 40 year lifetime assuming 30% MOX loading.

The AGR reactors, also operated by British Energy are not licensed to burn MOX fuel, but there does not appear to be any insurmountable technical difficulties with doing so. It is estimated that they could absorb about 30 tonnes plutonium over their remaining lifetime on a standard MOX cycle.

The Sellafield MOX Plant (SMP) of BNFL is due to operate in 1998 with a capacity of 120 t HM per annum for LWR MOX fuel. This plant is situated adjacent to the THORP reprocessing facility and is designed to utilise plutonium direct from THORP that may have been stored for several years. It will also be capable of receiving and using plutonium from other sources and this gives the UK the facility to return plutonium to reprocessing customers in the form of MOX.

Military plutonium recovered by the decommissioning of weapons could also be converted into MOX for use in LWRs or FBRs. In LWRs it would be downgraded and rendered 'inaccessible' in spent fuel. In FBRs it could be consumed completely. However, fast reactors which have been under development for many years are not likely to become commercially viable before 2030.

Direct disposal of spent fuel

With direct disposal the spent nuclear fuel is permanently disposed of intact without any chemical separation of the uranium and plutonium. Prior to the disposal of the fuel in a deep underground repository it has to be stored for several decades until its heat content has decreased. The disposal facility would be similar to that for HLW and ILW arising from reprocessing operations.

Whereas the technology of direct disposal has not been developed there would appear to be no insuperable difficulties and work is in progress in several countries. Safeguarding plutonium in spent fuel repositories over the long term could present problems.

The Main Issues

The main issues to be addressed in deciding on policy for spent fuel management are economics, waste management, sustainability and proliferation. These will be addressed in turn.

Economics

The economics of both plutonium recycling as MOX and the re-enrichment of reprocessed uranium depend on many factors, notably on the price of new uranium concentrate and the cost of enrichment. At the present time uranium prices are very low compared with earlier forecasts and enrichment prices have fallen dramatically as a result of new technological developments.

Under current conditions therefore the economics of MOX recycling in thermal reactors is controversial. Reprocessing of LWR spent fuel solely to produce plutonium for recycling as MOX is not likely to compete with fresh uranium fuel. But given that reprocessing has been carried out and waste stabilised in addition to the plutonium being made available, then the extra cost of fabricating MOX fuel (as compared with enriched uranium fuel) might be justified in view of the savings in uranium and enrichment costs. If MOX fuel fabrication costs are no more than about 4 times the price of uranium fuel fabrication then this may allow a LWR to see a small economic advantage in recycling MOX. Today MOX fuel costs are higher than this, but increased MOX utilisation will bring costs down.

In the UK, the economics of burning MOX in AGRs will be less favourable than in LWRs because of the lower enrichment of AGR fuel. In this case the savings in enrichment are much less while the MOX fabrication cost penalty is greater than that for a LWR. Modifications to the fuel route of AGRs would also be required. MOX recycling in AGRs is unlikely to be economic unless fuel fabrication costs can be substantially reduced. This may be possible in the future.

However, UK plutonium could possibly be leased or sold to overseas utilities as MOX fuel. The MOX would be under international safeguards and, under article 4 of the Non-Proliferation Treaty, it would be subject to end use restrictions. France, Germany, Belgium and Switzerland all have reactors licensed for MOX possibly with spare capacity.

Waste Management

A common misunderstanding about reprocessing is that it generates considerably more waste than direct disposal per tonne of fuel. This is not the case. Reprocessing and recycling reduce the need for additional ore mining, processing and enrichment, and hence reduce wastes generated by these processes. Taken as a whole over the complete fuel cycle this leads to less total waste being produced from reprocessing and recycle than from direct disposal but this factor is not greatly significant.

When considering only the volume of high and intermediate level wastes, which contain 99.9% of the total radioactivity found in wastes associated with reprocessing, the volumes are comparable with those for direct disposal. The wastes requiring deep geological disposal are therefore about the same for both options.

Developments are in hand to further reduce waste volumes from reprocessing through continuous improvement programmes and the application of new technologies.

Sustainability

Sustained economic growth on a global basis puts increasing demands on energy supplies and the energy resources to meet these demands are finite.

Nuclear reactors consume only about 3% of the original fuel. Reprocessing enables unused uranium and plutonium to be recovered and recycled whereas direct disposal wastes this valuable energy resource.

If used in the once-through cycle in LWRs, the world's cumulative natural uranium demand will grow such that the known resources (about 3.3 million tonnes of uranium) of less than \$30/pound U_3O_8 will be used up by around 2030 to 2040 and all the known resources (about 4.7 MTU) will run out by around 2040 to 2060. Then after 2110 to 2150, the world's ultimate resources (about 18 MTU), including the speculative resources that are yet to be proved, will be exhausted.

If FBRs are introduced after 2030, the cumulative natural uranium demand will show an upper limit less than half of the world's ultimate resources.

However, the development of sodium-cooled fast reactors has been beset by technical difficulties in the UK, France, Japan and elsewhere and fast reactors may well not become commercially viable anywhere for several decades. Nevertheless fast reactors represent the only sustainable long term option which could close the fuel cycle and optimise the generation and consumption of plutonium as well as make best use of the world's uranium reserves.

The above predictions are based on the WEC reference forecast to 2020 assuming that nuclear power will continue to increase at the same rate thereafter. This is unlikely to be an accurate forecast but it serves to illustrate the long term issue of uranium supply and the sustainability of nuclear power.

Proliferation

The current policy for the management of separated UK plutonium is one of continuing to accumulate and store plutonium for future use. There appears to be no technical reason to change the policy. However, such stockpiling of plutonium is seen by many as posing a proliferation threat, but experience under international safeguards has been excellent and there has been no diversion of civil plutonium anywhere in the world.

The policy whereby plutonium stocks are kept to a minimum by balancing the rate at which it is produced by reprocessing with the rate it is consumed as MOX has much to commend it. Nevertheless there could be good commercial or strategic reasons to modify this policy and allow plutonium stocks to increase. With high standards of storage under international safeguards this can be justified.

Concluding Remarks

The following conclusions can be drawn from the above discussion on the various aspects of the spent fuel management options based on experience in the UK.

- interim storage of spent fuel is technically feasible even for the long term - it is a necessary pre-cursor to either reprocessing/recycling or direct disposal and it maintains both options open
- the reprocessing/recycling option is well proven and it is available now: direct disposal may prove to be technically feasible. Both options are likely to be pursued in parallel over the coming years and both could be operated without giving rise to an unacceptable environmental impact
- economic differences between the two options are likely to be small and out weighed by uncertainties in cost estimates and strategic/policy issues
- sustainability is a key issue; the world's supply of economically recoverable uranium could be exhausted within the next 50 years or so unless the policy for recycling with fast reactors is adopted
- both reprocessing and direct disposal facilities are capable of being safeguarded and neither option presents the main proliferation risk - this is likely to be clandestine plutonium or highly enriched uranium production outside international safeguards
- so far as public acceptability is concerned the main issue relating to spent fuel is the geological disposal of radioactive waste and this is common to both the reprocessing/recycling and direct disposal options. Transport is also a concern, but as in waste disposal the technology is well developed and the problem is mainly one of perception
- the choice between the options will be dependent on many factors and different countries and even utilities within a country may come to different conclusions depending on the individual circumstances pertaining at the time
- it is unlikely that new developments will have a significant impact on spent fuel management policy, at least in the medium term.

セッション３：「核燃料サイクルを長期的に考える」

東京電力（株）取締役
原子力本部副本部長
兼　技術開発本部副本部長
榎本　聰明

本日は核燃料サイクルを長期的に考えるという演題で、これまでの原子力発電の持つ意味を振り返って見た上で、今後我々はどのような姿勢で核燃料サイクルを捉え、技術開発を行っていけば良いのか、日本の状況とそれに関連して最近感じるところなどをお話させていただきたいと存じます。

１．我が国の原子力発電、これまでの意義――軽水炉の効果

現在、原子力を取り巻く情勢は極めて厳しいものがあると言うものの、軽水炉による発電の方は、細かなトラブルは経験しつつも、ここ数年間、大変順調に推移してきており、稼働率も３年連続して８０％を越えております。我が国の軽水炉は米国の技術を導入し、それを国産化し、更に改良標準化を図る、という段階を踏んで開発を進めてきたわけですが、その技術は安定し成熟の域に達しつつある、といえます。

我が国は資源小国であってエネルギーのセキュリティ確保、すなわち必要とする量を適正な価格で確保する事は、我々の長い間の悲願でありました。原子力はその悲願を達成する可能性の高い手段であることから、これまで技術開発を積極的に進め、その成果が実ったということができると思います。

事実、開発当初においては、近い将来化石燃料に代わるものとして期待され、また、化石燃料が潤沢に存在する時代においても、化石燃料に対するバーゲニングパワーとしての役割を発揮し、エネルギー価格の安定に寄与してきました。

２．将来の原子力が持つべき意味合い――技術革新の効果

このように軽水炉を中核とする発電炉の開発利用は一定の成果を達成してきました。しかし、原子力というエネルギー源のもつ潜在力を考えるなら、これはそのごく一部を利用してきたにすぎない、と私は考えています。これまで原子力のおかげで我々が享受してきた利益を「原子力開発第一期」の効果と呼ぶとするなら、技術革新を更に進めることで「原子力開発第二期」の効果とでも呼ぶことができる、更に大きな利益を付与しうる潜在力を原子力は持っている、と言うことができます。将来を考える上で、これら原子力が持つ意味合いの重要さは、軽水炉技術が成熟したからといって決して失われるものではありません。この原子力というエネルギーが持つ大きな力を発揮させるには、「第二期の原子力開発」に向けた長期的努力が必要であります。

３．今後の原子力開発へ向けて

この第二期の開発のポイントは、経済性の更なる向上と、原子力技術開発の間口を広げることにある、と私は考えています。

（これまでの開発のやり方）

原子力の開発初期においては、そのエネルギー資源論的効果を、厳しい安全性への要求を満たしつつ早期に現実のものとすべく、限られた資源の有効活用をはかり、また技術を早期に定着化することに主眼が置かれました。このため、開発のパターンを単一的に絞り込み、かつ体制も経済的な競争を排した重厚な保護の下に開発を進めてきたように感じられます。その甲斐あって、我々は安全性、信頼性の面では世界でもトップ・レベルと言ってよい今日の水準を達成した、ということができます。

（経済性）

しかし、冷戦構造の解消、経済のグローバル化などから、エネルギー資源の持つ戦略的意味合いは一時的にせよ、相対的に希薄化の傾向にあるようにも見える一方、各種エネルギー間の競争は激化してきている、ということができようかと思います。他エネルギー源との競合の中で、軽水炉が今後も従来の地位を確保していくためには、安全性と信頼性を維持しつつ、原子力産業の一層の効率化、スリム化、合理化を図り、国際競争力をつけ得るよう、我々関係者は今一層の努力を払わねばなりません。

これらの努力の中で、軽水炉については、基本的には市場原理の中で生き延びなければならない、と考えられますが、原子力を環境面でどう位置付けるかという新たな課題もあり、その位置付けについては今後更に十分に検討していく必要があるものと言えます。

また、これから開発・利用する技術についても、その技術の経済性の有無が実用化を考える上で重要な判断要素となる、ということができます。民間における実用化とは、社会、市場の中で価値を産み出す見通しが得られて初めて達成し得る、ということを考えるなら、開発利用にあたる関係者は、安全を確保しつつ経済性を追求する、という命題が常に社会から与えられている、という自覚を持つことが必要であろうかと思います。

（開発に許される時間）

原子力の究極的目標、すなわち国民的悲願でもあるエネルギー・セキュリテイ確保の重要性はいささかも変わっていない、ということができますが、最近の情勢を見ると、セキュリテイに対する緊急度には緩みが見られるといえます。開発途上国のエネルギー需要など、不確定性もあり、長期的には予断を許さない要素もあるものの、原子力の究極的目標の達成に対する許容タイム・スケールは延びてきているように感じられます。もんじゅ事故などにより高速増殖炉の開発自体にも遅れが見込まれる今、我々は柔軟な姿勢を持って、この与えられた時間を有効に使わなければなりません。

（資源配分）

原子力という技術が本質的に持つ時定数の長さを差し引いて考える必要はあるとしても、我々はこのような開発の基軸を見直す絶好の機会を手にした、ということができると思われます。原子力の潜在的可能性をもっと引き出すためにも、開発資金と人材投資の重きを従来の発電システムから、バックエンド・システムにシフトすることがまず必要であります。

（開発目標見直し）

そして周囲の産業や、それを支える工学に見られる多くのイノベーション、最近の技術開発成果を踏まえて、過去に棄却した技術も含めて、今一度考えられる技術を幅広くサーベイし、間口を広げた上で、研究を進め、技術評価を行って絞り込みを行う、そしてその時点で最適な目標設定を再度行う、というプロセスを取ることで、革新的な技術に挑戦すべきであると考えられます。

（使用済燃料貯蔵への理解の必要性）

従来、しばしば現状の原子力開発状況をもってして「トイレなきマンション」との批判をうけてきました。使用済燃料の処理処分方法の道が開かれていないという問題提起でありますが、トイレだけの問題なら、そもそもその発生量はごく僅かである上、イギリス、フランス、日本などで、少なくとも一つそれを再処理する方法が実証されています。世界的に見れば、ガラス固化体、使用済燃料の別によらず、技術的には処分方法が確立されつつあり、高レベル廃棄物処分の実施主体も２０００年には設立されることとなっており、我々は既に使用済燃料を処理処分する技術は手中にしつつあるといえるでしょう。

問題はそれが将来人類の負託に応える最適な方法であって、それを今やることが国民にとって、また人類にとって最良であるか、という点について合意を形成する必要がある、ということであろうかと思います。そのためにも、我々はできる限り複数のオプションを提示して行く必要があると思われます。そのための検討、合意の形成の時間を考えれば、使用済燃料を当面貯蔵するオプションについても理解を得ていく必要があると言えます。

（国際協力）

技術立国を進める我が国にとっても、グローバル化した経済の延長上で技術の実用化を考えるなら、国際協力を通じてより効率的な技術開発を進めること、またそれによって自主技術を核として、世界中の多くの場所で使われる技術を開発していくことが重要であろうかと思われます。また、今日我が国の原子力界が直面する諸課題は、我が国のみならず、各国に共通の課題でもあるものが多く、これらに対する具体的解決方策も国際協力の下、検討していくことが重要と考えられます。

（開発に対する精査の仕組み）

このような技術開発は、長期的な視点から安定的かつ着実に推進する必要があります。しかし、このことはこのような開発は競争原理に基づく市場の精査を受けにくい性格を持つことを意味します。従ってその開発が合理的、効率的に行われているか否か、について外部も含めた厳しい目で評価を継続的に行うことが健全な技術開発上必須であると考えられます。それと同時に開発に参加する関係者全てが応分のリスクを分担し、自律的に価格競争力のある技術を作り上げるような仕組みが今後は必要であるように感じられます。

日本が技術開発のフロンティアに立つ場面がこれからは増えることと考えられますが、先頭を走る者にとっては、常に技術評価を行いつつ優れた技術を残し、また開発を中止すべき技術は経緯にとらわれず躊躇なく捨てる決断ができるような仕組みが必要であると言えます。

（国の役割）

また、政府をはじめとする公共部門は、このような巨大技術の開発推進の中心的役割を担う他、立地のような中央と地方の利害が絡んだ政治的課題や、社会から強い要請のある原子力との共生策などの課題についても、重要なエネルギー政策の一環ととらえ積極的に関与していくことが期待されます。

このように、我々は、与えられた時間を有効に使って、今後のエネルギー市場動向を注視しつつも、今一度我々が第二期の原子力開発へ向けたビジョンを描き、従来の延長線上から離れて柔軟に戦略を考える必要があるものと言えます。

４．まとめ

原子力は既に世界の電力の１７％を供給するに至っており、エネルギー供給上重要な意味合いを担っています。しかし、原子力のもつ潜在的な能力からするとこれはほんの一部にすぎないことも事実であります。原子力を取り巻く情勢は今後もしばらくの間、厳しく推移すると思われます。しかも、その中で経済のグローバル化、電気事業の自由化議論、行政改革による省庁再編、地球環境問題に対する対処、など多くの課題や環境の変化が予想されます。時代はまさに変革期にあるわけですが、来世紀に向けて原子力に与えられた重要な役割はいささかも軽くなることはない、と考えられます。与えられた時間的余裕を有効に活かして、これまでの技術の枠にとらわれずにブレークスルーを志向した努力が我々に対して求められている、ということができようかと思います。我々は変革を負担と捉えるのではなく、むしろ自由度の大きい好機と捉えて、今一度原点に立ち返って、第二期の原子力利用開発に向けて、関係者が力を合わせて協力し合っていく必要があるものと考えております。

以上

榎本聡明氏の英文は巻末に掲載してあります。

Mr. Enomoto's thesis is at the end of volume.

Summary

Nuclear Fuel Cycle Back-end Policy in Germany

Helmut Engelbrecht, Preussen Electric Co., Germany

From the very beginning of nuclear industry in Germany up to today the nuclear fuel cycle back-end was always in the focus of public and political interest. Due to the changing attitude towards nuclear issues, strategic long-term approaches to provide closed fuel cycle services failed and alternative solution had to be developed. With the increasing competitive pressure on electricity generation, in future, only commercially attractive technics and services will have a chance to be implemented. The challenge to German nuclear industry is to look for new or at least economically improved fuel cycle procedures without endangering the established industry routine.

International co-operation on fuel cycle issues, we trust, will help to give nuclear generation a successful future.

Nuclear Fuel Cycle Back-End Policy in Germany

Ladies and Gentlemen,

Before engaging into the subject I would like to introduce PreussenElektra to you, the company which I am representing.

Slide 1

PreussenElektra is the second biggest utility in Germany, serving the North of our country. PreussenElektra is shareholder in 8 nuclear reactors and is responsible for the operation of 5 of these units. Therefore PreussenElektra has been involved in all nuclear fuel cycle considerations in Germany so far and is actively taking part in the discussion to shape the future of this industry.

If you want to understand the situation of the German nuclear fuel cycle industry today, Ladies and Gentleman, you have to be aware of its historic development. Therefore I would like to introduce to you some of the important historic data that in my opinion are the keystones essential for the understanding of the given situation.

From the very beginning in 1956 up to now German Nuclear Industry, German politics and even public interest valued the back-end of the nuclear fuel cycle as strategic and therefore essential for the viability of our industry. By the way this is even true for the nuclear opponents who have concentrated their activities almost entirely to these subjects as well.

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As early as 1958, research on reprocessing of spent nuclear fuel started, mainly driven by the chemical industry which believed by then that recycling of uranium and plutonium would create great value. The first nuclear reactor was put in operation in 1961, in 1963 the first plutonium fuel fabrication was launched, 1967 the final repository in the salt dome of Asse became operational, on a test basis, and in 1971 reprocessing in the Karlsruhe plant started. So at the beginning of the 70's the closed nuclear fuel cycle was a reality in Germany on a small pre-industrial scale. It was common understanding that the nuclear industry would be developed to become the major electricity supply source and that, in order to be independent of energy imports, the whole nuclear fuel cycle industry had to be established in Germany.

Consequently in 1976 the German government asked the utilities to create a nuclear centre in which all fuel cycle back-end activities should be concentrated. The site Gorleben was selected because there an undisturbed underground salt dome promised to be suitable for the final deposit for all nuclear wastes especially high active material. The planning included a reprocessing plant of 1.400 t HM/a capacity, uranium and plutonium fuel fabrication facilities, waste treatment and final disposal.

By then it became obvious that the chemical industry had lost its interest in recycling, so that the responsibility for the establishment of nuclear fuel cycle industry was given to the utilities, the nuclear generators. In order to motivate them to establish the recycling industry rapidly the government required - as a precondition for nuclear operation - the proof that spent nuclear fuel could be treated properly. As evidence contracts or operating facilities had to exist that gave the certainty that the fuel to be discharged in the next six years was covered. In order to fulfill this obligation the utilities decided that in advance to the availability of the recycling centre in Gorleben reprocessing contracts had to be signed with Cogema and BNFL.

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At this time of the development, nuclear industry in Germany had to experience the first setbacks. Nuclear opponents received more public support than before. And even more important, the expected growth of nuclear generation proved to be overestimated. Nuclear industry had to adjust its capacities accordingly.

In 1979 the responsible politicians decided that the Gorleben recycling facility had to be canceled due to a lack of general political support. Only facilities for interim spent fuel storage, for spent fuel treatment and the final repository were considered politically feasible in Gorleben.

The German utilities down-sized their national reprocessing capacity requirement to 350 t HM/a to be built in Wackersdorf and decided - as substitute for Gorleben - to enlarge their pilot MOX fabrication facility in Hanau to 100 t HM/a. At the same time they decided to develop the process of direct disposal of spent nuclear fuel, in order to have this technology available as an alternative to fuel recycling.

A detailed study was performed which demonstrated that from the safety perspective there was no disadvantage in direct fuel disposal compared to the closed nuclear fuel cycle. Consequently the German utilities in 1985 decided to plan and build the spent fuel treatment plant (PKA) in Gorleben.

In 1989 the reprocessing project Wackersdorf proved to be much more expensive than expected. At the same time it became obvious that Cogema's and BNFL's reprocessing facilities could not completely be filled by the national reprocessing requirement in these countries. By then the idea of the European Union - just a big vision in the 60's - seemed to be more and more realistic, the goal of national independence on all nuclear fuel cycle issues was no longer pursued. Therefore Germany decided to give up the Wackersdorf project. To fulfill the legal

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requirement, to prove six years in advance possibilities to take care of spent nuclear fuel, additional reprocessing capacities in Cogema and BNFL facilities were booked by the German utilities. A second very important event in 1990 was the German reunification. Even though all East-German nuclear generation was stopped after reunification, the Morsleben final repository of the former GDR managed to get an interim permit to continue low level nuclear waste disposal up to the year 2000.

The capacity in Morsleben adds up to two West-German repository projects, Konrad and Gorleben. Disposal of radioactive waste in Germany is a federal state responsibility. All steps of the fuel cycle are realized in private responsibility, except - with reference to the long time span involved - waste disposal. Today forecasts show the volume for waste disposal available in all three underground repositories exceeds the German demand. So from the utilities' perspective there is a strong economic motivation to seek international co-operation on this matter.

Due to increasing political problems with plutonium utilization, a few years later in early 1994 the MOX-fuel fabrication in Hanau was stopped, too. With this decision, all attempts to build up a German recycling industry had failed. Consequently the German government changed the atomic law in 1994, and gave up the legal preference for the recycling of nuclear material. Today recycling and direct spent fuel disposal both are legally valid back-end options for the German nuclear utilities. So today only economic facts guide the decision which back-end solution will be chosen for the discharged fuel.

I would like to draw your attention to a very interesting fact. I have mentioned many projects which failed. Success was achieved with higher degree of certainty when nuclear projects were based on international co-operation. Certainly international partners are no warranty against

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failure. But such multi-national nuclear projects seem much more resistant against local political objections than national projects are.

So keeping this historic development in mind, where do we stand today ? What are the economic facts that guide the decisions ?

You are certainly all aware of the reprocessing techniques. Being partner in the co-operation with BNFL and COGEMA I am quite sure we all rely on the same technical and commercial data of reprocessing and recycling. The German considerations for direct disposal of spent nuclear fuel might not be so familiar to you. Therefore I would like to briefly introduce this procedure to you.

Slide 2

The base concept for direct disposal assumes that the fuel assemblies discharged from the core will remain in the fuel pond for a five year cooling period. Then up to 10 t/HM are placed into one transport and interim storage cask (publicly known as Castor cask). This cask will be transported into an interim storage facility.

This cask storage is a dry storage, the fuel is sitting in a helium atmosphere. When the final disposal of high active material will be possible, estimates today assume this to be 30 years ahead, the fuel has to be handled again before being finally disposed off. Top and bottom nozzle will be taken off. The pins will be pulled out of the structure and packed into a canister. The canisters and the fuel assembly structure will be packed into a final storage cask (called Pollux). This repacking into a new cask is required because the given technology does not permit to bring the Castor cask down into the repository, due to its gross weight of more than

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120 tonnes. Even the Pollux cask taking up just four tonnes of HM, requires extraordinary shaft technics, which had to be developed on purpose to download the gross weight of up to 80 tonnes which is expected for the Pollux final disposal gear.

Besides this reference concept there are a lot of flexibilities given thanks to the spent fuel treatment facility (PKA) which has been built in Gorleben and which will get its operation license in 1999. If nuclear power stations cannot provide spent fuel with 5 year cooling time, smaller cask could be loaded and transported to the Gorleben interim storage. After cooling for some extra time a cask reloading could be performed in order to optimize interim storage capacity requirement.

A further flexibility offered by the given facilities in Gorleben is the possibility to pack the fuel pins (with or without shearing) into a canister which matches the design of a HAW glass canister, similar to those received from the reprocessing plants. Depending on the future underground storage technics this step would allow a standardization of final disposal packages and thereby minimize the efforts to handle the waste packages underground. Please note that even though the spent fuel treatment facility is existing in Gorleben, the German utilities do not intend to repack the fuel before the boundary conditions for the final disposal of high active waste and fissile material has been defined. Especially safeguard issues have still to be clarified.

Slide 3

So in comparison, direct disposal of spent fuel is a rather simple process. Its final implementation is very much dependent on the final repository requirements it will have to fulfill.

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As long as these conditions are not known, direct disposal simply means long-term interim storage of spent fuel.

As mentioned before as far as the back-end of the nuclear fuel cycle is concerned the German utilities are in a rather good position. They have the choice between two technically proven and legally valid alternatives. The choice due to increasing competitive price pressure on the generation cost, can only be influenced by commercial considerations.

If you look at the historic development of nuclear fuel cycle costs, you realize that over the last 20 years the fuel cycle back-end costs have developed to be the major factor. In Germany 2/3 of fuel cycle costs are spent for the back-end. I trust that this situation is not too much different in other countries, that are engaged in recycling. Certainly a big part of these back-end costs are related to final disposal of wastes or spent fuel. For the German utilities, even though they have to pay 93 % of the cost incurred for final disposal activities, there is hardly any chance to optimize in this respect. Realizing final disposal of nuclear waste as already stated is a federal state obligation, most likely we will have big overcapacities judged with respect to underground storage volume, but there is no chance for a commercial optimization. Therefore, when deciding on the back-end fuel cycle alternatives from the German perspective, the cost comparison is excluding repository considerations.

Slide 4

As reprocessing has grown into a mature technical status, we already have seen price reductions here. We definitely will encourage Cogema and BNFL to further optimize their processes and reduce prices accordingly. Still unreasonable price levels are given for MOX fabrication. In the near future, when given plutonium piles have been reduced there will be no

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MOX fabrication by German utilities unless there is a commercial incentive in doing so. MOX fabrication costs of today, being 10 times higher than uranium fuel fabrication costs make recycling prohibitive.

With respect to the interim storage of spent nuclear fuel, there are no big uncertainties either. The problems in cost judgment are linked to so far unknown requirements that might arise with defining the boundary conditions that spent fuel will have to fulfill in order to be finally disposed off. Here a big range of cost uncertainties will remain.

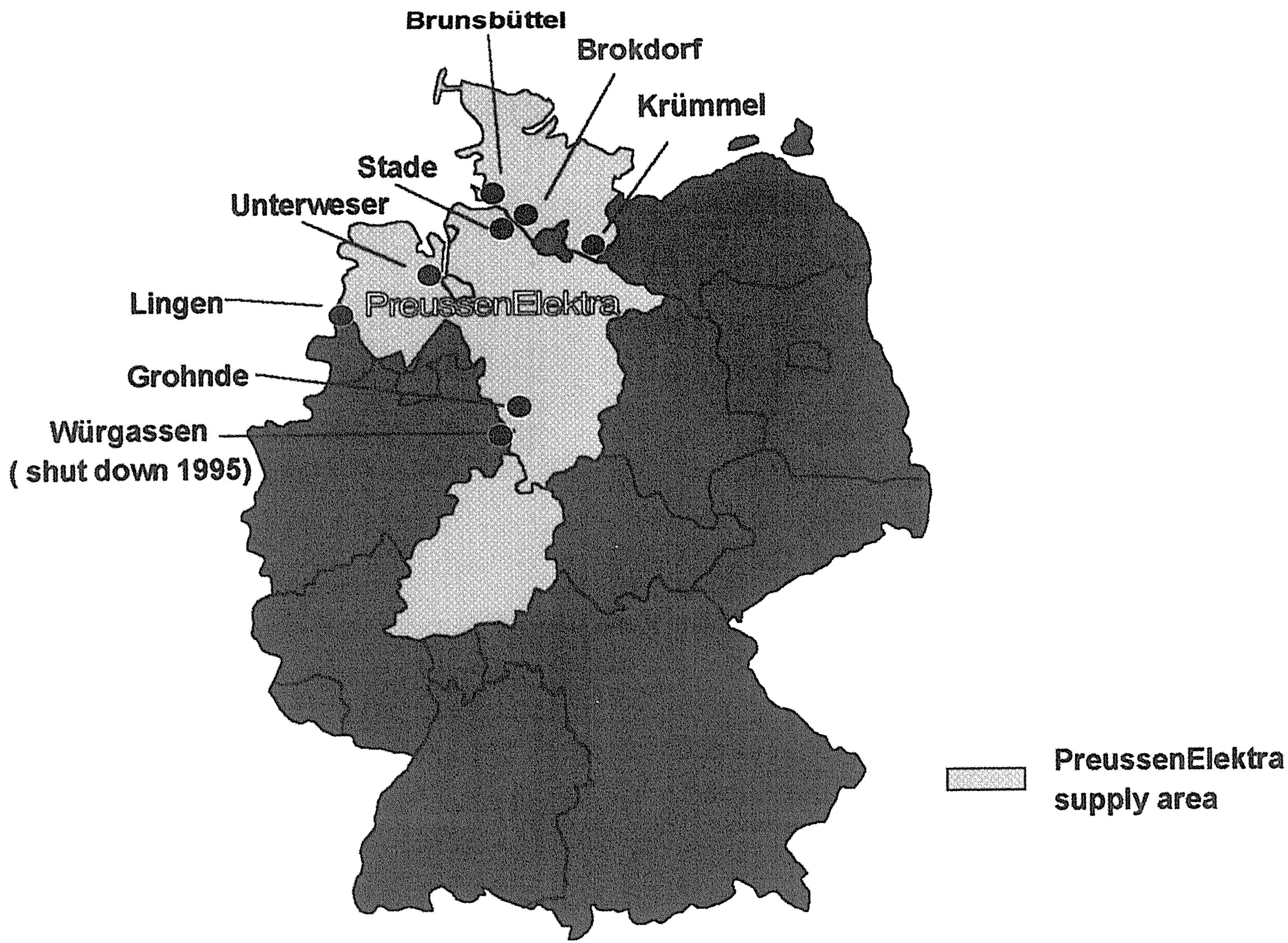
But, we all should be aware, that if nuclear generation wants to survive in a competitive electricity market, only price reductions are possible. In Europe already today combined cycle gas generation on full cost basis is cheaper than the marginal costs of some smaller nuclear power stations. So, the only way that the German utilities will use the flexibility which they gained by developing alternative solutions for the back-end of the fuel cycle is to cut their generating costs to be fit for competition.

So let me summarize:

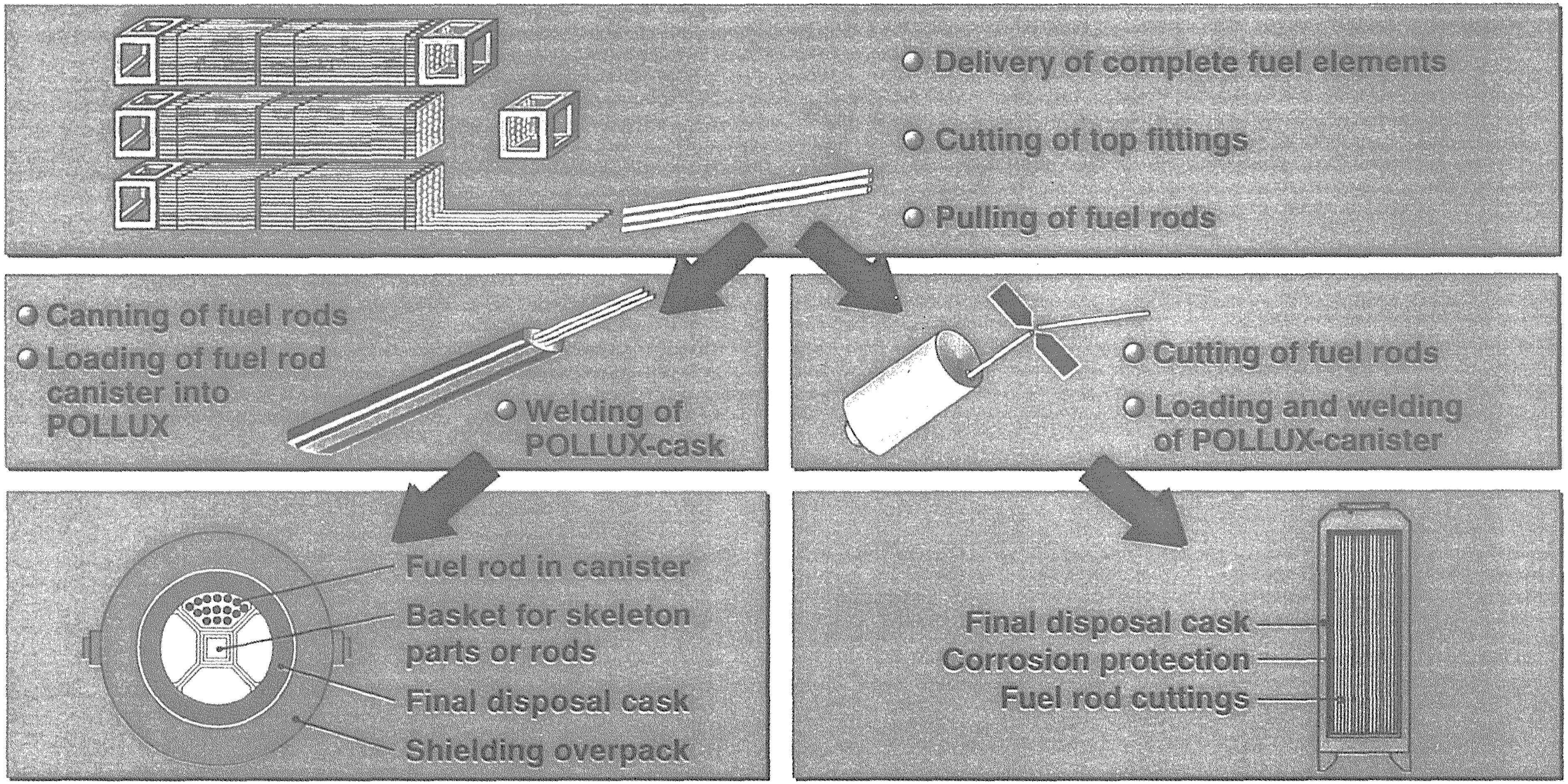
⇨ On one hand the recycling industry is essential for long-term utilization of nuclear fission based energy generation, is strategically important because it gives independence in energy supply, but it is commercially attractive only if utilized on a big scale.

⇨ On the other hand direct disposal of spent nuclear fuel permits just the short term usage of the given nuclear generation capacities, there is no strategic long-term perspective to it, but big flexibility is achieved thanks to doing nothing but store the fuel. Therefore direct disposal today promises to be the low cost approach to solve the nuclear fuel cycle back-end.

What seems to be at first glance a thesis - antithesis situation already provides the synthesis in itself. We all, I trust, believe in the benefits of nuclear energy generation. Therefore let's co-operate to give it a future. Nuclear generation has to prove its value in competition with fossil generation. To do this we have to reduce costs which is only possible if we use the already given infrastructure. International co-operation opens the chances to do this on the big scale necessary to reduce unit costs. Let's co-operate on all steps of the nuclear fuel cycle in order to reduce the projects dependence on local political considerations. We will benefit from the vast international knowledge we have all built up in the past and by doing this we will gain much more flexibility to cope with the multiple constraints our industry faces today.

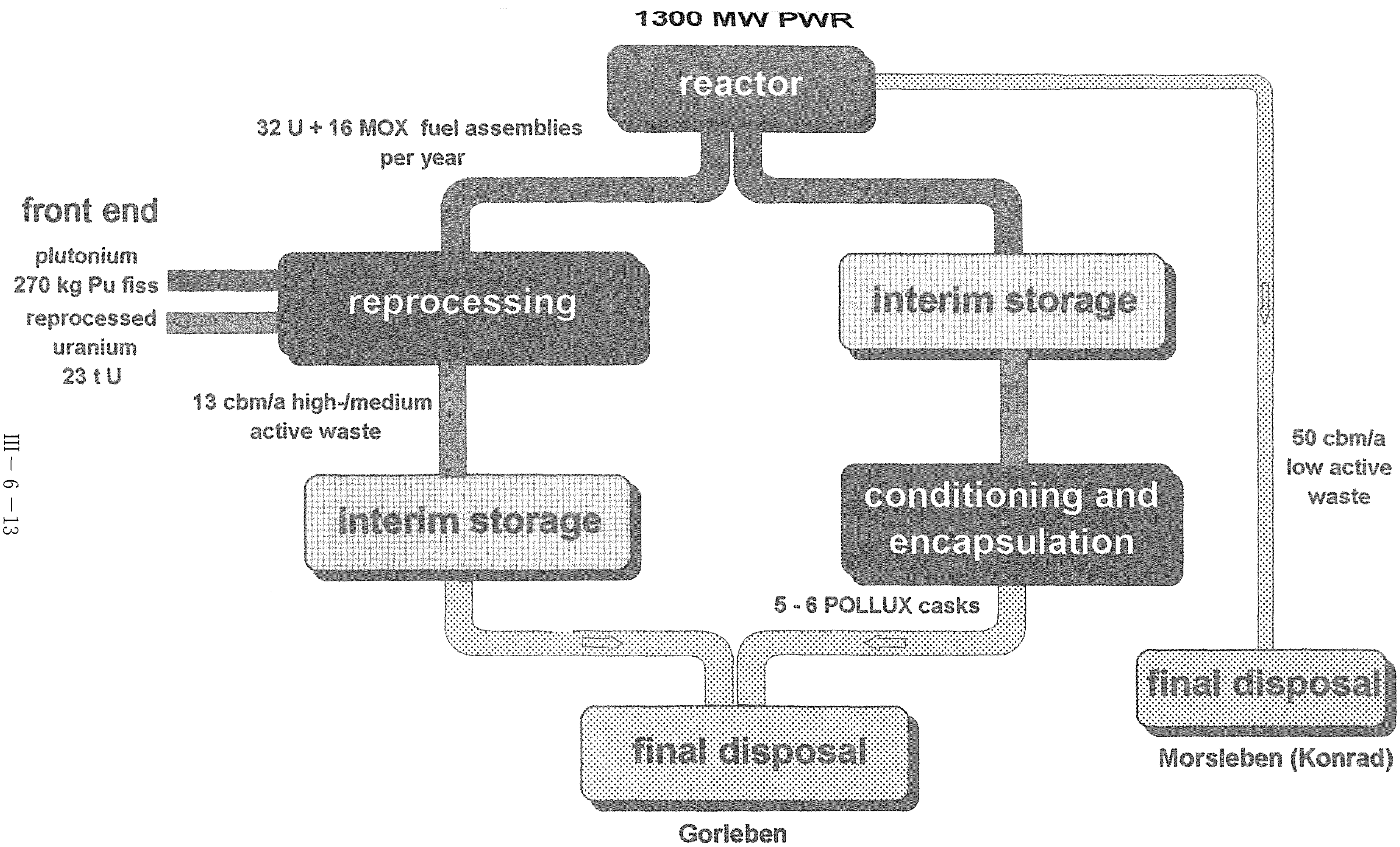


PreussenElektra	**PreussenElektra** Locations of nuclear power plants	1998 MK-Bec standbr1.pre

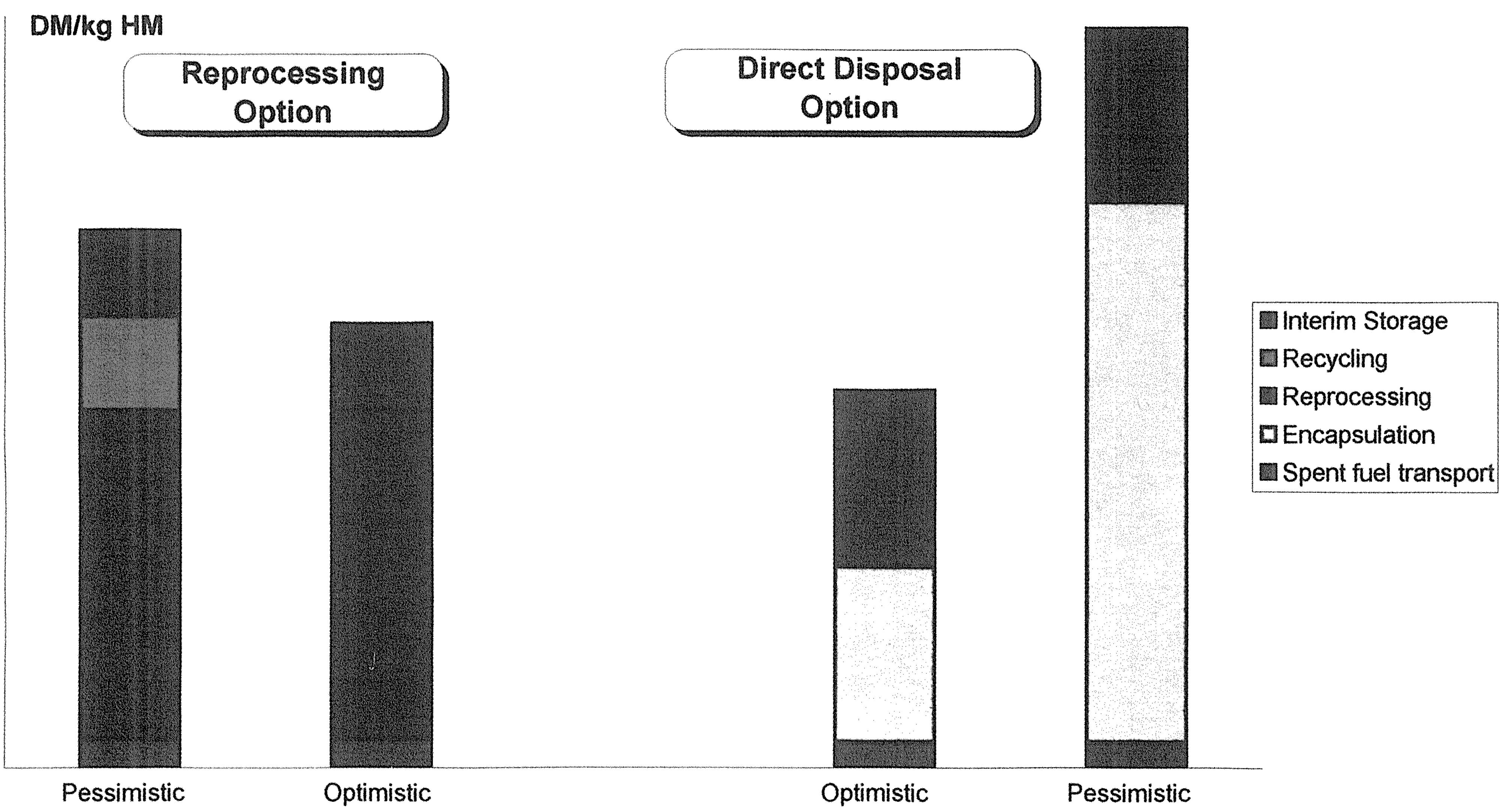


	Pollux - cask	Pollux - canister
Diameter	1,50 m	0,43 m
Length	5,50 m	1,34 m
Weight	65 t	1 t
Content	8 PWR Fuel Elements	*0,5 PWR Fuel Element*

PreussenElektra **Conditioning and Encapsulation Systems** *1998 MK-Bec*



PreussenElektra | **Nuclear Fuel Cycle - Back End** Options | 1998 MK-Bec kreisl5e.pre



PreussenElektra | Cost Comparison between Reprocessing and Direct Disposal Option (DM/kg HM) | MK-Rdt: 03.03.1998

Presentation Paper

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It is my pleasure to express at this session my views on back-end fuel cycle in Korea, especially on radioactive waste management.

Current Status of Nuclear Power in Korea

Korea has twelve operating nuclear units, ten PWRs and two CANDUs. July 1, 1997 marked a milestone in Korea's 20 year history of nuclear electricity generation, when nuclear power capacity exceeded 10 million kW with the commencement of commercial operation of Wolsong Unit 2, the second CANDU reactor. Also, Ulchin Unit 3, the first Korean Standard Nuclear Power Plant (KSNP), was connected to the national grid on January 6, 1998 and its commercial operation is scheduled for June 1998. Nuclear power is the major source of electricity in Korea and handles the base load generating more than one third of the country's electricity. Six additional units consisting of 4 PWRs and 2 CANDUs are now under construction, and 2 PWR units are in the planning stages. The planned expansion of this nation's nuclear generating capacity is an attempt to curb the increasing dependence on fossil fuel imports.

Radioactive Waste Management

However, proper treatment and disposal of radioactive waste have been a national concern. Various state-of-the-art volume reduction technologies have been adopted to reduce low- and intermediate-level radioactive wastes(LILW) from power reactors. After a decade of unsuccessful efforts in search of a LILW disposal site, the government decided that the major task of the national radioactive waste management program should be transferred to the Korea Electric Power Corporation (KEPCO) in January 1997. Based on experience and technology accumulated through the construction and operation of domestic nuclear power plants including KSNP, KEPCO is implementing the national radioactive waste management project. A disposal facility for LILW will be in operation in about 10 years from now.

Spent Fuel Management Policy

The national acceptability of a particular back-end strategy depends on Government demonstrating a long-term commitment to nuclear power and providing a clear environment of a chosen strategy. In the context of the nation's primary objective to improve energy security and sustain economic development, the two priorities are energy conservation and protection of the environment. Because Korea has scant natural energy resources of its own, its economic development over the last 30 years or so has been fuelled by almost entirely by imported energy. It is not surprising, therefore, that the improvement of national energy security is one of the foremost objectives of the national energy policy. In nuclear power generation, the achievement of national energy security is not, however, solely dependent on the politics and economics of uranium procurement or front-end fuel cycle logistics. Implementation of an effective back-end fuel cycle strategy which makes optimum use of present and planned generating plants is a highly significant element in the formulation of policy in this area. Also, environmental advantages must be viewed in the context of the complete fuel cycle. The national policy on the long-term management of spent nuclear fuel is to wait and see for the time being.

As regards direct disposal, it is observed that despite the comparative novelty of the technology involved and potential problems with regard to its public acceptability, this route currently commands substantial international support. Some nations have adopted this as the preferred spent fuel management strategy. To date, however, there has been no commercial scale operation of direct disposal facility of spent fuel or high-level radioactive waste(HLW). In the mean time, to provide flexibility in spent fuel management, MOX fuel utilization through international cooperation might be considered. The legal and technical aspects related to the storage, treatment and disposal of spent fuel are specified in the Atomic Energy Act. According to this Act, the management policy is reviewed and determined by the Atomic Energy Commission(AEC). AEC had decided that spent fuel be stored until a decision of direct disposal or recycle will be made.

R&D Efforts

The major issues to be addressed in relation to direct disposal of spent fuel concern the means by which man and the environment can be adequately protected from the harmful effects of waste in a way to minimizes transfer of responsibility to future generations. These problems should be resolved by R&D. Development of a multi-barrier approach, waste acceptance criteria and repository design for long-term isolation of radionuclides would all be included amongst the technical criteria to be satisfied. The long-term integrity of spent fuel or HLW packages needs to be proven. R&D on deep geologic disposal has been conducted by relevant research organizations in accordance with a long-term plan established by the Atomic Energy Commission. Basic research programs on the following four areas have been continued: performance assessment and disposal system development, geoenvironmental study, engineered barrier development, and radionuclide migration study. A joint research program for the development of DUPIC (Direct use of spent PWR fuel in CANDU reactors) fuel cycle technology is also being conducted in partnership with Canada, USA and the IAEA.

原子力産業会議・年次大会

「科学技術は２１世紀に何をもたらすのか」

-異業種間競争と技術融合のダイナミックス-

東京大学・先端研
教授　児玉文雄
（1998 年 4 月 22 日）

２０世紀に進展した技術進歩を長期に亘って観察した結果，M. Tushman と P. Anderson（1986）は，「インクレメンタルな技術変化が長期間継続した後に，この漸増的な進化プロセスは，非連続的な技術進歩により中断（punctuate）される」という現象を発見した．セメント技術についての 1888-1980 年間に及ぶ技術変化や，ガラス製造技術についての 1890-1980 年間に亘る技術変化の観察結果により得られたものである．

このような分析結果に基づいて，技術的非連続性を，それまでに蓄積してきた技術を更に一段と向上させる非連続性と，既存の技術蓄積を破壊してしまうような非連続性に分類・整理した．そこで，前者の技術進歩を「技術蓄積向上型」（competence-enhancing）と呼び，後者を「技術蓄積破壊型」（competence-destroying）と呼んでいる．「蓄積型」は当該産業が保有している技術ノウハウの上に構築されるのに対し，「破壊型」は当該産業に蓄積されてきた知識を陳腐化してしまうものである．例えば，ターボ・ジェットの技術進歩は先行したジェット・エンジンを土台にしているのに対し，機械式の時計や真空管のメーカーの技術は，クウオーツ式時計や集積回路の出現により旧式のものになっていった．

Harvard 大学の Branscomb 教授は，その著書「Beyond Spinoff」（Alic; 1992）において，技術進歩のプロセスを次のように記述している．技術進歩は追加的改善のプロセスを長期間に亘って経験する間に，その費用対効果の比率は段々

と低減していく．この緩慢なプロセスは，革新的な技術群の出現により突然中断されるが，その非連続性は元を辿ればその大部分は基礎研究の成果に帰着される．そして，この新しく出現した技術は既存技術の持つ基本的な障害を取り除き，技術進歩を新たな改善のプロセスへと導いて行く．一方，技術開発の市場は，実際に技術が創造されるまでは，明らかなもの（articulated）とはなり得ない．そこで，「仮想敵な市場（virtual markets）」を想定することが重要となる．このような仮装市場は，技術的可能性が示唆するよりは，社会・経済的ニーズのパーセプションから派生することが多い．

では何故，追加的技術改善のみによる技術進歩のプロセスは，その費用・効果比を低減させて行くのだろうか？ 米国の進化経済学者、R. Nelson と S. Winter（1982）は、技術進歩の累積的性質を「自然軌道（natural trajectory）」という分析概念で説明した。つまり、現在の研究は効果的な新技術を生むとともに，将来の研究のための自然な出発点を準備する，という考え方である。そして、「自然変種（natural variety）」の「近傍（neighborhood）」の概念を主張する。つまり、ある有効なシステムが一旦確立されると、変更を加えるとしても些細なものに留まるというものである。

しかしながら、技術的可能性は，多数の異なるクラスの技術群から構成されていることもある。これらのクラスのなかで、技術進歩はある特定の軌道に従う。任意の時点で、あらゆる R&D は、特定の クラスの技術群にだけ焦点を当てて、他のクラスの技術群についてはなんの注意も払わない。この「経路依存性（path dependency）」は、技術開発では頻繁にみられる．そして，これによってシステムが全体としては最適とは言えない経路に「ロックイン（lock-in，固定化，凍結）」される可能性が出てくる。日本の原子力開発、わけても高速増殖炉開発には、この理論が当てはまっている可能性を否定できない（Cowan; 1990）．

したがって、公共政策の是非をめぐる議論は、「研究開発を現在の経路から如何にして『アンロック（unlock）』するか（解き放つか）」、また，「如何にして可能性のあるすべての軌道を探すか」，という点を主眼にすべきである（児

玉　1997）．この政策論議は，先に述べた「技術蓄積破壊型」の技術的非連続性についての分析により得られている科学的知見に依拠すべきである．すなわち，インクレメンタルな技術的改善のみからなる緩慢なプロセスが，どのように中断されたかの分析が必要なのである．

MIT の J. Utterback (1994) は，46 個に及ぶ非連続的な技術革新の事例 (26 事例がプロダクトの技術革新で，20 事例がプロセスの技術革新である) を収集し，殆ど 4 分の 3 の非連続的技術進歩の事例は，本来とは異なる業種によって達成されたものであることを解明した．すなわち，46 の中の 12 事例は既存の業種内の競争によりもたらされたものであるのに対して，46 の中の 27 事例は既存の業種以外の業種によりもたらされたものである．技術革新の発生源を認定できなかった事例は 7 事例であるが，その理由は当該の非連続性が出現する以前には，該当する業種が存在すらしていなかったからである．

このような Utterback の分析結果は，本論文の文脈からは何を意味しているのであろうか？すなわち，最適軌道から逸脱した技術開発をアンロックするという非連続的な変更に必要なのは何か，ということに関する含意である．分析結果が明らかにしているのは，非連続な技術進歩は，多くの場合「異業種間競争 (Interindustry Competition) 」(Kodama; 1995) がもたらした結果であるということである．

しかし，Tushman 等の分析で述べたように，技術進歩の非連続性には，技術蓄積向上型と蓄積破壊型の 2 種類が存在する． 最適性に欠ける軌道から技術開発をアンロックするのに有効なのは，技術蓄積破壊型の非連続性である．そこで，技術革新の形態と技術開発の形態との相関を分析することが必要となる．技術革新の形態には，技術蓄積向上型と蓄積破壊型という二分法を採用し，技術開発の形態としては，同業種内競争と異業種間競争という二分法を採用し，両者の間のクロス分析をしてみよう．その結果を， Utterback の分析で取り上げられている事例の内容と共に， 表 1 (蓄積向上型) と表 2 (蓄積破壊型) に示す．

まず，技術蓄積向上型の技術革新についてクロス分析を見てみよう．表1によれば，15事例の中の11事例が同業種内競争によりもたらされたものであり，4事例だけが異業種間競争の産物であるということになる．すなわち，一旦最適軌道に入った後の技術開発の形態としては，同業種内の熾烈な競争が有効であると想定できる．

表1．向上型技術革新の事例と同業種内競争とのクロス分析

同業種内競争：
- 半導体メモリー．
- 空冷式エンジン；
- 水素冷却式発電機；
- コンピュータ制御キルン；
- エディソン式長尺キルン；
- 機械式シリンダー状ガラス；
- 熔融塊式(Gob)製瓶機；
- 二重ゴブ式板硝子成形機；
- 連続鋳造；
- 連続引き抜き銅線；
- 繊維方向性強化板材．

異業種間競争：
- 電動式タイプライター；
- 集積回路；
- 連続式縦型キルン;
- 原子力蒸気発生システム．

Source: Compiled by the author from Figures 9-3 and 9-4 in J. Utterback, *Mastering the Dynamics of Innovation* (Boston, Harvard Business School Press, 1994), 205-206.

次に，技術蓄積破壊型の技術革新についてクロス分析を見てみよう．表2の集計結果は，27事例の中の23事例が異業種間競争によりもたらされ，同業種内競争でもたらされたものは4事例しか存在せず，蓄積向上型とは全く逆な結果になっている．すなわち，最適ではない軌道に施錠されている技術開発を開錠するためには，異業種間競争という技術開発の形態が不可欠なのである．

表 2. 破壊型技術革新の事例と異業種間競争とのクロス分析

同業種内競争：
- 懸垂式余熱器；
- 引き抜き式板ガラス製法；
- 連続成形；
- フロート式板ガラス製法.

異業種間競争：
- 集積回路の微細加工化；
- トランジスタ；
- 電卓；
- 房飾り付カーペット；
- 超並列処理コンピュータ；
- ロータリーキルン；
- 引き上げ式板ガラス製法；
- ビニール；
- セルロイド・フィルム；
- 人工製氷法；
- 人造宝石；
- 小型液体酸素製造装置.
- フォトリソ露光装置；
- ラジアル・タイヤ；
- ディーゼル機関車；
- ボールペン；
- 航空機用ジェットエンジン；
- 冷蔵機械；
- 白熱電球；
- 鋼鉄製自動車；
- 酸素吹き込み製鋼；
- 直接還元製鉄法；
- 光ファイバー.

Source: Compiled by the author from Figures 9-3 and 9-4 in J. Utterback, *Mastering the Dynamics of Innovation* (Boston, Harvard Business School Press, 1994), 205-206.

しかし，破壊が必ずしも自然発生的に新しい建設に結び付かないことも事実である．すなわち，異業種間競争は必要条件であるとしても，技術開発を改めて最適軌道に乗せるための充分条件ではない。 Stanford 大学の Rosenberg 教授（1976, 1983）は、１９世紀後半の米国の経済と技術との相互依存関係を，工作機械工業の成立過程を中心に分析した．その結果， 1840 年から 1910 年にか

けての米国経済においては，工作機械工業が新技能と新技術の習得と普及のセンターであり、この技術の普及は、兵器工業、ミシン工業、自転車工業、自動車工業というように順を追って、段階的に行われたことを明らかした。すなわち，２０世紀に実現されることになる米国経済繁栄の技術的基盤（machino-infrastructure）が，どのようにして構築されていったかを解明したのである.

工作機械工業の研究に続いて，技術進歩と経済との相互依存関係を広範囲にわたって研究した結果に基づいて、Rosenberg は「近代技術」の成立条件を，「補完性（complementarity）」、「累積効果（cumulative impacts）」、「産業連関性（interindustry relationships）」の３つの特徴という形で整理している．「相互補完性」とは，発明は決して単独で効果を発揮できるものではなく、補完的技術に依存することが大きいということである．工業経済の生産性の上昇は、お互いに連結している相互補完的な技術群の複雑な効果によって生ずる。従って、適切な観測単位は、単一の技術革新ではなく、相互連関している一群の技術革新である。誰が見ても大きな技術突破の場合でも、生産性上昇への直接の貢献は小さい。

「小さい改善の累積効果」とは、生産性上昇の大部分は、小さな改善を技術革新へと積み上げていくという形を取る。事実，高度に発達した産業経済においては、技術進歩の多くのものは余り目だたないものである．「産業連関性」とは、技術革新による生産性上昇の便益は、技術革新を造り上げた産業とは異なる産業により享受されるということである．従って、技術革新の便益を全部計上するためには、産業間に存在する連関を考慮しなければならない。ダイナミックな技術革新下の産業経済は、企業や産業に新しい専門化を作り上げる。伝統的な業種の境界の範囲内に、技術革新の結果を閉じこめることは出来ないのである.

しかし，２０世紀の最後の４半世紀に著しい発展を遂げた先端技術を特徴づけるのに，Rosenberg が展開した上記の特性で充分であろうか？ メカトロニクスやオプトエレクトロニクスの２つの事例に見られる如く、「先端技術」を特

徴づけるためには、これらの概念を更に拡大させなければならない。このような先端技術の事例は Rosenberg の研究には含まれていないので、この３つの特徴は萌芽期の先端技術の特性にしか過ぎないと言えよう。最近の先端技術も同じような特徴を持っているかも知れないが、技術が創り出される方法は変化している．Rosenberg が主張している「相互補完性」の特徴は長期の歴史分析によって抽出されたものである。従って、これらの現象は、歴史的偶然の積重ねの結果であり、決して意図されたものではなく、むしろ受動的な行動の結果である。しかし、メカトロニクスやオプトエレクトロニクスは、かなり短期間で開発され、しかも、異業種の異なる企業間の積極的な共同研究プロジェクトにより開発されたものである。このことは、技術革新の「制度的枠組み」が変化していることを示唆している．

「改善の累積効果」についての特徴は、遡及的分析により明らかにされたものである。従って、たとえ成功したプロジェクトにおいても、技術開発を行っている途上において、これらの特徴が明確に認識されるていたわけではない。しかし、メカトロニクスやオプトエレクトロニクスの開発事例においては、開発の初期段階から、これらの特徴が明確な形で認識されていた。このことは、技術革新の「動学的側面」の理解の水準が向上したことを意味している．「産業連関性」については，メカトロニクス技術の種々の機械類への普及の測定が参考になる．「メカトロ化した機械」を計算機制御付きの機械と定義すれば、各種の機械の総生産量に占めるメカトロ化した機械の比率により、その普及率を測定できる。このような測定により、種々の機械類におけるメカトロニクス技術の普及は、日本のすべての製造業を通して驚くほど早かった。事実、15 年も経たない内に、その普及は飽和点に達している。しかも、その普及は異なる業種で殆ど同時併行的に進行した。このことは、「技術普及の枠組み」が変化していることを示唆している。

以上を要するに，先端技術を充分に把握するためには、Rosenberg の洞察を包含し、且つ先端技術の新しい特徴を組み込むような、新しい理論の構築が必要

である．この特徴はRosenbergが近代技術で識別した特徴と、次のような点において異なっている。メカトロニクス革命は、機械技術が電子技術と材料技術と融合したことにより、オプトエレクトロニクス技術は、硝子技術がケーブル技術と電子デバイス技術と融合したことにより創り出された。メカトロニクスやオプトエレクトロニクスという言葉が示唆しているように、「融合」とは異種類の技術の単なる組み合わせ以上のことを意味し、そこには１＋１が３になるという算法が成立するのである．「技術融合」は、単なる組み合わせを越えており、技術革新に参加したものに新しい市場と機会を提供するので、「補完性」以上のものである。技術融合はいくつかの別々の技術分野を混合して、他ではみられない何物かを追加するのであって、小さな漸進的な「改善の累積」を越えている。技術融合は、異業種の異なる技術革新が、共同研究という形で同時併行的に進行するのであって、「産業連関性」を越えている（児玉；1991）．

既に述べたように，巨大技術開発をその経路依存性から開放するためには，異業種間競争が必要であるが，これは充分条件ではない．異業種間競争で出現する技術突破を契機にして，２１世紀に向けて巨大技術開発プログラムが最適な軌道を辿り始めるためには，「技術融合」が不可欠なのである．「技術融合」が不可欠なのである． 今後、この融合現象は製造業を越えて高度化していくものと考えられる．（Kodama; 1992）．

最近話題になっている，高度道路交通システム（Intelligent Transport System）は， 公共インフラと民間個別技術を結ぶ「社会システム融合」を目指したものであると言えよう．このような技術開発をどのように推進しているかについては，自動車技術と環境技術との過去の相互作用関係を振り返ってみることにより，その参照軸を発見することが出来る．まず，地域レベルの環境問題の典型的なものであった，自動車の排気ガス問題の解決には日本の自動車メーカーの貢献が大きかった．この問題解決へ向けての契機になったのは，本田技研の持つ「エンジン技術」についてのコアコンピテンスであった．しかも，このコアコンピテンスが次に続いた石油危機を契機として突然現れた低燃費問題題への

解決に遺憾なく発揮されたのである．すなわち，自動車エンジンで，燃料を「クリーン」に燃焼させることと「効率よく」燃焼させることとは，シリンダー内の混合ガスの流動を徹底的に調べ上げた，本田宗一郎氏にとっては同じ問題であったのである．現在は触媒技術が使われているが，この技術競争は，化学工業に対して自動車工業が勝利するという異業種間の技術開発競争の結果がもたらしたものであった．さらに，この問題の高度な解決は，集積回路によるエンジン燃焼制御技術との技術融合がもたらしたという形に発展していったのである．今後は，地球レベルの環境問題が自動車技術にとって致命的な役割を果たすであろう．ITS 技術の開発は，地球環境問題の解決には，一層高度化した社会システム融合が必要なことを示唆してるのではないだろうか．

エネルギー技術は，将来の炭酸ガス排出による全地球的な環境問題として，人類の生存という本質に係わっている．このような長期的観点からは，原子力技術への期待が大きくなっている．しかし，原子力は巨大技術である以上に，大規模・複雑システム技術である．しかも，燃料供給ー発電ー再処理という，自立した閉鎖系の構築を運命づけられてる．このことを勘案すれば，単一の社会システムの構築だけではなく， 政策レベルでの融合が必要とされていると言えよう． 事実，1997 年 5 月 16 日に閣議決定された「経済構造の変革と創造のための行動計画」においては，「新規産業創出環境整備プログラム」として，表 3 に示すような 15 産業分野が「新産業」として特定されている．しかも，この報告書の参考資料には，この 15 分野に係わる「関係省庁連携会議」の各省庁体制に関する表が添付してある（大蔵省印刷局；1997）．

表 3.　新産業創出環境整備に係わる「関係省庁連携会議」各省庁体制

	警察庁	総務庁	北道庁	防衛庁	経企庁	科技庁	環境庁	沖縄庁	国土庁	法務庁	外務省	大蔵省	文部省	厚生省	農林省	通産省	運輸省	郵政省	労働省	建設省	自治省
医療・福祉関連分野																					
生活文化関連分野																					
情報通信関連分野																					
新製造技術関連分野																					
流通・物流関連分野																					
環境関連分野																					
ビジネス支援関連分																					
海洋関連分野																					
ﾊﾞｲｵﾃｸﾉﾛｼﾞｰ関連分																					
都市環境整備関連分																					
航空・宇宙（民需）																					
新ｴﾈﾙｷﾞｰ・省ｴﾈﾙｷﾞｰ																					
人材関連分野																					
国際化関連分野																					
住宅関連分野																					

（出所）：大蔵省印刷局，「経済構造の変革と創造のための行動計画」（1997 年 5 月 16 日，閣議決定）

上記のような表の作成作業により一層明示的になる，複雑に錯綜している各省庁の連携関係は，新産業創出のためには「政策融合」が不可欠なことを，図らずも明らかにしていると言えよう．逆に言えば、このような政策融合によって始めて、原子力開発の目標設定が「自立した閉鎖系の設計・構築・運用」という一般的な技術開発課題に翻訳され、これが科学技術全体の索引車になる可能性が出てくるのである。環境問題が深刻化する来世紀を考えれば、この技術開発命題は、現存する技術システムばかりでなくこの後出現するものも含めてあらゆる「人工物」に課せられた、今後の 100 年間を通した普遍的な技術課題

になるであろう。けだし、各時代を特徴づけるような技術革新は、要求が最も明確な（articulated）応用分野への果敢な技術的挑戦により触発され、これを「virtual market」と想定した技術開発により実現され、これが他の応用分野へと普及・伝幡して行ったという歴史を繰り返してきたのである。

来るべき２１世紀社会においては，いくつかの高度な「融合」が技術革新の源になるであろう．融合は協調し合うという意味で、異業種間競争とは対極的な関係にあるが，この２つの動きが相互に重なり合って技術革新が進み新産業の創造につながる（児玉; 1998）．このような創造のダイナミックスが，原子力開発と他の先端技術の相乗的発展を展望するのに当たっての基本概念となるべきである．しかも，高速増殖炉のような革新的な社会・技術システムの創造ダイナミックスのサイクルは，それに従事している研究者・技術者・計画者の単独の世代で閉じるとは限らない．ある世代が開発・蓄積してきた技術的資産を次の世代が継承し、時代の変化に伴い新たに発生する社会・経済的要請に応える形で、技術開発の方向を修正・発展させるという長期的なダイナミックスを想定すべきである。すなわち、自己完結的なエネルギーシステムの完成には，数世代にまたがる継続的な技術開発活動を必要とするのである．

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コンピュータと原子力

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要旨

原子力は、多くの分野の科学と技術を結び付けた総合科学技術である。したがって個々の分野の科学や技術の発展が原子力の発展を促す一方、原子力分野での必要性が個別の関連分野の発展を促すという相互作用によって、双方の分野のスパイラル的発展が可能となる。そのひとつの例に、原子力とコンピュータの相互作用がある。この二つの分野は、黎明期を同じくし、両者は相互の牽引力として機能してきた。

このプレゼンテーションでは、コンピュータと原子力の相互作用による相互のスパイラル的発展を次の４期に分けて概観する。

第１期は、コンピュータ開発に原子力研究開発機関が積極的役割を果たした 1960 年代からコンピュータの性能が爆発的に向上した 1980 年代までを、

第２期は、コンピュータの性能向上を受けて大規模或いは実時間的計算が原子力分野でも盛んとなった 1990 年代までを、

第３期は、並列処理による超高速計算が切り開きつつある計算科学の新しい潮流の時代。これらの各時期におけるコンピュータと原子力の関わりと、両者が相互に牽引力となってスパイラル的発展がもたらされた実例を、日本原子力研究所、動力炉核燃料開発事業団、電力中央研究所での成果を例に取り説明する。

第４期は、計算科学の新しい潮流とともに、原子力が再びコンピュータ開発の牽引力となろうとしている１９９７年以降の状況について説明する。

１．はじめに

原子力は、多くの分野の科学と技術を結び付けた総合科学、総合技術です。従って、個々の分野の発展が原子力の発展を促す一方、原子力での必要性が個別の関連分野の発展を促すという相互作用によって、双方の分野のスパイラル的発展が可能となります。

その一つの例として、本日は、コンピュータと原子力がその黎明期を同じくし、両者の発展が分かちがたく結びついていること、また、主要な時期には、原子力がコンピュータ開発の牽引力となってきたこと、更に原子力とコンピュータが織り出す開発

の夢の幾つかを、日本原子力研究所の研究開発を中心に紹介したいと思います。

2．コンピュータと原子力の曙時代

コンピュータと原子力は、その黎明期を同じくし、手を携えて発展してきました。１９４９年、当時の米国原子力委員会は、高性能のコンピュータの必要性を痛感し、資金を提供してコンピュータの製作を行いました。その頃に製作されたコンピュータは、真空管２千本程度を使い、一秒間に実行できる加減乗除の演算回数は１０００回程度でした。

当時は、原子力の研究開発に必要とされる計算量と比較してコンピュータの能力が不足しており、原子力分野からの資金で、コンピュータの性能向上を加速する必要があったわけです。

同時期に日本原子力研究所でも真空管式のコンピュータを導入して利用を始めましたが、これは日本の第１号機でした。この頃から世界の原子力研究開発機関は、世界最高速のコンピュータを競って導入しており、この傾向は現在も続いています。

3．コンピュータ性能の爆発的向上

コンピュータの演算回路素子、記憶素子が真空管、トランジスタ、ＩＣ（集積回路)、ＬＳＩ（大規模集積回路、ＶＬＳＩ（大規模高密度集積回路）と移るにつれて、その計算性能は飛躍的に増大してきました。この５０年間のコンピュータの名目性能を横軸を年代、縦軸を名目性能として描きますと、線が３本になります。即ちマイクロプロセッサ単体の性能線（下位の線)、スーパーコンピュータの性能線（中位の線)、単体装置を複数搭載した並列コンピュータシステムとしての性能線（上位の線）の３本です。

特に注目すべきは、下位の線のパソコンやワークステーションに搭載されているマイクロプロセッサの性能向上です。1990 年前後の飛躍的な技術進歩（設計技術と集積度の向上）で、スーパーコンピュータの 10 分の 1 まで性能が向上しています。

この５０年間で単体の演算装置としては、実に百万倍、複数の演算装置を搭載した並列コンピュータとしては 10 億倍以上の計算性能の向上が実現されています。

このような進歩を原子力分野の中性子拡散計算コードＣＩＴＡＴＩＯＮの例で見ますと、30 年前には、１次元拡散方程式の計算がやっとでしたが、20 年前には２次元で計算でき、１０年前には３次元の計算が短時間で可能となりました。2000 年以降には、３次元が実時間に近い速さで計算できるでしょう。

4．原子力分野での最近の活用例

計算空間の多次元化、実時間的処理、大規模計算が盛んに行われるようになりました。実時間的処理、大規模計算について最近の日本原子力研究所の成果を中心に活用

例を幾つか説明しましょう。

次の２つは実時間的計算の例です。

（１）環境汚染物質の大気中の移流と拡散の予測

実時間的処理の例では、１９８６年のチェルノブイル事故による環境への放射性物質の風に乗った流れと広がり、地面へ落ちた量を２週間にわたって推定計算したものがあります。計算の結果は、実測値と良く一致しています。結果を分かりやすくするために、１日を３０秒に短縮して表示しています。迅速な対応が必要とされる緊急時には、実時間的予測が必要で、最近のコンピュータの発展によって、これが可能となりました。

（２）国際熱核融合実験炉の設計支援

同じく実時間的処理の例として、現在、国際熱核融合実験炉ＩＴＥＲの設計活動が日本、米国、欧州、ロシアの４極の共同作業があります。

実験炉第１壁のタイルは１枚が４トンもある大きなもので、その補修作業は、周辺の放射線が強いことから遠隔操作で行う必要があります。ＣＡＤデータを利用した遠隔操作のシミュレーション・システムは、実際の補修の事前解析に有効です。また、補修時にシミュレーションを実時間的に実行することによって正確な作業実施が可能となります。

次に大規模計算の例を幾つか挙げましょう。

（３）大規模構造物の放射線遮蔽の解析

理化学研究所と日本原子力研究所が兵庫県播磨に建設した大型放射光施設Ｓｐｒｉｎｇ－８が完成し、昨年の１０月から動き始めました。これは、直線加速器で１ＧｅＶの電子を発生させ、シンクロトロンで８ＧｅＶまで加速した後で蓄積リングを周回させます。電子の軌道を強い磁場で曲げると、強い光が発生します。この光を使用して、様々な研究が行われています。

発生した光は、ビームラインと呼ぶ通路を通って実験装置に導かれます。この光は強い電磁波なので、実験室周辺は十分な遮蔽が必要です。光を粒子の集まりとして見ると、実験室の遮蔽の計算には膨大な計算時間が掛かりますが、最近の高性能コンピュータのお陰で、期限内に安全設計を完了することができました。この計算には、原研開発のモンテカルロ計算装置も使われました。

（４）人間型ロボットの動作シミュレーション

原子力施設における定型的作業、例えば巡回点検作業などの自動化手段の一つにロボットの利用があります。日本原子力研究所では、研究炉ＪＲＲ－３の一次区画のＣＡＤモデルを製作し、その一次区画内で２足歩行型ロボットによる巡回点検の

コンピュータシミュレーションを行いました。その後、一次区画の一部分のモックアップモデルを製作し、そこでメーカー製作の２足歩行ロボットに原研開発の視覚情報処理システムを搭載して歩行させ、最後に現実の研究３号炉の一次区画内の歩行実験を行いました。

ロボット動作そのものの運動学的シミュレーションにはさほど計算時間は要しませんが、ロボットと環境との相互作用、特に環境の映像化と空間線量の計算に膨大な計算時間が必要です。それによってロボット搭載の電子機器の受ける線量や同一作業を行う人間の臓器が受ける線量などの予測が可能となります。

（５）高速増殖炉配管温度計の設計解析

高速増殖炉「もんじゅ」の二次主冷却系配管の内部に突き出した温度計さや破損の原因究明のために動力炉核燃料開発事業団では、数値解析によってこれを行いました。

流れによって「さや」に振動が生じます。流れを左から右へ向かうとし、温度計は円柱で表して赤い粒子と青い粒子は、それぞれ流れに対して円柱の右半分と左半分の円柱の表面及び中心線上からの流れを対応させて計算結果を分かりやすく表示する工夫を凝らして、時間の移動と共に移動する円柱の位置、円柱によって分けられた流れから生じる渦の状態について知見を得ました。この解析は、空間では円柱直径の千分の１（10マイクロｍ）、時間では円柱の振動周期の１万分の１（１マイクロ秒）に分解することで可能となったものです。

（６）高速増殖炉の構造物熱疲労解析

これも動力炉核燃料開発事業団による解析結果です。

高速増殖炉では、炉心で発生する熱をナトリウムによって取り去ります。炉心の出口付近では、ナトリウムの温度の揺らぎが構造材に伝わり、その材料が熱疲労を受けることが予想されます。計算のモデルは、高温のナトリウム（３２０Ｃ，２ｍ／ｓ）を噴き出す燃料集合体を模擬したノズル、低温のナトリウム（２８０Ｃ，２ｍ／ｓ）を模擬したノズル、炉内構造物を模擬した２つの噴流が衝突する水平板（厚さ１５ｍｍ）から構成されています。

噴流は、ノズルから流れ出た直後は大きく振動していますが、水平板に近づくに従って振動の周期と幅が急激に減少することが分かりました。

（７）地球気候変動の解析

最近は、環境保全という制約の下でのエネルギー開発と利用が重視されています。そこで、長期にわたって排出される炭酸ガスの影響を予測することが重要となります。

電力中央研究所は、最近３２台の演算装置を持つスーパーコンピュータを使い、２００時間の計算時間をかけて、これからの１２５年間にわたる地球全体の地表面温度上昇の予測計算を行いました。計算モデルとコードは、米国大気研究センター（ＮＣＡＲ：Ｎａｔｉｏｎａｌ Ｃｅｎｔｅｒ ｆｏｒ Ａｔｍｏｓｐｈｅｒｉｃ Ｒｅｓｅａｒｃｈ ）で開発された大気・海洋結合モデルとコードです。これも最新の高性能コンピュータの出現によって始めて可能となったものです。

５．新しい潮流

コンピュータ性能の飛躍的向上に伴い、計算科学と呼ばれる科学技術の手法が注目されています。これは、実験データの助けをできるだけ借りないで、電子や原子レベルならシュレディンガー方程式、分子レベルならニュートン方程式、流体ならナビエーストークス方程式などの基本原理から物質や自然現象を構成してゆこうとする手法です。

次の３つは計算科学的手法による現象予測の話です。

（１）中性子捕獲による脳腫瘍の治療

原研東海研究所の４号原子炉は現在改造中です。完成は今年の７月を予定していますが、実験装置のひとつに中性子捕獲治療装置を設置します。

この装置を使えば脳内にできた腫瘍を中性子によって破壊することができます（ＢＮＣＴ）。これまでは、この治療は、患者の脳を切開しています。開頭しないで中性子を利用できれば、患者と医療関係者の負担は大幅に軽減されます。そのためには、照射時間を正確に予測する必要があります。現在高速のコンピュータを使って遮蔽と予測計算のシステム整備を進めているところです。

これは、原子力とコンピュータが共同して、新たな医療技術の開発に努めている例と言ってよいでしょう。

（２）冷却水中の気泡発生メカニズムの解明

原研の計算科学技術推進センターでは、電力中央研究所と協力して、原子炉の冷却水中に発生する気泡の発生メカニズム解明の研究を進めています。気泡の量を正確に知ることは原子炉の安全運転には重要な意味があります。

これには、セルラーオートマタと呼ぶ単純な計算法で長時間計算を行い、発生のルール発見を行う一方、発生の理論モデルの構築、実験との比較という、理論、計算、実験の三位一体の方法論で研究を進めています。この三位一体の方法論が計算科学の最も望ましい姿です。

メカニズムが解明されれば、これまで実験に頼っていた部分を理論式或いは計算で置き換えられる可能性があります。

（3）原子衝突のメカニズムの解明

高いエネルギーを持つ原子他の原子に衝突させたときに生じる反応をコンピュータで模擬することなども計算科学的手法が活躍する場となります。原研では、量子力学的分子動力学法という計算手法を開発し、原子同士の衝突の核反応の計算をしています。これによって、反応は１０の－２４秒という速い時間間隔で発生します。 従って実験では、反応の結果しか測定できませんが、量子力学の分野にまで拡張した分子動力学法という計算手法によって、このような微細、高速の物理現象の予測が可能となりました。実験が困難な自然現象に対しては、計算科学の手法が大きな力を発揮します。

この計算手法で、炭素１２と炭素１２の衝突、炭素１２とニオブ９３の衝突、銅６３と金１９７の衝突などのシミュレーションを行い、種々の知見を得ています。

６．更なる高速化を求めて

次は計算の更なる高速化の話です。

（1）最近20年間のコンピュータの性能

この２５年間の主なコンピュータの性能向上には著しいものがあります。1976年出荷のスーパーコンピュータＣＲＡＹ－１の性能を１としますと、１９９０年には70倍、1995年には7000倍の性能向上が実現しています。２００１年には、これの30倍以上の性能向上が予測されています。

（2）新しい開発計画

日本では、原子力がこのような高速コンピュータ開発の牽引力となっていることを説明しましょう。

現在のコンピュータは高速になっていますが、地球規模の詳細な気候変動を計算する、或いは原子、分子レベルから物質構成を行うには、十分に速いとは言えません。近年、エネルギー開発も、環境制約の条件を考慮しながら進める必要があり、原子力と環境との関係もより密接なものとして捉えられるようになってきました。原子力の優位性を言うには、気候変動との関係を定量的に示すことも必要です。そこで日本原子力研究所は、宇宙開発事業団と協力して、このための高速コンピュータの開発を始めています。原子力が再びコンピュータ開発の牽引力を務めるわけです。その成果は、気候変動のみならず、物理、化学、材料、物性、放射線の生物影響、その他の研究開発分野に大きな進展をもたらすことでしょう。

7．終わりに

本日お話したかったことは、コンピュータによって先端的な原子力の先駆け的研究が引っ張られ、また、逆に原子力がコンピュータ開発の牽引力となっていること、両者の共同作業が極く近い将来に実現するかもしれない夢を生み出す可能性もたらしていることです。この講演からそのような事実の一端を汲み取って頂ければ幸いです。

Computers and Nuclear Energy

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Abstract

Nuclear energy based on nuclear science and engineering, by definition, falls within the category of quite a comprehensive nature ranging multiple disciplines. Accordingly, development in the nuclear energy R&D takes so-to-say a spiral course that once progress occurs in certain individual fields of science and engineering other than the nuclear energy, it evokes and prompts another development in the nuclear energy, and vice versa.

One good example of this interactive process between the nuclear energy and other fields is that with the computer technology. Both computers and the nuclear energy born nearly at the same point of human history, have, from the very beginning, worked as the driving force to one another.

In this review the speaker presents the history of the interactions between computers and nuclear energy with their spiral evolution by three four periods of time, i.e.,

(1) the first period, from 1960's through 1980's, in which nuclear R&D organizations played an aggressive role for the development of computers, and the progress in the solid state electronics brought the explosive computational capability available to mankind,

(2) the second period, the decade of 1990's, in which nuclear R&D organizations became to adopt, as their powerful means, real-time and/or large-scale computations owing to the advent of high performance computers,

(3) the third period, through present, in which nuclear R&D organizations are proceeding into the new era of advanced computational science and engineering based on the abundant capability of massively parallel computers, and

(4) the fourth period, from now to the near future, in which the computational demand in nuclear field is expected to play again a locomotive force for development of new, very high speed computers.

Using the research results made by the Japan Atomic Energy Research Institute, Power Reactor and Nuclear Fuel Development Corporation, Central Research Institute of Electric Power Companies and others, the speaker intends to illustrate the spiral evolution of computers and the science and engineering in nuclear energy field.

1. Introduction

Nuclear energy is a subject of science and engineering in many different fields. Therefore, while development in the scientific or engineering field urges development of nuclear energy, the necessity in nuclear energy promotes development in related fields. This relation enables spiral development of both fields.

As an example of such spiral development, I would like to introduce to you today the relation between computers and nuclear energy. They share their dawning era, the development of one is closely related to that of the other, that nuclear energy has been acting as a locomotive force of computer development. And I would like to introduce some of the new worlds woven out by computers and nuclear energy.

2. Era of Dawning of Computers and Nuclear Energy

Computers and nuclear energy share their dawning era and since have been developing hand in hand. In 1949, the U.S. Atomic Energy Commission (USAEC) at that time strongly felt the necessity of high performance computers, and supplied fund for manufacturing computers.

The computers produced at that time, which used about 2,000 electron tubes, only had performance of executing approximately 1,000 times of fundamental arithmetic operations per second.

In those days, the computer capability was very low compared with the amount of calculations required for the research and development of nuclear energy and, therefore, it was necessary to accelerate the improvement of computer performances by using funds from the nuclear energy field.

In the same period, the Japan Atomic Energy Research Institute

(JAERI) installed and started use of an electron tube type computer, and this was the first electronic computer introduced in Japan. From around this time, nuclear energy development organizations in the world came to vie with one another in introducing world's fastest computers, and this trend has been continuing up to today.

3. Explosive Progress of Computer Performance

As circuit components and memory of computer changed from electron tube to transistor, IC (integrated circuit), LSI (large-scale integration circuit), VLSI (very large-scale integration), the performances of computers sharply increased.

When we describe the nominal performances of computers developed during these fifty years in a graph which abscissa indicates age, while the axis of ordinate represents nominal performances, we can find three lines of performances.

The lines indicate for microprocessors(lower line), for supercomputers(middle line) and for parallel computers(upper line). Anyone who draws the lines can easily recognize the facts that during the period of these fifty years, the computing performances of microprocessors increased more than one million times, and those of parallel computers achieved as much as no less than one billion times increase.

The contribution of such rapid progress of computer performance to the nuclear energy may be expressed in the following simple example.

About thirty years ago, the best calculation made by computer was one dimensional neutron diffusion equation for reactor core. Twenty years ago, this calculation was made for two dimensional case and, ten years ago, the calculation for three dimensional case came to be made in minutes. At present, this calculation can be made at a speed of near real time with a high speed computer.

4. Recent Computer Applications in Nuclear Field

With sharp progress of computer technology, multidimensional calculations, real-time processing and large-scale calculations came to be practiced frequently also in the field of nuclear energy. Regarding real-time processing and large-scale calculations, let me show you some examples of application centering around the achievements obtained recently by the Japan Atomic Energy Research Institute(JAERI).

In the following let me introduce you two examples of near real time calculation.

(1) Prediction of Airborne Radioactive Materials

As an example of near real-time processing, we can show you a calculation made for estimating the amounts of advection, diffusion and deposition of radioactive materials over two weeks in the environments caused by the accident at Chernobyl in 1986. The results of calculation well agree with the measured values. Real time calculations are necessary in case of an emergency which requires quick responses, and these have become possible with recent development of computers.

(2) Design Assistance to ITER

This is also an example of real-time processing. At present, design activities of international thermonuclear fusion experimental reactor ITER are being promoted under a joint work by Japan, United States, Europe and Russia.

The tiles used for the first wall of the experimental reactor are very large ones, with a weight of four tons for each piece. The repair work of the tiles must be carried out by remote operation because of strong radioactivity in the surrounding area.

A simulation system of remote operation utilizing CAD data is effective for preliminary analysis to be made before the actual repair work. Moreover, it becomes possible to perform a repair work accurately by executing a simulation in real time at the time of the repair.

Next let me show you some examples of large-scale calculation.

(3) Shielding Analysis of a Large-scale Facility

The large facility Spring-8 for synchrotron radiation was constructed in Harima, Hyogo Prefecture, Japan, jointly by the Institute of Physical and Chemical Research (RIKEN, Japan) and the Japan Atomic Energy Research Institute (JAERI) and was put into commission in October, 1997.

It consists of a linear accelerator which generates electrons with

1 GeV energy, a synchrotron which accelerates the electrons to 8 GeV, and a storage ring which holds the electrons for a long time. A strong light beam is generated if the trajectory of the electrons is bent with a strong magnetic field. Many kinds of researches are being done by utilizing the light beam sources.

The generated light beam is led to experimental devices through a channel called beam line. The room for experiment and the surrounding area must be shielded sufficiently well because this beam is a strong electromagnetic wave. If you consider a beam as a group of particles, it takes an enormous amount of calculation time for analysis of shielding of the room, but we could complete safety design within a scheduled period thanks to a high-performance computer of recent development. We also used a supercomputer Monte-4 for the shielding analysis. The computer was designed and developed by JAERI for high speed calculation of particle transport .

(4) Human-shaped Robot in Nuclear Plant

As one of the means for automation of routine work such as inspection patrol in a nuclear power plant, utilization of robot will be useful. This is a simulation of a human shaped robot walking in the primary compartment of the research reactor JRR-3 of Japan Atomic Energy Research Institute (JAERI) located at Tokai-mura village, Ibaraki Prefecture. Although not much calculation time is required for the kinetic simulation of the robot motions themselves, it takes an enormous amount of time for the calculation of interactions between the robot and the environments, especially visualization of environments and calculation of spatial dose. This makes it possible to estimate the dose of electronic equipment loaded on the robot, the dose of organs of a person who executes the same work.

(5) Design Analysis of Sheath of Thermometer in Pipe of FBR

The Power Reactor and Nuclear Fuel Development Corporation (PNC) has made computational analyses for investigation of the cause of damage of a sheath of thermometer which incurred the shot down of the fast breeder reactor Monju.

In the analyses the sheath diameter were separated in ten microns and the calculations were done for a time step of one microsecond. Owing to this resolution of fine mesh, the calculation exactly showed vibrations and movement of the sheath in sodium flow, vortices caused by the thermometer.

(6) Thermal Stress Analysis of FBR Structure

Let me show you one more example obtained at PNC.

The heat generated in the fast breeder reactor core is removed by sodium flow. Near the outlet of the reactor core, swaying temperature of sodium is transferred to the structural material. Therefore the material is faced with the thermal stress.

A calculation analysis was done by making a model which consisted of two sodium flows of high temperature(320 C, 2m/s), low temperature(280 C, 2m/s) and a plate. The two flows were blown out from neighboring two nozzles separately and finally collided with the plate. The calculation showed that the periods and widths of the flows rapidly decreased according to the decrease of distance between the plate and the flows.

(7) Prediction of Global Change

In recent times, much emphasis has come to be placed on development and utilization of energies under the restriction of environmental protection. For that reason, it becomes important to estimate the influences of carbon dioxide emitted over a long period.

The Central Research Institute of Electric Power Companies recently performed calculations for estimating the increase of atmospheric temperature for a period of 125 years to come, by using a supercomputer having 32 processors and with a calculation time of 200 hours. The calculation model and code is a combined atmospheric & ocean model developed by the National Center for Atmospheric Research (NCAR). This has become possible also with the advent of high performance computers of recent development.

5. New Tidal Wave

With rapid and explosive increase of computer performance, attention is being paid to a methodology called " the computational science and engineering", CSE for short.

This is a methodology for understanding the structure of matters and natural phenomena, not by experiments nor theory but from calculations based on fundamental principles such as Schroedinger equation in the case of electron and atomic level, Newton's equation for molecular level, Navier-Stokes' equation for fluid, etc.

Let me show you some examples of research and development which utilize the CSE methodology. Following three R&D are such examples which are being carried out at JAERI for prediction of phenomena by using the CSE methodology.

(1) Introduction of New Boron Neutron Captured Therapy

The JRR-4 research reactor at Tokai Research Establishment at JAERI is currently under reconstruction. In this reconstruction , which is planned to be completed in July this year, a medical treatment system for Boron-Neutron-Captured-Therapy(BNCT) is to be installed.

By using this system, it becomes possible to destroy a tumor formed in the brain. While the treatment had been executed by opening the patient's brain in the past, it becomes possible to make the treatment without opening the patient's brain with the utilization of neutron with higher energy, thus sharply reducing the burden on both the patient and the medical staff. For that purpose, it is necessary to accurately estimate the irradiation time, etc. Development of a system for estimation is currently under way by utilizing high-speed computer.

This may be said to be an example of joint development of new medical technology using nuclear energy and high-speed computer.

(2) Discovery of Mechanism of Air Bubble Generation in Coolant

The Center for Promotion of Computational Science and Engineering(CCSE) at JAERI is promoting a study for elucidating the mechanism of movement of air bubbles formed in the cooling water of a nuclear reactor, in cooperation with the Central Research Institute of Electric Power Companies. If we can obtain accurate knowledge about the amount of air bubbles, it has a significant meaning for the safety operation of a reactor.

This study is being promoted by a method of comprising theories, calculations and experiments. It consists of discovering of rules of generation & movement of air bubbles through a long calculation time using cellular automata on one hand, and building a theoretical model for the generation and comparing the results with experiments on the other hand. This methodology of trinity is the most desirable style of CSE. If the mechanism be elucidated, it will give us a possibility of replacing the portion which has so far been supported by experiment by theoretical formulae or calculations.

(3) New Method for Simulation of Nuclear Reaction

Simulation of nuclear reactions such as collisions of high energy particles with other atomic element is one of the most important applications of the methodology of CSE. The nuclear reactions occur in short time of 10 to -24 power second, and it is difficult to observe details of the phenomena by experiments.

For the purpose of the simulation, a computational method called quantum molecular dynamics has been developed at JAERI.

By using the computational method, we can estimate behavior of such atomic elements as carbon-12, carbon-12, copper-63 when they collided with carbon-12, Niobium-63, gold-197, respectively.

6. New Development Plan for Very High Speed Computer and Its Relation with Nuclear Field

Next, let me touch upon further speeding up of calculations and new development of a very high-speed computer which are stirred by requirements in relation with nuclear energy.

Currently available computers work at high speed, but their speed is not sufficiently fast for calculating detailed climate change in global scale or for composing substances from atomic or molecular level. In recent years, conditions of environmental restrictions must be taken into account also in the promotion of energy development, and the relation between nuclear energy and environments came to be grasped as a closer one than it was before. To advocate superiority of nuclear energy, it is also necessary to quantitatively indicate the relation with climate changes. For that reason, Japan Atomic Energy Research Institute (JAERI) started development of a high-speed computer for that purpose, in cooperation with National Space Development Agency of Japan (NASDA). Nuclear energy is again acting as locomotive force for the development of high-speed computer here. The results of this development will provide a great power not only for the study of climate changes but also in various fields of research and development such as physics, chemistry, materials, physical properties, influences of radioactivity on living beings.

7. Concluding Remarks

What I want to say today is that advanced pioneering studies of nuclear energy are led by computers and, conversely, nuclear energy also acts as locomotive force for the development of computers, a possibility that joint work between the two may produce scientific and technological progress which will be realized in the very near future.

I shall be happy if this lecture helps you to have a glimpse of such facts.

Thank you for your attention.

２１世紀の原子力を目指して
－原子力における技術の高度化－

（株）東芝 原子力事業部長　待場 浩

１．まえがき

原子力における技術開発はABWRの完成により一つの区切りを迎え、今後はABWRを標準としたプラント建設の時代を迎えようとしている。また、これと並行してABWRの次の世代の原子炉であるABWR Ⅱの構築へ向けての技術開発を進めているところである。ここではまず、ＡＢＷＲの開発技術についてまとめるとともに、原子力における技術の高度化の例として、将来に向けてのABWR Ⅱの技術開発について述べる。次に、今後のプラント建設に対する技術開発動向として、エンジニアリングの高度化を進めておりこの内容について説明する。最後に、運転プラントに対する技術の高度化の例として、自動機器を活用した予防保全技術の開発について紹介する。

２．ＡＢＷＲの完成と開発技術

世界初のABWRである東京電力柏崎刈羽６号機は1996年11月に、２番目の同７号機は1997年７月に営業運転を開始した。ABWRは世界の軽水炉技術を集大成したものであり、今後のBWRの標準となるものである。

ABWRの開発目標は、より一層の信頼性・安全性の向上、運転性・操作性の向上を図り、建設費，運転費の低減により経済性を向上させ、さらに被ばく・放射性廃棄物の低減を目指すものである。これらの目標を達成するために、ABWRでは、インターナルポンプ（RIP）、改良型制御棒駆動機構（FMCRD）、鉄筋コンクリート製格納容器（RCCV）、高度計測制御設備などの多くの優れた新技術を取り入れている。この結果、現在稼働中の柏崎刈羽６号機，７号機は、いづれも当初目標を上回る優れたプラント性能を示している。

ABWRには多くの開発技術があるが、その１例として炉心下部プレナム流流速分布解析について紹介する。

ABWRでは出力を増加しているために炉心が大型化されるとともに、インターナルポンプを採用したため従来のジェットポンププラントに比べて、下鏡形状、炉内構造物が変更されている。このため、炉心下部プレナムの流動状況を把握するために、炉心下部プレナム流流速分布の３次元解析を実施した。これにより、炉内流動状況を把握するとともに炉心下部プレナム構造の健全性を確認した。この手法の妥当性は、NUPECで実施された実証試験により検証されており、また実機における炉内流動振動試験でもその有効性が実証された。

ABWRの完成により技術開発は一つの区切りを迎えたが、既にさらなる技術改良を

目指した技術開発を進めている。

次期プラントについては、標準化を阻害しないで適用出来る機器単体の合理化や周辺設備の合理化を進めている。

その一例としてFMCRDのマグネットカップリングが挙げられる。これは、駆動部の基本構成をそのままにして、軸封部にマグネットカップリングを採用しシールレス化したものである。シール部をなくすことによって軸封部からのリークの可能性がなくなるため､より一層の信頼性向上を図ることができる。

さらに将来に目を向けると、ABWR の次の世代の BWR である ABWR Ⅱの開発に向けた技術開発も着々と進められている。現在考えられている新技術としては、大型化により燃料体数及び制御棒（CR）／制御棒駆動機構（CRD）数の削減を図り燃料取替時間を短縮した大型燃料、スクラム機能と調整機能を分離することにより簡素化を図った機能別 CRD、静的な安全系により安全性の向上を図りシビアアクシデント時の除熱を行う静的熱除去系などのほか、大容量逃し安全弁、新型主蒸気隔離弁、静的可燃性ガス再結合器などが挙げられる。

3．エンジニアリングの高度化

今後のプラント建設をより合理的に進めるためのエンジニアリングの高度化の一つの施策として、ＡＢＷＲに関する標準データベースの構築を進めている。これは、情報の標準化によるプラント建設の効率化を目指したもので、ＡＢＷＲ建設実績に基づく標準データベースの作成、情報の構成管理、業務プロセスの標準化・電子化である。

エンジニアリングの高度化の第二の施策として、プラントメーカとベンダーおよび電力会社との間での電子的な情報交換を進めている。これは、電子的な形でのタイムリーかつ確実な情報の連携により、プラント建設の効率化を目指したものである。また、行政サイドとの間においても、審査の効率化を目指して、許認可申請の電子化を進める計画もある。

システム的には、プラントメーカ内で作成される設計情報をプラントデータマネジメントシステム（PDM）により統合し、さらにこの情報を生み出す業務をワークフローにより管理し、また情報の構成をデータベースにより管理するものとしている。

4．軽水炉時代の長期化を見据えた技術開発

軽水炉時代の長期化に加え、新規立地点の確保が困難になっている状況から、運転プラントの寿命延長を図ることは重要であり、このためには予防保全技術の高度化が必要である。現在、点検・診断技術、炉内の予防保全技術などの技術開発を進めているが、一例としてシュラウド取替工法の開発について紹介する。

ＢＷＲでは、シュラウドの応力腐食割れが近年国内外の経年プラントで発見され、より耐食性の高い材質のシュラウドに取替える工法の開発が必要とされていた。この

ため、遠隔操作のシュラウド切断装置、開先加工機、コンパクトで信頼性の高いシュラウド溶接装置などを主体としたシュラウド取替工法を開発し、その実現化を図った。

本シュラウド取替工法は、高度の技術を要しながらも、非常にシンプルで信頼性の高い予防保全技術と言える。この技術を柱として、今後もさらなる技術開発を進めていき、原子炉の長期安定運転に貢献していく所存である。

放射線を使った医療技術はここまで来た

放射線医学総合研究所特別研究員
舘野之男

はじめに

医療技術には、病気を診断するためのものと、病気を治すためのものとがある。放射線を使った医療技術にも当然この二つがあり、どちらの分野も最近、驚くほど進歩している。今回の講演では、時間の関係で、診断に限って話をした。

1　目に見えるものとしての病気

病気の特徴的な変化は大抵が体の内部にある。西洋では17世紀頃から、死体を解剖して見出した所見を基礎にした医学が発達しはじめ、これが現代医学の源流をなしている。

2　体の中を透かして見る

解剖学を基礎にした医学では、病人の体内を、解剖した時と同じように見ることの出来る手段がほしいところである。しかし、人間が初めてそういう手段を手に入れたのは、19世紀の末、ドイツの物理学者レントゲンが発見したエックス線によってである。

3　エックス線写真で病気を見る

とはいえエックス線で可能なのは、割り切って言えば、骨と肉と空気の識別ができるだけで、病気が見えるのではない。そこには本質的に越えがたい溝がある。そして、その溝を越えようとする努力がその後営々と続けられていて、その成果はエックス線診断学という学問に体系づけられている。

4　造影剤を使う

エックス線の識別能力を高めるには造影剤を使う。例えば胃を見るには、バリウムというエックス線を通さない物質と、空気というエックス線を通しやすい物質の二つを造影剤として使う。これが完成したことで、胃の粘膜などは、解剖したときと同じように見ることが出来るようになった。

5　「透かして見る」から「割って見る」へ

エックス線で「透かして見る」という方法にはもう一つ大きな欠点がある。人体のような立体的なものは「透かして見」たのでは、前後が重なってよく分からなくなってしまうのである。そこで登場したのが「割って見る」技術である。それがCTである。

6　情報取得手段の多様化

最近ではさらに、体の中の情報を取るのに、エックス線だけではなく、超音波も

用いる。また高周波も用いる。MRIといわれている技術がそれで、強い磁場の中に入れた人体に高周波を照射すると、人体がこだまのように高周波を返してくるのを利用する。これらによって、様々な生体情報が得られるようになった。

7　「割って見る」から「三次元的に見る」へ

こうした新しい技術はいずれも、人体を断面図として見せることが多い。しかし、最近では、立体的にも見せられるようになり、ますます解剖に近くなってきた。

これについては、幾つか、ビデオを供覧した。

8　解剖を超える

放射線を使った医療技術ではさらに、解剖しても見えない人体内部の活動を、巧妙な方法で見えるようにしたものがある。講演では、体内でのブドウ糖の使われ方を示したものと、脳内の神経伝達系の活働を示したものとを供覧した。

9　おわりに

Unique Russian Technologies Related to Nuclear Energy

(Sergey Zykov, Deputy Executive Director of International Science and Technology Center, Moscow)

Influence of Nuclear Industry on the Other Branches of Russian Economy.

Due to the historical peculiarities of our country development, the creation of nuclear industry was first of all linked to the development of nuclear weapons. Under the extremely hard economic conditions immediately after the end of the second world war the large scale activities were started aimed on the emerging of completely new industry branch starting practically from zero level.

The priority of such political incentives as willing to obtain new type of weapons may, perhaps, be unattractive from the panhuman point of view, but now I want to step apart from initial motivations and to analyze the situation just from the economical point of view.

The science, formerly always suffering from the lack of funds and supported mainly by the rich sponsors and minor government support of universities, suddenly found itself in the unique situation where at its disposal appeared significant material resources and the almost unlimited support was granted from the upper political level.

Unfortunately, the recognition of the science's ability to be a real source of economical prosperity by itself, came to main business organizations much later than unique power of science was recognized by politicians. Thus, first real significant investments into science were made mainly under the strong political motivations.

The results appeared to be remarkable. Besides solving the "major task", it became necessary to solve "on the way" a great number of supplementary problems not directly related to nuclear science and technology. This "side-tasks" by themselves proved to have enormous internal potential capable of self-sustaining development and extremely useful for other, non-nuclear applications.

The most impressive examples of such developments may be the emerging of computer technologies initially oriented just on solving weapon design problems. Now it is impossible even to imaging the everyday life of any ordinary citizen without computers or at least calculators. The other example was the necessity of creating industry capable of producing adequate measurement and control instrumentation. This led to the development of vacuum and semiconductor technologies that formed the basis for the further commercial applications resulted in the modern boom in industrial and home television, electronics, etc. The need for new chemical processes involving unusual aggressive and exotic media gave a rise to the material science. Even such branches as medicine and geology, mining and construction were greatly influenced by the "forced" progress in nuclear industry.

Even the electricity power production on nuclear plants itself was essentially the "byproduct" of plutonium production both in Russia and US. In this area we even have a sort of a paradox because in case if nuclear reactors would be designed initially for the purpose of power production the final concepts might be with high probability very different from the standard contemporary designs. In particular, the uranium–thorium fuel cycle have in many cases serious advantages in comparison with present uranium-plutonium standard inherited from the weapon era.

After the impressive demonstration of efficiency of serious investments in science its power became evident already for wide business circles and for politicians already without any connection to the initial defense tasks. Thus, the nuclear industry became the "birth point" for many scientific technological and industrial applications that are now stand firmly on their own feet and their nuclear origin not so obvious.

The Examples of Nuclear Related Technologies Implemented in RF.

In Russia all nuclear related technologies were initially developed in frame of Minatom structure (the previous name of the Agency was Ministry of "middle machine building"). All activities in this branch of industry were completely funded by the state budget. The majority of supporting infrastructure was also incorporated into the Ministry.

The number of different technologies developed in frame of Minatom activities is too large even for simple listing of them. I would like just to describe few of them. Some of the technologies will be illustrated by video materials prepared at the marketing office of Minatom, the others will be just mentioned.

Russian Federation was the pioneering state in the development of nuclear powered fleet. The geographical layout of Russia made it extremely important to have the possibility of using Arctic Ocean as a route for supplying Siberian and Far East regions. The role of nuclear icebreaker fleet for providing such a possibility can not be underestimated. The natural continuation of the nuclear fleet development was the emerging of the concept of floating nuclear power units for energy supply at the remote locations where the construction infrastructure is absent and long power supply lines are not economically beneficial.

The other example that may seem to be rather far from nuclear origin is the development of superconductivity technologies. The way of superconductivity utilization from pure laboratory applications to large scale industrial implementation was defined at initial steps by the necessity of production of high power magnets for particle accelerators. The majority of technological developments in this area in Russia are now concentrated in the Institute of Inorganic Materials named after academician Bochvar. This is the leading Minatom Institute dealing also with fission material technologies and waste disposal schemes.

One of the important civilian outputs from the military branch of nuclear energy research became the development of precise explosive technologies. Now the specialists from Russian military research centers (Sarov and Snezhinsk) are capable of providing services in such unique areas as explosive destruction of outdated buildings, reinforced concrete basements; precise cutting of large metal constructions (ships, submarines) by the so-called "cord-explosive" technology; effective borehole drilling with explosive perforators, etc.

Development of complicated chemical processing plants besides other innovations required application of different filtration procedures, sometimes in a very unusual conditions. One of the results of such motivated research was the creation as a separate task production of a variety of filter materials and devices. This materials include the range from the fabric filters for personnel protection against dust and aerosols up to ceramic filters for aggressive media and nano-filters based on particle induced micro-holes in different thin films.

The self-sustaining production brunch is now the manufacturing of radioactive sources for the large range of scientific, technical and medicine applications.

ISTC and new technologies.

Global changes in the former Soviet Union led to the qualitatively new situation in the funding conditions in scientific organizations. The governmental programs of scientific development were dramatically reduced and a large number of scientists, first of all in defense oriented research establishments experienced sharp reduction of governmental funding. At the same time the development of private business in CIS had not reached the point when corporations are able to develop long term scientific programs driven by potential commercial interest.

The potential risk of "brain drain" of the scientific and technical specialists from the defense related areas was the major motivation for establishing in Moscow of International Science and Technology Center (ISTC). The Center was established in 1992 by signing the intergovernmental Agreement by initial Parties: European Atomic Energy Community and European Economic Community; Japan, Russian Federation and United States.

The main goal of the ISTC as defined in Agreement is to develop, approve, finance, and monitor science and technology projects for peaceful purposes, which are to be carried out primarily at institutions and facilities located in the Russian Federation and, if interested, in other states of the CIS and Georgia.

The objectives of the Center shall be:

- To give weapons scientists and engineers, particularly those who possess knowledge and skills related to weapons of mass destruction or missile delivery systems, in the Russian Federation and, if interested, in other states of the CIS and Georgia, opportunities to redirect their talents to peaceful activities;
- To contribute thereby through its projects and activities: to the solution of national or international technical problems; and to the wider goals of reinforcing the transition to market-based economies responsive to civil needs, of supporting basic and applied research and technology development, inter alia, in the fields of environmental protection, energy production, and nuclear safety, and of promoting the further integration of scientists of the states of the CIS and Georgia into the international scientific community.

Now, on the sixth year of its existence and after almost five years of actual operations, ISTC is a mature international organization with unique experience in managing R&D projects in CIS countries. The Center supported projects enjoy tax-free status within CIS and have exemption from customs fees. More than 280 CIS institutions and about 17000 specialists participate now in ISTC projects at different levels. The overall funding has reached $160M and the number of supported projects exceeds 540.

Among unique features of ISTC projects are direct payments to individual project participants, full transparency of any project activities even at the closed sites within Minatom. During past years ISTC involved as funding Parties Sweden, Finland (now acting within European union), Norway, and Republic of Korea (now finishing accession procedures). CIS countries participating in ISTC projects now include besides Russia also Kazakhstan, Belorussia, Kyrgyzstan, Armenia and Georgia.

Initially ISTC was completely relying on funding from governmental sources, but now the Center is actively developing Partner program aimed on the attraction of private and other funds from entities interested in establishing business relations with CIS countries. In case of projects consistency with ISTC goals and objectives the Center may provide Partners with its unique infrastructure adjusted to the specific local conditions of CIS and that have proved its efficiency during more than four years of active operations.

The completed ISTC projects (now it is about 40 of them) give an examples of successful development of new technologies in the areas of environmental monitoring and remediation, safety of nuclear reactors, production of stable isotopes and others. At present stage ISTC may be considered as almost ideally adjusted infrastructure in CIS for the promotion of international R&D works at the pre-commercialization stage.

生命の起源および進化における放射線の役割

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1）はじめに

およそ４５億年とされている地球の歴史の中で、私たちが何らかのかたちで生命の痕跡を見出すことが出来るのは、今からさかのぼって約３５億年迄である。それ以前の約１０億年の間については生命体は存在しなかったと考えられる。しかし、例え生命体が存在しなかったと言っても、その間、地球は決して静的な状態を保っていたわけではない。そこでは生命の発生を準備するための様々な過程が止まることなく進行していたと考えられる。地殻内での諸々の変動や地表における風化作用、そして熱や放電や放射エネルギーによる無機物質の変化、有機物質の生成およびその高次化等がそれである。こうした様々な過程を私たちは化学進化と呼ぶ。進化が単なる変化でないのは、その物質変化がその場限りの偶然の所産ではなく、一つの原因がある結果を生み、その結果が次には原因となってさらに新たなる結果を作り出すと言った具合に、一定の道筋に沿って行われるからである。従って、化学進化は必然の過程であり、その行き着くところに生命の起源がある。そしてまた、後に生物がたどった一連の進化の過程や社会発展の過程も、ともに必然の過程としてその延長線上にあると考えることが出来る。

１８３０年から１８５９年にかけての３つの偉大な発見（シュバンとシュライデンによる細胞説、ヘルムホルツによるエネルギー保存・転化則、ダーウインによる進化説）を基にして、化学進化から生命の起源・進化に至る道筋を科学的空想の段階でみごとに予見したのはEngelsであった（1873～1883)。Pasteurによって生物は決して自然には発生しないこと(自然発生説の否定（1862))が立証された僅か十数年後に、新たなかたちでの自然発生を予見したこの思想家の洞察力には驚くほかはない。この問題に対する自然科学者側からの取り組みはそれから約５０年後の事となる。すなわち、コアセルベートに関する実証的研究を踏まえつつ、より克明なかたちでその道筋を提示したのはOparin(1938)であった。さてOparinの唱える原始細胞が陽の目を見るためには原始細胞を構成する様々な分子が原始地球上で生成し、濃縮していく過程が実証されなければならない。すなわち、生命体が出現する以前に、この地球上では無機物の世界から有機物の世界への変換が生起したことを実験的に確かめなければならないのである。

２）ミラーの実験とその意義

Oparinの提起後四半世紀を経て、Millerが初めてこれに取り組むことになる。当時は大学院生であったMillerは教授であるUreyの考えに従い、当時は地球の原始大気と考えられていたメタン、水、アンモニア、水素の気体中の放電により、各種の有機酸やアミノ酸が合成されることを報告した（1953）（図１、２及び表１）。Millerの実験の卓越したところは、彼が化学者であり、化学反応が平衡関係を基礎として成り立つことを当然のこととして受け入れることが出来た点に由来する。演者等の年代はMillerの仕事が発表されたおよそ１５年後にようやく自分で選んだ自分の研究に没頭出来る身分を得た階層である。演者自身は生物に対する放射線の作用を一生の課題として取り組んできた者であるが、放射線に限らずおよそエネルギーと云うものはそれを受けた相手を破壊するもの（複雑系⇨単純系、高分子⇨低分子）だと云う定式化された観念にとらわれすぎて、まさか互いの濃度によっては逆の反応が進行することなど考えも及ばなかったのである。（ミラーの実験では、アミノ酸や有機酸等の放電による反応生成物は反応容器内を循環した後、冷却されてトラップされる様に設計されている。すなわち反応容器中には常に原材料物質しか存在しないので全体としての反応は一方的にしか進まない）。

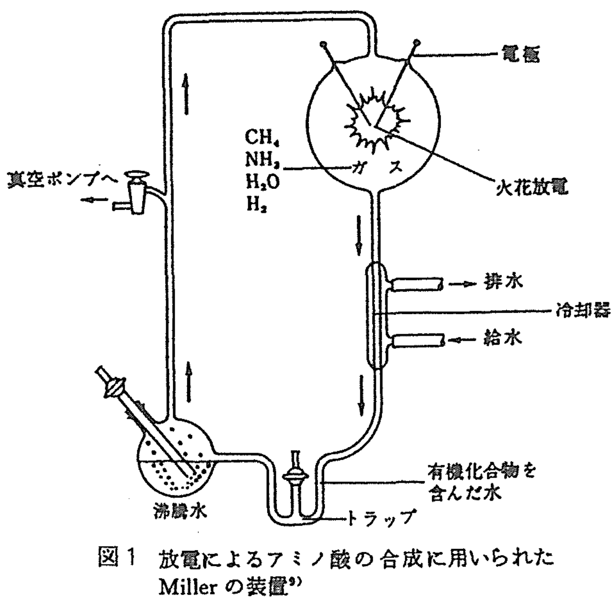

図１ 放電によるアミノ酸の合成に用いられたMiller の装置[9]

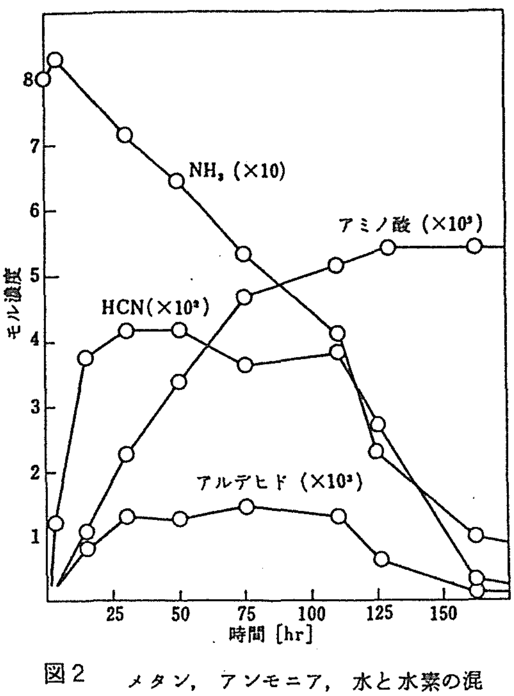

図２ メタン，アンモニア，水と水素の混合物に放電中のMiller の装置のU字管中のアンモニア，シアン化水素とアルデヒドおよび小フラスコ中のアミノ酸の濃度[10]

表1 CH_4, NH_3, H_2O と H_2 の混合物の放電からの収率：710mg の炭素を CH_4 の形で与えた

化合物	収率 [mol×10^5]
グリシン	63
グリコール酸	56
ザルコシン	5
アラニン	34
乳酸	31
N-メチルアラニン	1
α-アミノ-*n*-酪酸	5
α-アミノイソ酪酸	0.1
α-オキシ酪酸	5
β-アラニン	15
コハク酸	4
アスパラギン酸	0.4
グルタミン酸	0.6
イミノジ酢酸	5.5
イミノアセトプロピオン酸	1.5
ギ酸	233
酢酸	15
プロピオン酸	13
尿素	2.0
N-メチル尿素	1.5

3）化学進化に利用されたエネルギー源～電離放射線の意義～

ミラーとユーリイによる先駆的な実験が出されて以後、化学進化と生命の起源に関する数多くの実証的研究が行われる様になってきた。これらの研究においては主として放電、電磁波、衝撃波、超音波、紫外線等がエネルギー源として用いられている。これらのエネルギーは宇宙空間や地球内外を通して普遍的に存在するものである（表2＆3）。このうち、強エネルギー紫外線は原始地球大気の表層部において、また低エネルギー紫外線は原始海洋にまで到達してそれらの場における化学反応に重要な役割を果たしたであろう。一方、原始地球表面においては、放電や火山からの熱によって様々な化学反応が進行したものと考えられる。事実、Miller 以降の実験において際立っているのは、FoxとHarada等によるアミノ酸、蛋白様物質の無生物的合成の研究とPonnamperuma等による核酸関連物質の無生物的合成に関する研究であろう。前者は熱を後者は紫外線をこれらの研究に主として用いた。放電や熱、紫外線が用いられたのは、これらのエネルギーが原始地球上に大量に存在したと考えられたからであるが、同時にこれらのエネルギーが何処の実験室に

表2 初期化学進化にとって可能なエネルギー源

源	エネルギー 地球表面の平均 [10^{20}cal/y]
^{40}K の崩壊（現在）	0.3
^{40}K の崩壊（2.6×10^{9} 年前）	1.2
紫外線照射，150nm 以下（1500Å）	0.08
紫外線照射，200nm 以下（2000Å）	4.5
火山活動（1000°C の溶岩から）	0.04
いん石衝突	おそらく 0.05
雷	0.05

表3 現在の地球上に供給されるエネルギー

	cal/cm² 年×10^{-10}
太陽からの全エネルギー	132,000
$\lambda<250$ mμ	300
$\lambda<200$	45
<150	1.8
放電	2.1
放射能	0.4
火山	0.07
宇宙線	0.0008

おいても手軽に組み立てられ、利用できるものであることが大きい。これに反して電離放射線は設備や維持に莫大な経費がかかるので、何処の実験室でも自由に使えるものではない。しかしながら、実験室においてシミュレーションを行うにあたって放射線の利用ほど便利なものはない。それは放射線の場合、系に吸収されたエネルギーの評価が容易であり、さらに反応結果を解析する手法（G-value，平均致死線量等）が確立しているからである。また、興味あることに、化学進化の実験において熱や放電をかけたのと同じ様な系に放射線をかけた場合には、反応生成物の質と量においてほぼ同様な結果が得られることが立証されている（表４）。

表4　シリカ存在下加熱により，および放電により合成されたアミノ酸の組成†

アミノ酸	熱合成 石英砂 (950°C) [%]	熱合成 シリカゲル (950°C) [%]	熱合成 シリカゲル (1050°C) [%]	放電合成 火花放電†† [%]	放電合成 無声放電†† [%]
アスパラギン酸	3.4	2.5	15.2	0.3	0.1
トレオニン	0.9	0.6	3.0	—	—
セリン	2.0	1.9	10.0	—	—
グルタミン酸	4.8	3.1	10.2	0.5	0.3
プロリン	2.3	1.5	2.3	—	—
グリシン	60.3	68.8	24.4	50.8	41.4
アラニン	18.0	16.9	20.2	27.4	4.7
バリン	2.3	1.2	2.1	—	—
アロイソロイシン	0.3	0.3	1.4	—	—
イソロイシン	1.1	0.7	2.5	—	—
ロイシン	2.4	1.5	4.6	—	—
チロシン	0.8	0.4	2.0	—	—
フェニルアラニン	0.8	0.6	2.2	—	—
α-アミノ酪酸	0.6	—	—	4.0	0.6
β-アラニン	?†††	?†††	?†††	12.1	2.3
ザルコシン	—	—	—	4.0	44.6
N-メチルアラニン	—	—	—	0.8	6.5

† 塩基性アミノ酸は十分調べられていないのでこの表には記載しない．加熱反応生産物についてのいくつかの分析はリシン（オルニチン）とアルギニンに相当するピークを示した．

†† Miller (1955) の結果より計算し直した．

††† β-アラニンのピークはつぎの別の未同定のピークと区別できない．

さて、どの様なエネルギーがどの様な反応に寄与するかを考察するにあたって最も大切なことは、その存在量ではなく、与えられたエネルギーが如何に特異的な場所において特異的な反応に寄与するかである。電離放射線は疑いもなく原始地球上に大量に存在し、化学進化や生命の起源にとって重要な各種の有機分子の合成に役だったと考えられる。また、ひとたび生命体が地球上に出現するや、突然変異を通してプレカンブリア紀に見られたようなより早い生物の拡散にも役立ったであろう。しかしながら、電離放射線は実験を行う上での制約が強かったため、その生命の起源と化学進化における役割を実証するための研究はこれまで殆ど行われなかった。近年、内外に各種の放射線発生並びに利用施設が充実されるに従って生命の起源・進化におけるその重要性を立証する研究が行われるようになってきた。本国際会議はこのような背景を受け、最近、集積されつつあるデーターを整理すると共に、化学進化・生命の起源における放射線の役割を再評価し、放射線反応の局在性と特異性に着眼した新しい研究方向を開くことを目的として、世界でも初めて計画されたもので、誠に時宜にかなった試みであると云うことが出来る。

4）放射線反応の局在性と特異性

原始地球上における電離放射線源としては太陽からの紫外線を除くと、宇宙線と地殻由来のものとに大きく分けることが出来る。両放射線エネルギーの量は地球の生成直後は別として、安定に達した頃以降、すなわち化学進化や生命の発生および進化の過程が進行するであろう頃には今日とそれほど大きくは変わらなかったと考えられている。このうち、地殻由来の放射能（^{40}K, ^{87}Rb, アクチニウム系列の諸核種等）は土壌近辺に存在し、その周辺にのみエネルギーを供給することになるので、宇宙線等に比べるとはるかに局在性が高い。また、宇宙線由来の放射線の場合でも、例えば速中性子が空中や水中を通り抜ける過程で減速され、熱中性子となって土壌中の各種の元素に吸収された後に発生する放射線や反跳原子核の寄与を想定するならば極めて局在性が高いものとなる。その様な事例については既に演者等が$^{30}Si(n,\gamma)^{31}Si$反応によって得た^{31}Si核のβ壊変によって生じた反跳^{31}P核による燐酸化合物類の合成や ^{32}P核のβ壊変によって生じた反跳^{32}S核によるシステインの合成によって、生起し得ることを実証している（図３）。一方、他種のエネルギーにはみられない放射線だけの特異性と云うことになると、β-壊変を含む弱い相互作用においてはパリテイが保存されないと言う現象をあげなければならない。このことがPasteurの「宇宙は本質的に非対称であり、生物を構成する分子の非対称は地球上に存在する何らかの非対称の反映である」との予見を説明する可能性を提起するからである。それには以下に説明する二つの可能性がある。すなわち、弱い相互作用とは原子の中で電子と陽子、中性子の間で働く力であり、Weinberg, Salam & Glashowの統一理論によれ

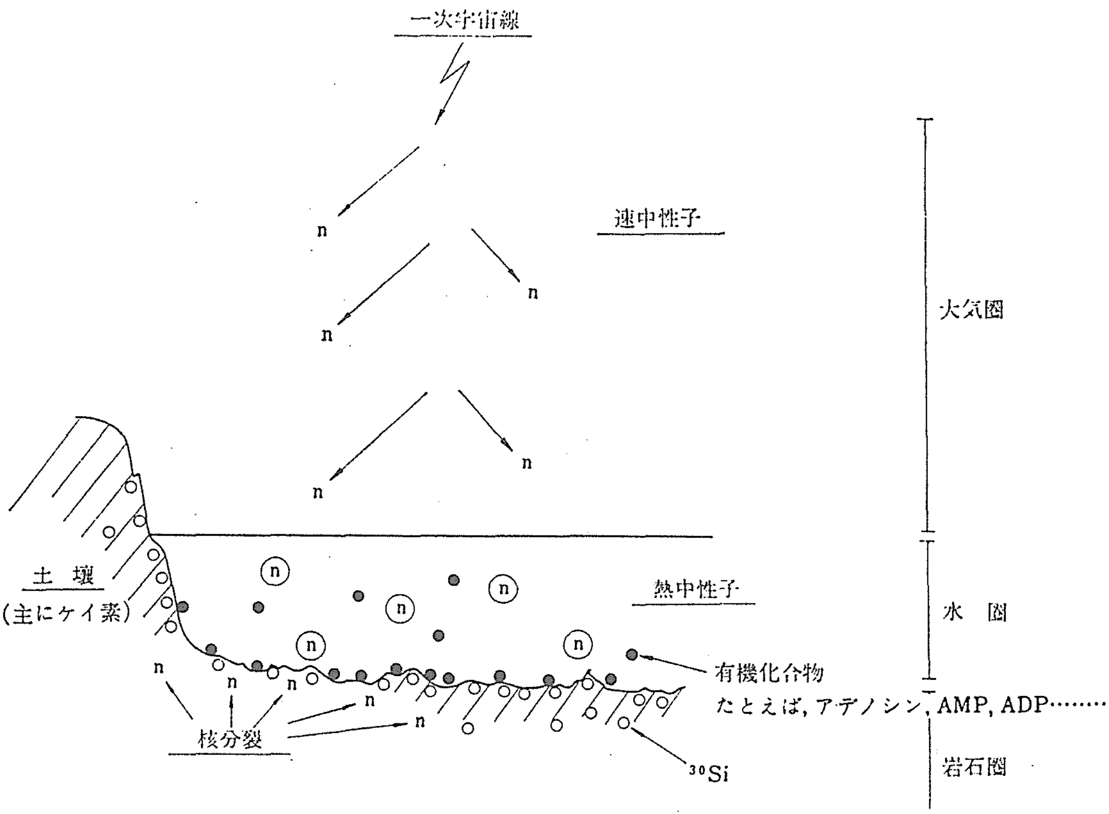

図３　原始地球上におけるリン酸化の模型図

ば、これには弱荷電カレント（W相互作用）と弱中性カレント(Z相互作用）の二種類がある。原子核がβ−壊変する時にはW相互作用が働く結果、放出された電子は左巻きに偏極する事になる(Lee&Yang (1956) および Wu (1957))。偏極した電子と鏡対称の分子構造（従って、電子構造）をもつ左右異性分子間の相互作用において、何らかの違いを見出すための努力がこれまでも続けられてきた。一方、Z相互作用が原子の中で働いていることはCERNの加速器を用いて中性ボソンZ^0粒子の存在が確認されることによって証明された(1983)。電子が原子核に近ずくとZ相互作用により僅かに右巻きの螺旋軌道をとるようになる。すなわち、D型分子とL型分子ではこの電子の存在によって、鏡対称ではなくなることになる。この結果、両異性分子自身の持つエネルギーや安定性も僅かながら異なることになる。両分子間に存在するこの差が化学進化の長い歴史の間に拡大・増幅され、今日の生物世界に見られる非対称の原因となったと考える。

５）本国際会議の成果

以上、おおざっぱな解説ではあったが、今回の国際会議の必要性と意義についてはご理解頂けたものと思う。終わりにあたり、本会議によって得られた成果を以下に列記する。

イ）　原始地球上における化学進化及び生物進化の過程において電離放射線の果たす役割

の重要性が認識された。

ロ） 電離放射線の原始地球上および宇宙空間における局在性とそれによる化学反応の特異性が重要であるとの認識が喚起された。

ハ） 原始地球上および宇宙空間における電離放射線量と線量分布等に関する新しい評価が提出され、局在する場において放射線が果たす化学反応に対する寄与に関する展望が開かれた。

ニ） 原始地球に近い環境であることが知られている土星の衛星であるタイタン大気中で現実に引き起こされている化学変化や宇宙ステーション「ミール」中で採集された水中に含まれていたアミノ酸等に関する新しい知見が数多く報告され、注目を引いた。

ホ）「弱い相互作用におけるパリテイ非保存」と生体分子のホモキラリテイとの関連を類推する上での幾つかの新しい理論が展開された。またこれを立証するための幾つかの実験結果が報告された。さらに、近年、内外での各種の高エネルギー高粒子線密度加速器の建設に関連して、偏極したベータ線を照射する技術の開発が進行しつつある点に鑑み、如何にして上記仮説を立証するかについての、問題提起がなされた。

ヘ） 生物の進化に対する放射線の役割についても大いに議論がなされた。ネオダーウイニズムの立場からは生物に固有の複製ミスによって、進化は充分に説明されることになるが、別の立場からすると複製ミスが起きるためには放射線等によってDNAが損傷を受けることが必要であり、生物固有の複製ミスを起こす能力は放射線や環境変化に対する一種の適応現象であることになる。４５億年の長きに渡って、地球上に存在し続けてきた微弱な放射線の作用を取り除いた環境をモデルとした実験を行うのは不可能なことなので、提起された問題が早急に解決されることはあり得ないと考えられる。今後とも放射線生物学、遺伝学、進化学等の立場から積極的な問題提起と議論を進めることが必要であろう。

ト） 生物学から化学、物理学、天文学等々の広い領域に渡る専門家が一堂に会し、しかも全員が抜け落ちることなく最後まで熱心な討論を行うことが出来たことが最大の収穫であった。それは互いの知識を深めあい、また個々人にあっては予想もしなかった新しい考え方を自分の研究に導入する契機を得る上で、極めて重要な役割を果たした。

謝辞

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Session 3: "Fuel Cycle in Long-term View"

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1. Nuclear Power in Japan: Its significance up to today--Effects of LWR

Although the situation surrounding nuclear power generation is difficult today, power generation with light water reactors has advanced very successfully in the past several years in spite of some minor troubles, and their capacity factor has exceeded 80% for the last 3 years. Our light water reactors have been developed through a process of introducing US technology,. developing it into our own technology and advancing it further with improvements and standardization. I believe we may be able to say the technology is now stabilized and reaching a stage of maturity.

Our country is a minor power in terms of resources, and the preservation of energy security or capacity of securing energy of necessary quantity at equitable prices has been our earnest wish for long time. Since nuclear energy was considered as a means with a high potential of fulfilling this desire of ours, we have aggressively promoted its technical development, which, I believe, has borne fruit today.

It was hoped at the outset that nuclear power would replace fossil fuel in the near future, and in fact, it played an important role as a bargaining tool in procuring fossil fuel, and even during the time when fossil fuel was available in abundance, as helping stabilize energy prices.

2. Significance of Nuclear Energy in the Future—Effects of Technical Innovation

In this way, the development and use of power reactors, of which the light water reactor is the core, has demonstrated a certain accomplishment. Considering the potential which nuclear energy has as an energy source, however, I believe that we have utilized only a very small part of it so far. I am of the opinion that nuclear energy has the possibility of exhibiting much greater power, which may be called the effect of "second-stage nuclear energy development", through advancing technical innovation further, in contrast with the merits we have enjoyed from what may be called the effect of "first-stage nuclear energy development".

Considering our future, the significance of the potential of nuclear energy will never diminish, even after light water reactor technology has matured. In order to make full use of such potential of nuclear energy, long-term efforts toward " second-stage nuclear energy development" should be made.

3. Toward Future Nuclear Energy Development

I believe the main points of this second-stage development are the further enhancement of the economics and the expansion of the range of technical development of nuclear energy.

(Our approach to nuclear energy development in this past)

During the early stage of nuclear energy development, emphasis has been placed on the effective use of our finite resources and in order to swiftly digest the technology and to reap the benefit of our efforts from the energy resource point of view quickly. I feel accordingly that we have undertaken the development by directing development efforts toward a unitary object under a heavily protective system eliminating economic competition. We can safely say that it is owing to such system that we have been able to accomplish safety and reliability at world-class levels.

(Economic performance)

In my opinion, competition among various kinds of energy sources is intensifying now, while the strategic significance of energy sources is relatively less apparent, though temporarily, due to the dissolution of the Cold-War structure and economic globalization. In order for the light water reactor to continue maintaining its important position in future in competition with other energy sources, we, the people in this business, will have to make greater efforts in bringing about the competitive power of our technology through increasing efficiency, streamlining and rationalizing the nuclear industry while maintaining its levels of safety and reliability.

I believe basically that the light water reactor must survive under the market principle through those efforts being made. On the other hand, how we should give nuclear energy a role in dealing with environmental problems is a new issue, which we will have to further examine in future.

It is needless to say that the economic character of any new technology to be developed and applied is an important factor in deciding its commercialization. The people who participated in such development and application should always be conscious that it is the task given to them by society to seek after its good economic performance while maintaining safety, because commercialization of technology by the private sector can only be realized when there is a prospect of that technology producing a value in society and the market.

(The time allowed for our development work)

While the importance of possessing energy security, which is the ultimate objective for the use of nuclear energy and also our earnest wish, has not changed in the least, the urgency of attaining security seems to have lessened under recent conditions. Although these are some unpredictable elements in the long term, such as the uncertainty of energy supply conditions in developing countries, it seems that the allowable time scale for fulfilling the ultimate objective of nuclear energy has been extended. We will now have to use this thus granted time effectively, with a flexible stance, when the development schedule of the fast breeder reactor itself seems to be delayed due to the Monju accident and other reasons.

(Allocation of resources)

Even though we need to consider long time constant that nuclear energy development requires due to its nature, still we are able to say that we are granted an ideal opportunity to re-examine the fundamental direction of such development. In order to make the most of the potential power of nuclear energy, it will be necessary for us to shift the weight of investment of financial and human resources from conventional electricity generation to the solution of back-end of the fuel cycle problems.

(Re-examination of development targets)

I believe it necessary for us to employ a process of broadly surveying useful technologies, including those available from the results of recent technical developments in peripheral industries, and various innovations to be found in their supporting engineering fields. Even technologies once abandoned in the past may be considered. Then we can narrow them down to the most prospective technologies for our purpose through technical study and evaluation, to redefine our optimum targets in the course of this process. We are demanded to meet the challenge of developing innovative technologies.

(Need to gain understanding on spent fuel storage)

In the past, we were often criticized by figuratively comparing the present development condition of nuclear energy development with "mansions without a toilet". It is meant to allude to the problem of not having established the means for treating and disposing spent fuel. If it is only the matter of a toilet, the amount of discharged spent fuel is extremely small in the first place, and at least one method of reprocessing is being demonstrated in the U K, France and Japan. Globally, the methods of disposing of vitrified solids and spent fuel are already technically established, and a business entity to undertake the disposal of high-level waste is scheduled to be established in 2000. We can say that we already have the technology to treat and dispose of spent fuel.

I believe the problem is to build a consensus as to whether it is the best method to respond to the trust of future mankind, or whether it is best to do it now for the people or broadly for mankind. For this problem, we need to present before the people as many options as possible. In consideration of the time required for study and consensus formation, it will be necessary to gain understanding on storage of spent fuel for the immediate future.

(International cooperation)

Even though we are endeavoring to establish a country rich in high-level technology of our own, still it is important under globalized economy, to undertake technical development efficiently through international cooperation for commercialization of technologies. By this way, developing technologies which include our own technologies as the core, those would be applicable in many places in the world. Many of the various issues our nuclear industry faces today are issues we face in common with other countries. It is considered important also to study specific measures to solve them under international cooperation.

(Scrutiny of R&D)

Such technical development needs to be undertaken with stable and unyielding efforts from a long-term point of view. This in turn will mean, however, that such process by its nature is difficult to subject to the scrutiny of the market. Accordingly, continuous auditing by uncompromising eyes, including those of outsiders, as to whether such development is being performed rationally and efficiently, is considered essential for sound technical development. At the same time, I feel it necessary now to have a system in which all the parties participating in the development of technology adequately share risks so that price-competitive technologies can be developed autonomously. There will be an increasing number of cases in which Japan finds itself on the frontier of technical development in the future. It is necessary that a system be provided for the one who is taking the lead to choose and keep useful technologies and to unhesitatingly suspend development of technologies unworthy of continued efforts without regard to their history through a continuous technical evaluation process.

(The role of the government)

It is also expected that the public sector, including the government, as part of an important energy policy, will shoulder a central role in the promotion of the development of such large-scale technology. Also it is hoped to positively participate in resolving political issues involving conflicting interests between the central and local areas, such as with siting, and in finding a way of symbiotic application of nuclear energy, as strongly asked for by society.

I believe it necessary for us to sketch out our vision once again to be prepared for the second stage of nuclear energy development and to draw up our strategy flexibly without sticking to the extension of the past through effective use of the time allowed us, closely watching the future movements of the energy market.

4. Summary

Nuclear energy already has significant implications in energy supply conditions supplying 17% of the world's energy today. It is also true that we utilize only a small part of the potential capacity of nuclear energy today. The situation surrounding nuclear energy is anticipated to continue to be difficult for some time to come. Added to such difficult situations are many issues and changes expected to emerge in its environment, such as economic globalization, deregulation of electric utility business, reorganization of central government offices through administrative reform and global environmental problems. While we are in an age of transition, the importance of the role given to nuclear energy shall not alter in the least in going into the next century. I believe we are required to do our utmost to make a breakthrough, but without prejudice with respect to past technologies, making the best use of the time granted to us. We should not regard transition as a burden but rather as an opportunity providing us with latitude, and we need to join our forces toward the second stage of nuclear energy development after putting ourselves back at the starting point again.

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