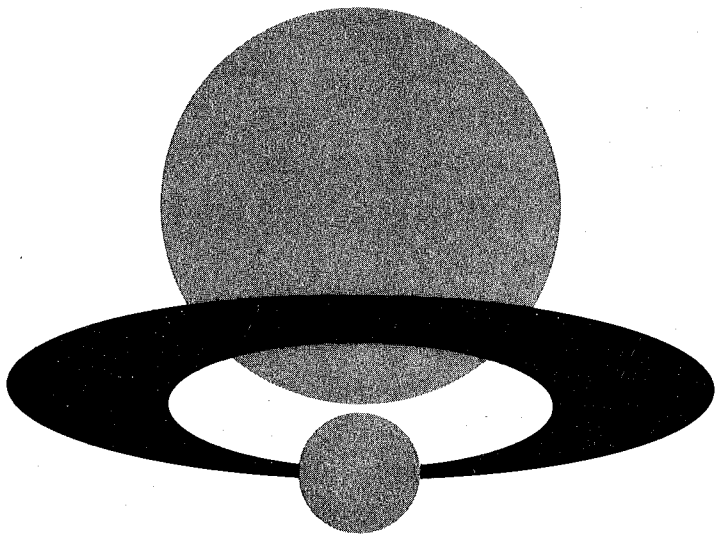
THE 20TH JAIF ANNUAL CONFERENCE

第20回原産年次大会



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JAPAN ATOMIC INDUSTRIAL FORUM

日本原子力産業会議

日本原子力産業会議資料室
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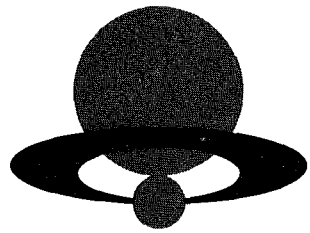


大会準備委員長挨拶

(社)日本原子力産業会議副会長

山　下　　勇

原産会長所信表明

(社)日本原子力産業会議会長

有　澤　廣　巳

原子力委員長所感

原子力委員会委員長、科学技術庁長官

三ツ林　弥太郎

大会準備委員長挨拶

日本原子力産業会議
副会長　山下　勇

本日、原産年次大会の記念すべき第２０回大会の開催にあたり、大会準備委員会を代表してご挨拶申しあげる機会を得ましたことは、私の深く慶びとするところであります。

省りみますと、昭和４３年２月、第１回原産年次大会が開催された当時、世界の原子力発電規模はわずかに1,０００万ｋW、原子力発電所を有する国も１１か国に過ぎませんでした。

以来２０年、世界的な原子力発電開発への努力の結果、今日の原子力発電規模は、２億8,０００万ｋWになんなんとし、約３８０基の原子力発電所が世界の２６か国で運転されております。この結果、世界の原子力発電電力量は年間１兆4,０００億ｋWｈを超えるに至っておりますが、これはほぼ４億ｋℓの石油に匹敵すると試算され、世界の石油貿易量の約３０％に相当いたします。第１回当時の状況に比べますとき、まさに隔世の感があります。

しかしながら、ここに至ります過程はきわめて起伏に富むものであり、世界の原子力開発はさまざまな試練と幾多の困難に直面しつつ、これを乗り越えて参りましたことはご高承の通りでございます。

原子力発電は実用期にある今日もなお、克服すべき多くの課題を抱えております。とくに、近年における世界的な経済活動の低迷、石油需給情勢の変化、さらにはスリーマイル・アイランドやチェルノブイリ事故などが、世界の原子力発電計画に少なからぬ影響を与えております。しかし、２１世紀を見通す視点から、世界的な資源問題、全地球的な環境問題などを考えますとき、原子力のエネルギー利用は不可避であり、これからの世界の経済社会を支えるエネルギー供給と技術基盤の確立に果たす原子力の役割には、きわめて重く大きなものがあります。

大会準備委員会は、このような認識に立って、「国際経済社会の発展に果たす原子力の役割」を今大会の基調テーマに据え、流動する現下の情勢の中で、原子力が果たすべき役割と責任をあらためて確認し、進むべき方向とその前に横たわる諸課題の解決策を探ることを意図した次第であります。

わが国におきましては、昨年、通産省や電力界が２１世紀へ向けての原子力ビジョンを相ついで発表し、原子力の役割とその位置づけをより明確に打ち出しております。また原子力委員会は、目下、新しい原子力開発利用長期計画を策定中であり、現在、審議は最終段階にあると伺っております。

本日は原子力委員長・科学技術庁長官の三ツ林大臣に政務ご多端の折柄、特にご臨席いただき、本開会セッションにおいてご所感をいただきますことは、この意味からもきわめて意義深いものがあると考えます。

エネルギー情勢、原子力をとりまく環境は国によって異なりますが、各国とも２１世紀を見据えた原子力開発計画を着実に具体化しつつあると申せましょう。セッション１では、「２１世紀に向けての原子力の役割」をテーマに、原子力開発を強力に進めているフランスの今後の展望をフランス原子力庁のカプロン長官が、　そしてソ連のルコーニン原子力発電大臣がチェルノブイリの事故を越えて進もうとしているソ連の決意を、　また国際原子力機関のブリックス事務局長からは安全問題を含めての国際協調による原子力開発への姿勢が、　マーシャル・イギリス中央発電庁総裁からは最近方針が固められた軽水炉路線を含む新たなエネルギー戦略が、　インドのラマンナ前原子力委員長からは同国の原子力技術開発の考え方とその取組みが、　それぞれ明らかにされることでしょう。引き続き日本からは、平岩東京電力会長が開発推進上の諸課題とそれへの対応を提起しつつ日本の原子力開発を長期的かつ国際的な側面も加えて展望し、　米国原子力産業会議のグラハム副理事長は米国の原子力発電活性化への産業界の対応について、　また台湾電力公社の陳社長は原子力開発の今後の進め方について、それぞれ所信を発表されます。

このセッションでは、これら各氏の講演を通じて、原子力開発の必要性が国際的に再確認されるとともに、各国の原子力開発への取り組み姿勢と決意が、より鮮明に表明されるものと期待されます。

明日午前のセッション２は「原子力研究開発の新しい展開」であります。原子力は技術エネルギーであるといわれますが、実用化、産業化の段階を迎えて、これまで積み上げられてきた国の研究開発の成果をいかに効果的に民間に移転し、活用していくか、また研究開発をめぐる環境条件が厳しさを増していくなかで、これからの開発目標をいかに設定し、いかに効率的に研究開発を進めるかを考えます。

基本的認識、展望と課題に関する大島東京大学名誉教授の発表についで、　米国原子力規制委員会のカー委員、　西ドイツ連邦研究技術省のレーア局長による両国の現況や国際協力の考え方も伺い、研究開発に深く関与されている日本の各界代表がそれ

ぞれの立場から意見を表明します。

一方、原子力の今後にとって国際協力はきわめて重要であります。原子力開発はその平和利用による恩恵を世界各国が等しく享受しうるよう、各国が協力し合って進めるべきであります。しかし、その協力を真に効果あらしめるためには、多面的な努力が必要であります。セッション3「アジア地域における原子力開発と国際協力」では、この問題を取りあげ、藤波原子力委員の基調講演に次いで、中国原子力工業省の李次官、　韓国科学技術院の林教授、　インドネシア技術評価応用庁のパンガベアン部長、　それに第1セッションでも講演されるＩＡＥＡのブリックス氏、　インドのラマンナ氏にも加わっていただき、日本の代表、専門家の方々を交え、調和と実効ある国際協力のあり方を求めてパネルディスカッションを展開します。地域をアジアに絞りましたのは、“隗より始めよ”という大会準備委員会の考え方に立つものであります。

大会第3日目のセッション4「発展する原子力技術」では、原子力分野の最先端を行くユニークな技術の数々が、映像を駆使して紹介されます。原子力技術はそれ自体が一大先端技術システムでありますが、それはさまざまな分野のひとつひとつの高度先端技術によって日々革新されつつあります。同時に、原子力分野で開発された技術には、他の産業分野に大きく波及する可能性を秘めたものも少なくありません。このセッションでは、日本の技術のみならず、フランスノバトム社のクレテさん、　カナダ原子力公社のリンチさんの興味ある技術システムの紹介も予定されております。ここでは新しい技術の今日と未来が描かれるものと期待されます。

本大会の最終セッションは「燃料サイクル産業の課題と展望」であります。原子力発電がよくその使命を果たしていくためには、燃料サイクルの確立が不可欠であり、しかもそれが産業として定着し、成長していくことが望まれます。そこには必然的にさまざまなエネルギー・ソースとの競合が生じますし、むしろ適正な競合が生じなければなりません。このセッションの持ち方、進め方については、大会準備委員会の活発な意見、検討を踏まえて、いわばセミ・パネル討論ともいうべき形式をとり入れましたが、これに呼応するかのように、このセッションには世界の燃料サイクル産業を代表する有力な企業、機関の責任者が多数参画されています。ウラン濃縮の分野ではフランス原子力庁のコーツさん、　ウレンコ社のパーライトさん、　米国エネルギー省のロングネッカーさん、　また再処理の分野からはフランス核燃料公社のルジョーさん、　西独クラフトベルクウニオン社のビュルクレさん、　英国原子力公社のウイルキンソンさん、　そして回収ウラン転換の分野からはコミュレックス社のペリシエ

タノンさん、　混合酸化物燃料の分野からはコモックス社のベイリオさん、　西ドイツアルケム社のシュトールさんです。いずれも斯界の権威であります。このセッションでは、いま燃料サイクル産業に求められている技術的革新と経済性追求の両面を中心に据えて、まず豊田東京電力副社長がわが国の現状と考え方を明らかにした上で、只今ご紹介いたしました九人の海外発表者から、これに応える形で各国の燃料サイクル産業の姿勢と今後の努力の方向が示されることでしょう。

以上、本大会の構成とねらいについて概略ご説明申しあげましたが、３日間にわたるこの大会の各セッションにおいて、それぞれ論議が深められ、その成果がこれからの原子力開発に役立つことができれば、大会準備委員会として慶びこれに過ぐるものはございません。

最後になりましたが、本大会の議長、発表者をご快諾いただきました大会関係者各位に厚く御礼申しあげますとともに、本大会にご参加くださいました皆様、とりわけ、はるばる海外からご参加くださいました方々に心から感謝の意を表しつつ、私のご挨拶を終らせていただきます。

第２０回原産年次大会
原 産 会 長 所 信 表 明

日本原子力産業会議
会長　有 澤 廣 巳

第２０回原産年次大会の開会にあたり、一言ご挨拶申し上げます。

昨年は、チェルノブイリ原子力発電所で事故が起き、原子力に対する信頼が大きく揺らぎました。とともに、グローバルな環境問題としても大きくクローズ・アップされてきました。今年、東京で開催されました国連環境特別委員会では、原子力の取扱いをめぐって紛糾、原子力廃止論もでたほどです。しかし私は、原子力ではなく化石燃料の燃焼による酸性雨、酸性雨による森林破壊、さらには二酸化炭素による温室効果など緩慢な、しかし休むことなく増大している地球的規模での環境の悪化について、むしろ憂慮しています。

昨年のアメリカ国家気候計画報告では「地球の平均海面水位は過去５０年間、年間平均２.３ミリで急上昇している」とし、その原因については、大気中の炭酸ガスの増加による温暖化を最も有力とみています。

地球を取り巻く炭酸ガス濃度の上昇と、化石燃料の消費量とが、全く比例した動きを見せていることは、無気味な警告といえます。

これに対し原子力は、化学反応による燃焼とはまったく違い、物理的な原子核反応によって生みだされるエネルギーです。技術の発展によって、大量のエネルギーを、クリーンで安く供給できる、新しいエネルギーということです。原子力で唯一の問題といえる放射能の管理についても、技術によって、いかようにでも厳しくできるはずです。

私は、原子力が人類をエネルギー問題から解放できるとの認識をもって進めてきました。この認識は今も変わっていません。

しかし、チェルノブイリ事故のように、放射能の管理に失敗し、環境に大きな影響を与えれば、原子力利用は大幅に制限されることになります。そうなれば、エネルギー問題からの解放の夢が打ち砕かれ、新たなエネルギー危機を招きかねません。

さきほど申しあげた通り、エネルギー変遷の歴史のなかで、新たに登場してきた原子力は、大量のエネルギーを安定して供給できるという、天恵ともいうべき性質を備

えています。この利用を損うことのないよう、原子力開発を進めているすべての国が、原子力関係者一人一人が、人類にとっての、この天恵を十分認識し、責任ある行動をとっていくべきです。

さて、わが国の原子力開発についてですが、原子力は電源の主力となるとともに、設備利用率でもここ数年７０％以上で安定しています。この高いパフォーマンスは、導入、開発の初期に発生したトラブルに、メーカー、電力などが一丸となって立ち向かっていった結果と考えます。

原子力開発の前半の歴史では、大きな成功をおさめたといえますが、高レベル廃棄物処理・処分も含めた後半の燃料サイクルの確立については、いよいよこれからが正念場といえます。世界に通用する燃料サイクルの事業化のためには、新たな決意をもって挑戦していかなければいけません。とりわけその要である再処理については、簡単に考えるわけにはまいりません。

再処理施設は、原子力発電所と比べ、高温・高圧といった条件ではありませんが、大量の高レベル放射性物質を取り扱う、複雑な工程をもった一種の化学工場です。東海工場の例をみるまでもなく、事業としてやっていくことは容易ではないと考えます。

事業化というからには、運転に支障をきたすようなことがあってはなりません。厳しい放射能の管理はいうまでもありませんが、機器の系列の多重化、トラブルの予防などを考慮した設計を行っていかなければいけません。このためには再処理工場の建設はもとより、運転にあたっては、わが国で唯一の実績をもつ動燃の経験、人材を、事業会社のもとに一つに結集し、政府の支援も得ながら事業化を達成すべきです。

これからは、事業会社が軽水炉燃料の再処理技術の改良、改善を行えるよう、自らが技術を持っていかなければいけません。一方、動燃は、ＦＢＲ用燃料など、軽水炉以外の再処理技術の開発を進めていくべきだと考えます。

ウラン資源の有効利用を約束する再処理は、事業会社の問題としてのみならず、わが国の原子力政策の成否がかかっています。また、その成功は、世界のエネルギー問題からの解放の扉を開くことになると信じます。

国内の燃料サイクル完結への挑戦の他に、原子力発電に成功し、成熟期を迎えたわが国原子力界が、これから積極的にチャレンジしていくべきテーマの一つは、全く新しい安全概念に基づく原子炉の開発です。

私は、これまでの工学的な安全装置を主体とする安全概念の考え方から更に進んで、原子炉の異常事態が起きても、自然の原理によっておさまるような、いわゆる固有の安全性を有する炉の研究開発が必要と考えます。

この炉は技術の帰結として、中小型炉になると思いますが、地域暖房や工業用としても利用できます。さらに運転が容易で、経済的なものとすることによって、多くの需要を喚起することは間違いありません。これから原子力を導入しようとする国のニーズにも合うと考えます。

原産が、今年2月に派遣しました東南アジア原子力代表団は、近隣諸国の原子力に対する関心が、一昨年訪問したときよりも高まってきている、と報告しています。特にインドネシアでは、ハビビ科学技術大臣が代表団に対して、「石油コストは今後上昇すると思う。そのため原子力を積極的に導入していきたい」とまで述べています。また、その他の途上国からは、わが国における中・小型炉開発について、大いに関心が示されています。

21世紀には、わが国を含め、世界各国が着実に原子力時代を迎えられてこそ、地球社会の未来は約束されたものになると確信いたします。

最後になりましたが、この大会の開催にあたり、国内外から参加下さいました発表者の方々はじめ、山下準備委員長、ならびに各セッションの議長の方々に対し心からお礼申し上げます。本大会の基調テーマであります「国際経済社会の発展に果たす原子力の役割」について有益な示唆が得られますよう祈念いたしまして、私の所信を終わらせていただきます。

以　上

JAIF CHAIRMAN'S ADDRESS

Hiromi Arisawa
Chairman
Japan Atomic Industrial Forum, Inc.

20th JAIF Annual Conference
April 14, 1987

As we begin this 20th JAIF Annual Conference I want to extend my cordial greetings to all our distinguished participants.

Last year the accident at the Chernobyl nuclear power station shoock the public confidence that had been placed in nuclear energy. It also became a subject of discussion as an environmental question with global consequences. Some participants in this year's Tokyo session of the United Naitons World Commission on Environment and Development, in a stormy discussion argued for an end to nuclear power in considering how to deal with nuclear problems. But I would point out that this issue is no more disturbing than the problem of acid rain from the burning of fossil fuels, not from nuclear power, and the disastrous impact that such rain has on the forests, and the greenhouse effect caused by carbon dioxide--phenomena that are increasing slowly but inexorably toward environmental disruption on a global scale.

In a U. S. National Climatological Project report last year, a warning was given that the earth's mean sea level has been rapidly rising in the past 50 years at an average rate of 2.3 millimeters a year. The major cause of this, according to the report is the warming of the atomosphere from the increasing content of carbon dioxide.

This is an ominous warning that the density of carbon dioxide around the earth is increasing in exact proportion to the consumption of fossil fuels.

In contrast with this, nuclear power is a form of energy produced by nuclear fission as a physical phenomenon, not by combustion as a chemical reaction. It is a new and clean form of energy which can be supplied in increasing amounts and at reduced cost with the progress of technology. Radioactivity, perhaps the only real problem with nuclear power, with progress in technology can be kept under as rigid control as could be desired.

I am committed to the development of nuclear power with the understanding that it will resolve the problems of energy for mankind. This my understanding is as firm as ever it was.

But if failure in the control of radioactivity, as was the case at Chrnobyl, were to have a vast damaging effect on the environment, the utilization of nuclear energy would be very considerably restricted, and mankind's dream of being free from the problems of energy would fade away and a new evergy crisis would ensue.

Nuclear power, as I have said, is a newcomer in the history of energy, blessed by nature with the ability to provide an abundant and constant supply of energy. If, without fail, the use for it is to be found, every country and every person committed in the development of nuclear power must be well fully aware that it is a blessing to mankind, and assume full responsibility in the conduct of nuclear affairs.

The development of nuclear power in Japan has now reached the point of becoming the mainstay of power sources. The capacity factor of plants has been raised to more than 70% over the past four years. This high performance of nuclear power is the result of the concerted efforts that manufacturers and electric utilities have made to eliminate troubles that confronted them in the early days of its introduction and development.

It can be said that we have achieved great success in the history of nuclear power through the first stage of its development. Now the second stage is just beginning with the great task of establishing the fuel cycle including the management of high level radioactive waste. If the fuel cycle is to be industrialized at world level, we must face the challenge with fresh determination. Reprocessing, in particular, is the key to this and we can never be over-optimistic.

Reprocessing plant is a chemical facility which operates -- though not under conditions of high temperature and high pressure such as apply to nuclear power plants -- under a complex process, in that it requires the handling of large quantities of high level radioactive materials. Perhaps you will be able to see from the example of the Tokai plant that its industrialization is no easy task.

For any nuclear plant to come into commercial operation, one has to see that nothing interferes with it. Not only must radioactivity be kept under strict control, but also equipment must be on a multiplex system, designed to ensure that there will be no trouble. So the Power Reactor and Nuclear Fuel Development Corporation (PNC), Japan's only organization that has to credit the construction and operation of a reprocessing plant, should be the source to provide the experience and personnel necessary for an operating firm to carry it through to an industrialization program.

From now on, the operating firm will be required to be equipped with everything necessary to engage in the improvement and advancement of technologies for the reprocessing of spent LWR fuel. At the same time, PNC will find it necessary to push ahead with its projects for the development of technologies for the reprocessing of FBR and other non-LWR fuels.

Only when a reprocessing plant, with bright promise of the effective utilization of uranium resources, comes into steady operation can we be freed from the problems of energy supply. Thus reprocessing is not simply the task the operating firm must deal with, it is also the the key to the success of Japan's nuclear policy.

As success comes in our nuclear program, and maturity is reached in our nuclear activities, a new major subject for study is coming up, in addition to the challenge we must face in closing the fuel cycle in Japan, namely, the development of reactors based on a completely new concept of safety.

I am of the opinion that we need research and development for the reactor which has, what is called, inherent safety features. This reactor is not based on the present concept of engineered safety but on the system, by the law of nature, to cease fission reaction and remove

the heat in an emergency. From a technological view point, this reactor should be medium and small sized. This system could also provide a heat source for district heating and industrial purposes. If improvements can be made to facilitate its operation and improve its economics, there will certainly be an increasing demand for it. It wil also meet the needs of countries that are emerging into the development of nuclear power.

In a report on their tour of Southeast Asia in February this year, JAIF officials have point out that our neighboring countries are more keenly interested in nuclear power than they had been when our people visited there two years earlier. Prof. B. J. Habibie, Minister of State for Research and Technology of the Republic of Indonesia, told the visiting Japanese mission that he thouhght "the cost of oil would increase further" and that he would like to "promote the introduction of nuclear power into Indonesia." Other developing countries were also interested in the development of medium and small-sized reactors in Japan.

Only if Japan and other countries greet the 21st century with a firm approach to the nuclear age can we be assured of further progress of internaitonal society.

My special thanks in closing these remarks must go to the speakers from within Japan and those who have come from abroad to participate in this conference, and to Mr. Yamashita, Chairman of the Program Committee, and the chairmen of the sessions. I close my speech by hoping that useful suggestions will be made on the basic theme of this conference: "Nuclear Power: For the Progress of World Economy and Society."

三ツ林原子力委員長所感

第20回日本原子力産業会議年次大会

昭和62年 4月14日

本日，ここに内外から多数の原子力関係者をお迎えして，第20回日本原子力産業会議年次大会がかくも盛大に開催される運びとなりましたことは，誠に慶賀に堪えません。有澤会長，山下大会準備委員長をはじめ，今大会の開催に御尽力された皆様方に心からお祝いを申し上げますとともに，原子力分野で指導的な役割を果たされている参加者の皆様方に対し，心から歓迎の意を表する次第であります。

昨年一年間を振り返った場合，原子力開発利用始まって以来の事故と言われたソ連チェルノブイル原子力発電所の事故を抜きにしては語れません。直接被害に見舞われたソ連及び近隣諸国の方々には大変お気の毒なできごとであったわけでありますが，本事故については，ＩＡＥＡなどの場を通じて事故の解明が進むとともに，早期通報・相互援助の２条約の発効を始めとして，国際的な協力の動きも始まっております。またソ連においても数

々の改善措置を講じた上で，勇気を持って再び原子力発電の推進に取り組むなど，世界の原子力開発はこの不幸なできごとから立ち直るべく懸命の努力を続けているところであり，関係者の奮闘ぶりについては，全く称賛に値するものと感じ入っている次第であります。とともに，この事故に関してＩＡＥＡが行ってきた諸活動を高く評価するものであります。

今大会においては，「国際経済社会の発展に果たす原子力の役割」という基調テーマの下でさまざまな討論が行われると伺っております。国際的なエネルギー需給の緩和，ソ連チェルノブイル原子力発電所事故を契機に世界的に原子力開発利用の意義が問い直されている今，原子力が国際経済社会に果たす役割を改めて確認し，将来に向けての原子力開発利用の方向と進め方を討論することは，誠に時宜に適っており，実り多い成果が上げられるであろうことを確信するところであります。

さて，我が国の原子力開発利用は，昭和31年，ＩＡＥＡ憲章への調印と前後して，平和利用に限定した形で本格的に開始されました。当初，導入技術に頼って進められた我が国の原子力開発利用も，その後導入技術の消化

吸収及び国内における研究開発の推進に努めた結果，現在，軽水炉技術においては，その安全性，信頼性などにおいて欧米諸国に比肩し得るところまできているなど，着実な進展を見せています。特に原子力発電分野においては，昭和61年度末で商業用原子力発電所は33基，総出力 2,568万kW，昭和61年度の発電電力量に占める原子力発電の割合も約27％に達しています。今後も着実に原子力発電所の建設が進められる計画になっており，我が国は世界有数の原子力利用国としてますますその存在が重きをなすようになってきております。

一方，最近の原子力を取り巻く国際情勢を見ますと，世界全般のエネルギー需要の伸びの鈍化，エネルギー需給の緩和が進む中で，ソ連チェルノブイル原子力発電所の事故もあって，原子力発電の開発にブレーキがかけられる動きがあります。

原子力発電は，石炭及びＬＮＧとともに大きな供給力をもつ現実的な石油代替エネルギーであり，今後，相当長期を見ても，これらに匹敵する大きな供給力をもつ代替エネルギーは開発の見通しが得られておりません。現在，石油需給は緩んでいますが，長期的には石油需要の着実な増加が見込まれ，確実に石油供給の資源的制約が

顕在化するものと考えられています。このため，当面のエネルギー情勢に左右されることなく，国際的に原子力を始めとする石油代替エネルギーの開発に着実に取り組み，エネルギー需給を長期的に安定なものとする必要があります。

我が国はこれまで，どちらかと言えば自国のエネルギー源の確保だけを考え，原子力発電を進める国際的意義といったことはあまり考慮に入れてこなかったわけでありますが，当面のエネルギー需給が楽観的に見通せるがゆえに推進努力が弱まりがちなこの時期においてこそ，エネルギーの大消費国であり輸入量も世界一，二を争う我が国のエネルギー政策が国際エネルギー需給に与える影響の大きさを十分考えて，主体的，能動的に責任ある行動をとっていく必要があります。

さて，このような原子力を取り巻く情勢の中において，今後の我が国の原子力開発利用の長期的方向はいかにあるべきかを明らかにするため，原子力委員会ではまさに今，原子力開発利用長期計画の改定作業に取り組んでいるところであります。

現在，ほぼその骨格が固まりつつある新長期計画では，

次のような我が国の従来からの原子力開発利用の基本的な方向に変更がないことを確認しています。

その第一は，今後とも原子力開発利用を着実に推進していくことであります。我が国においては，これまでどおり社会・経済の進展及び国民生活の向上に原子力が大きく貢献することが期待されるところであります。

第二は，「平和利用の堅持」及び「安全の確保」を大前提として原子力開発利用を推進することであります。昨年4月のソ連の不幸な事故で関係者も一層認識を強められたことと思いますが，安全確保なしに原子力開発利用は有り得ません。

第三は，使用済燃料を再処理し，得られるプルトニウムを有効利用することであります。国内のウラン資源に乏しい我が国としては，これを原子力政策の基軸として，長期的観点から推進する必要があります。このため，自主的な核燃料サイクルの確立を図るとともに，炉型戦略としては「軽水炉から高速増殖炉へ」を基本にすることとしております。

このようなこれまでと変わらぬ考え方の下で，新長期計画においては，新たな情勢認識に基づいて，現行長期計画と異なる次のような点を打ち出すこととしておりま

す。

まず，当分の間緩和基調で推移すると見込まれる天然ウランの需給状況や，最近の我が国における軽水炉の定着状況にかんがみますと，現行長期計画で考えていたよりも軽水炉時代は長く続くものと考えられます。これからの軽水炉時代においては，これまでと違い，エネルギー全体の需要の伸びが鈍化する中で，エネルギー間の競争が始まると考えられますので，軽水炉の一層の質的高度化を図り，よりパフォーマンスの高いエネルギー供給源とすることが重要であります。

このためには，軽水炉の安全性，信頼性，経済性を更に向上させるための研究開発に取り組むとともに，核燃料サイクルの自主性の一層の向上を目指した技術の改良，開発に取り組むことが重要であると考えます。

他方，現在，新聞紙上をにぎわしている超電導に代表される材料技術，人工知能技術，レーザー技術など原子力にも関係の深い技術が日進月歩の勢いで進歩しています。技術開発を怠り，時代のニーズを先取りできなかった産業はいずれ衰退の運命が待ち受けていると言われております。原子力においても，今日の確立された軽水炉技術に満足することなく，常に新しい技術を積極的に取

り込んでいこうとする姿勢を失わないことが大切であります。

したがって，原子力分野の研究開発については，これまでのようにエネルギーの安定確保を目指して商業的な利用の早期達成に寄与するような研究開発に取り組むのみならず，核融合，放射線高度利用などまだ開拓されていない原子力のもつ広範な可能性の実現に向けた基盤的研究開発などにじっくりと取り組むことにより，技術的基盤を整備・強化して，今後の原子力に課せられた多様なニーズに弾力的に対応するとともに，関連する幅広い科学技術分野の水準向上のための推進力となるような創造的な原子力技術の創出に努めていくことが重要であります。

また，我が国の産業技術は，導入技術を基にいわゆる追い付き，追い越せ型の努力によって国際的水準に達し，今日，深刻な貿易摩擦を引き起こすまでになったわけでありますが，今後は，自ら新しい技術を創出し，科学技術を通じて国際経済社会に貢献していくことが強く求められているところであります。特に原子力分野においては，軽水炉の安全性・信頼性に関して優れた実績があり，またプルトニウム利用体系の確立を目指して着実かつ活

気ある開発利用計画を有している我が国に対する期待は大きく，これまで世界の原子力開発をリードしてきた米国，欧州と協力して世界の原子力開発利用の牽引車としての役割を果たしていくことが重要であると考えております。

我が国には，これまで軽水炉の導入，定着に熱意を傾けてきた人々を始めとし，多くの人材があります。また，国際的にもひけをとらない充実した研究組織もあります。我が国の軽水炉技術が世界的水準に達した今，軽水炉技術を確立させる時に見せた気概をもってこれらの人々，組織が原子力の基盤研究に取り組み，世界に貢献できるような多くの成果を上げることを期待いたします。

原子力は，エネルギー供給量の拡大，科学技術の振興などを通じて国際経済社会の発展に大きな役割を果たしてきており，また今後とも果たし続けることが期待されています。現下の国際情勢を見ると，今後とも世界共通の課題として原子力開発を進めていくことについて，残念ながら十分なコンセンサスが得られているとは言い難い状況にあります。

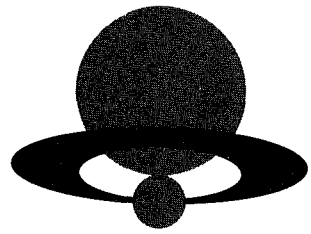
このような中にあって，我が国としては自ら世界の原子力開発に協力していくことにより，国際経済社会の発

展に貢献していく所存であり，またそれが我が国の使命であると確信しているところであります。

最後に，本大会におきましては，多数御参加の内外の有識者，専門家の方々の間で活発な意見の交換，忌憚のない提言がなされ，本大会が盛況のうちに成功を収められんことを祈念いたしまして私の所感を締めくくらせていただきます。

セッション1

２１世紀に向けての原子力の役割



フランスにおける原子力開発と２１世紀への展望

フランス原子力庁（ＣＥＡ）長官
Ｊ．－Ｐ．カプロン

ソ連における原子力技術開発計画

ソ連原子力発電大臣
Ｎ．ルコーニン

原子力開発と安全性における国際協力 — チェルノブイリ後の展望

国際原子力機関（ＩＡＥＡ）事務局長
Ｈ．ブリックス

イギリスにおけるエネルギー戦略

イギリス中央発電庁（ＣＥＧＢ）総裁
Ｗ．マーシャル

インドにおける原子力開発戦略

インド原子力委員会前委員長
Ｒ．ラマンナ

日本における原子力開発の展望 — 原子力開発推進のための課題提起

東京電力(株)会長
平　岩　外　四

アメリカにおける原子力オプション維持のための課題

米国原子力産業会議（ＡＩＦ）副理事長
Ｆ．グラハム

台湾電力の原子力発電開発の進め方

台湾電力公社社長
陳　振　華

THE FRENCH NUCLEAR POLICY FOR THE 21st CENTURY

Jean-Pierre Capron
Administrateur General
Commissariat à l'Energie Atomique

Mr Chairman, Ladies and Gentlemen,

It is a great pleasure and honor to attend this first session of the 20th JAPAN ATOMIC INDUSTRIAL FORUM, and to deliver my first international address as the head of the French Atomic Energy Commission to such a distinguished audience.

I feel all the more honored to be among you that this yearly forum is one of the most important events on the international nuclear scene.

I have been asked to make a presentation on the french nuclear policy for the next century. I'll try to give you some views on this topic.

I - THE FRENCH NUCLEAR PROGRAM

ORIGINS AND PRESENT ACHIEVEMENTS

1 - In FRANCE, the decision to resort to nuclear energy is the result of a deliberate governmental choice, which was implemented as early as 1945.

Since then, this decision has been confirmed by all the governments which have followed one another for the past 42 years at the head of my country and has been carried out with persistances. The reason behind this continuity is straightforward : the nuclear option is the only rational choice for a country,

- which has very scanty fossil fuel resources, but significant uranium reserves,

- whose scientists have always been in the forefront of nuclear research,

- for which national independence is a major political priority.

At the time of the first oil crisis, back in 1973, the scientific and technical knowledge, the human resources and the industrial experience which had been accumulated during almost 30 years were adequate to launch and ambitious nuclear power generation program and to develop a fuel cycle industry relevant with the requirements of the program.

The grassroot consensus on the nuclear issue, sweeping accross the boundaries of political affiliation, provided the french nuclear program with the stability and continuity which are a prerequisite for success in such a challenging undertaking.

2 - Let me give you a few facts about the present status of the french electronuclear program.

Whereas, back in 1975, only 17 TWh were produced by 10 nuclear facilities, last year 49 nuclear stations, representing a capacity of 45 000 MWe, supplied 241 TWh, that is to say more than three quarters of the electricity generated in FRANCE. Of these 49 units, 42 are standardized PWR's. 14 more are under various stages of construction and are scheduled to be connected to the national grid before 1993 and to provide an additional capacity of 17700 MWe.

It is worth pointing out that, on this grand total, two fast breeder reactors account already for 1500 MWe and that the first advanced PWR of the all-french 1400 MWe N4 design, presently in construction, should be commissioned by 1991.

During the same span of time, and industry covering all the segments of the nuclear fuel cycle has been built up almost from scratch. COGEMA, a fully-owned subsidiary of CEA, was created for this purpose and is now the only company in the world offering the complete scope of fuel cycle services :

- regarding uranium ore mining and prospection, COGEMA has become the world's largest operator;

- regarding uranium conversion, we represent a fourth of the world capacity;

- regarding uranium enrichment, we cover a third of the civilian capacity of the western world with EURODIF, 51% of which is owned by COGEMA;

- regarding fuel fabrication, COGEMA and FRAMATOME are partners in FBFC, the world major fuel element supplier;

- regarding reprocessing, the UP2-400 plant has reprocessed more than 1700 metric tons of LWR irradiated fuel since it was commissioned in 1976, which amounts to 80% of all the oxyde fuel reprocessed in the world for the past 10 years.

The running of this plant is extremely smooth and its nominal capacity is routinely exceeded.

3 - This choice in favour of nuclear power has proved :

- economically rewarding,

- technologically advanced,

- sound from the point of view of safety,

- responsible as regards energy conservation and security,

- environmentally constructive.

a) Economically rewarding

The benefits gained from this huge industrial effort are manifold :

- our overall energy independence has grown from 25% in 1975 to 46% in 1986,

- *the volume of our oil imports has steadily decreased as nuclear power stations phased out oil fired ones, thus greatly improving our balance of payments,*

- *the systematic, carefully planned, standardized nuclear plant construction program carried out by EdF, the french national utility, has dramatically reduced the cost of electricity generation and FRANCE presently enjoys one of the lowest production costs per kilowatt-hour,*

- *the performance of the french nuclear power stations, with an availability factor of over 80% on average, significantly higher than initially expected, has allowed exports of electricity to neighbouring countries, (especially UK, FRG, Switzerland, Italy) which provides a net surplus of 7 billions F. in 1986.*

b) - *Technogically advanced :*

Essential to the success of this national nuclear option was a significant R&D effort, performed by CEA with concern for application on an industrial scale. Such is the case, for instance, for reprocessing and fast breeders.

c) - *Safe :*

From the beginning, FRANCE has carried out a rigorous safety policy, the implementation of which has been made easier by :

- *the small number of partners : one utility, one reactor vendor,*

- *the systematic standardization, which saved human ressources and helped the careful and detailed investigation of generic problems which is essential to a good safety record. Moreaver, standardization made easier the training of competent and reliable operators.*

In addition, the french safety approach is characterized by :

- *the primacy given to a technical process to solve safety issues, based on close interactions between the operator, the safety authorities and their supporting experts;*

- *a deliberate policy of ever increasing safety and backfitting improvements to older reactor, whenever possible;*

- *a large effort devoted to the analysis of the experience derived from reactor operation and of the relevant events having occurred on foreign facilities, thanks to our numerous bilateral cooperations;*

- *in-depth reexamination of our approach in case of severe accidents : the THREE MILE ISLAND mishap prompted such a reexamination that resulted in several modifications being ordered on all french operating reactors. The TCHERNOBYL catastrophe, and the susequent report issued by the SOVIET UNION, was also carefully analysed. However, the reassessment of the french reactor safety ordered after this accident did not result in practical changes, since the TCHERNOBYL reactor design, the safety concepts and the operating procedures were of a very different nature.*

d) - *Responsible :*

The nuclear option has proved responsible :

- *because this policy has improved the security of our energy supply by diversifying it : nuclear power now covers more than one quarter of our total primary energy requirements and fossil fuels use is limited to these areas where they still are irreplaceable.*

This policy, if it were adopted by the other industrial nations would also keep more of the world fossil resources available for those developping countries that do not yet have the means to get acces to nuclear energy.

- *because our closed cycle policy keeps to a minimum the depletion of natural uranium reserves, thus contributing to the conservation of the world energy potentialities.*

- *because reprocessing affords the possibility to sort the wastes according to their activity levels and their radioactive period.*

As regards high level wastes, we have developed a vitrification method that has proved highly satisfactory. The MARCOULE vitrification plant, in operation since 1978, has produced more than 500 tons of vitrified wastes. A larger facility is under construction in LA HAGUE and should become operational by next year. The volume of high level long-lived wastes is much smaller than the volume of spent fuel, that must be treated as high level wastes in the open cycle option. Furthermore, the no-reprocessing option does not offer the same long term safety and non proliferation guarantees as vitrification.

In that respect, the waste management policy implemented in FRANCE ensures that non unwanted legacy will be left to the generations to come.

e) - Environmentally constructive :

The nuclear choice has positive consequences of the environment as is demonstrated by the french case. Between 1980 and 1986, sulfur dioxyde emissions from all sources have decreased in FRANCE by a factor of two, while in the same period electricity generation rose by 40%. This very encouraging evolution of the concentration in the atmosphere of a major pollutant has been made possible mainly by the decommissionning of a large number of conventional power stations simultaneously with the sharp increase in the number of nuclear plants connected to the grid : between 1980 and 1986, nuclear electricity output quadrupled, while its share in the overall electric consumption rose from 24% to 70%.

Pollution control measures such as desulfuration could not, by themselves, have brought such a dramatic change, as proved by other european countries, where the growth rate of nuclear power was insufficient and where drop of only 20% in sulfur dioxyde emissions was registered.

As regards carbon dioxyde, the amount released in the environment would have been higher in FRANCE by about 220 million tons in 1986 if the electricity produced by nuclear stations had been conventionally generated. Nuclear power is one of the few means at the disposal of mankind to escape the so-called "greenhouse effect", with its yet unpredictable impact on climate and biosphere.

II - THE INTERNATIONAL DIMENSION

One of the major features of nuclear energy is its international nature. That is why the french electronuclear program could never have been implemented "in a vacuum", through a narrowly self-centered, protective, isolationist approach. On the contrary, our effort was aided by an active policy of dense international relations in all domains pertaining to nuclear energy,

- on a bilateral basis with a growing number of countries,

- on a multilateral basis, through membership in the IEIA and other international organizations,

- in the framework of industrial cooperations, as well as agreements on areas of mutual interests with partners belonging to industrialized countries.

1 - As regards industrial cooperations, one of our oldest and most intense is with JAPAN. As early as 1966, contacts between SGN and the japanese engineering firm JGC resulted in the first preliminary studies for the TOKAI-MURA reprocessing facility. Since then, fruitful and confident relations have been built between the CEA Group and several industrial japanese partners :

This long standing relationship makes JAPAN our major partner in the fuel cycle industry. I am therefore extremely happy that this association is entering a new stage, since agreements are to be signed very shortly between JAPAN NUCLEAR FUEL SERVICE COMPANY, MHI and SGN, on the behalf of the CEA Group, for the construction of Japan's second reprocessing plant which will be located in ROKKASHO-MURA, in AOMORI Prefecture.

As regards reactors, to complete our nuclear plant construction program within the time imparted, a large reactor production capacity was developed by Framatome, the French PWR constructor which is also the supplier of nearly half of all the nuclear plants exported in the world since 1976.

This does not preclude Framatome from entering into new bilateral cooperation with other reactor suppliers as was illustrated by the recently announced cooperation of Framatome with KWU, to answer the indonesian call for bids concerning a 600 MWe reactor.

2 - We also cooperate with a number of major countries under bilateral agreements regarding research and development in specific fields, and especially in nuclear safety.

Let me dwell a little on this subject of safety. After Tchernobyl it has become a common place to say that high standards of safety are essential to build in the public mind, the confidence necessary to the continuing development of nuclear energy. We have always held this view and put it into practive in our national safety policies.

We are also cooperating with other countries in that field as well as in the framework of the IAEA.

We will continue to participate in such fruitful forms of international cooperation in the field of safety. However, there is, in our view, one mission that cannot be shared : the responsability of regulating and enforcing safety standards and policies. This responsability has to remain in the hands of national authorities :

- because the power to regulate and enforce regulations lies with the State,

- because, in a domain involving the health and protection of the population, the ultimate responsability cannot be delegated, or diluted in any supranational organization, under penalty of compromising safety itself.

3 - We are also in favour of multilateral joint projects, as long as it appears that it leads to an efficent gathering of strength.

As an instance of a successful international venture, let me mention, in addition to COMINAK, the EURODIF consortium, a private company the main shareholders of which, in addition to COGEMA, are italian, spanish and belgian. This concortium was able to raise an adequate funding and to increase the competition on the enrichment market which was dominated by a single producer before the commissioning of the TRICASTIN plant.

4 - We are convinced that acces to the peaceful uses of nuclear energy cannot be denied to <u>developing countries</u>, as it can be a key factor in their economical and social development an in the improvement of their standards of living.

Our policy has been and will remain one of active cooperation through bilateral arrangements with parteners who share our commitments to non proliferation. We feel that banning access to nuclear technology would be an unjustified and illegitimate excess that would be self defeating. That is one of the basic principles of our foreign nuclear policy which was recently restated by the french Prime Minister at the United Nations General Assembly on september 24, 1986 :

"FRANCE will continue to help the countries interested in getting access to the benefits of civilian nuclear applications, as long as appropriate international safeguards will prevent any diversion of this cooperation".

III - ENERGY IN THE 21st CENTURY

One of the big problems which lie in store for our generation is how to ensure a safe, reliable and cheap energy supply for the beginning of the next century. Either in terms of reserves, or of environmental impact, or of logistics, or of costs, the conventional fuels are subjected to limits and nuclear energy is fated to become an essential component of the supply of energy.

That is, in a shell, the argument I intend to develop in detail.

1 - COAL

The coal reserves are large and can last several centuries : at least 1400 billion tons for a yearly extraction rate of 3 billion tons.

However, coal is polluting, desulfurization is not cheap and generate waste. Even if we assume that the present standards on the environmental protection do not become more stringent, it precludes a massive comeback of solid fuels as the major energy source.

Moreover, the volume of international trade will remain modest at best, because coal is very expensive to transport and to handle, and does not travel easily. In consequence, it is penalized in EUROPE and in JAPAN, which are net importers.

2 - OIL

The world identified oil reserves amount to 100 billion metric tons, which represents 35 years of consumption at the present rate, but ultimate reserves are in the order of magnitude of 300 billion tons.

The big disadvantage of oil is that it is unevenly distributed. The Persian Gulf holds more than one half of the known reserves. That is why oil market are, at best, volatile and can fluctuate impredictably.

3 - NATURAL GAS

If natural gas is, in many ways, similar to oil, its logistics are more costly. Therefore, the key factor will remain the relative pricing of gas to oil.

4 - NUCLEAR ENERGY

Nuclear generation of electricity requires uranium, even if the corresponding cost is small when you compare it to the overall cost of the kilowatt-hour. However, the world uranium reserves could last at least a millenium, if fast breeders are put in general use.

From the point of view of environment, nuclear plants release almost nothing and are therefore cleaner than other forms of energy. Even though the reaction of public opinion after the TCHERNOBYL accident reminds us that nuclear energy still arouses irrational fears that cannot be ignored, it remains that this form of energy has had, since its origins, a safety record which is un paralleled when you compare it to all the other forms of energy.

From a financial point of view, nuclear electricity is the only way to locate added value in the consumer's country, whereas it lies with the producer in the case of fossil fuels.

For a country like FRANCE, nuclear electricity is now, even in these times of oil prices, competitive as long as the stations are connected to the grid longer that 1800 hours per year, when compared with oil, and 3700 hours when compared with coal.

It is the whole set of the advantages which leads FRANCE to go on with its nuclear program, in order to reach a penetration rate of 85%.

For other countries with similar situations, I am convinced that nuclear energy remains the most attractive option, as long as adequate efforts are devoted to safety and public opinion.

IV - THE FRENCH NUCLEAR OPTIONS FOR THE 21st CENTURY

As nuclear energy is in FRANCE to stay and grow, it is essential to ensure reasonable costs and excellent safety. Towards these ends, the following option are of vital importance.

1 - PWR's

The reactors to be ordered and built until the end of the century will be advanced PWR's of the N4 standard design, with a nominal capacity of 1400 MWe, which :

- *have been designed using a totally french technology,*

- *incorporate all the improvements suggested by the accumulated experience from operations,*

- *incorporate modifications required by the french safety authorities after TMI,*

- *satisfy new and even more exacting safety regulations,*

- *are designed for improved technical and econimical performance.*

Construction of the first reactor of the N4 series started at the end of 1984 in CHOOZ and is scheduled for connection to the grid by 1991 and the N4 PWR series will be the workhorse of EdF's program between now and the end of the century.

However, the long lead times of the nuclear industry require that we start thinking about the next generation of advanced PWR's.

In consequence, preliminary studies have started on this subject at EdF, FRAMATOME, and in CEA.

The PWR's of this new generation will need an improved operating flexibility, since the high penetration of nuclear electricity will, more than now, compel the newer reactors to follow closely seasonal and daily variations of the load. The design of the new reactor will also have to be simpler and their operation and maintenance, easier.

One of the options contemplated by FRAMATOME involves under-moderated cores and spectral shift capability, in order to use uranium more efficently. Such an option is also ideally suited for optimal valorization of the MOX fuels which be widely used in FRANCE at that time.

2 - *Developping Fast breeder reactors*

SUPERPHENIX, a 1200 MWe FBR, built through a European cooperation initiated in 1974, reached its 100% power in December 1986.

Superphenix is connected to the grid, and fast breeders already represent a few percent of the French operating nuclear capacity.

It should be kept in mind that Superphenix is a prototype, which has two consequences :

- *technically, the start-up phase offers the opportunity to detect and correct a number of technical problems we juste*

have one right now. This "debugging" phase should end in the near future.

- economically, as this is an industrial-size prototype, the cost of the KWh generated by Superphenix is higher (2,5 times) than it would be if produced by a standard French PWR. But it is lower than it would be if produced by a coal fired plant, which is already an achievement for a prototype.

One of our goals is the economic comptetitiveness of fast breeders. We are convinced that this goal is within our present technical capabilities, and will be attained in a reasonable time.

We have already been working for several years towards reducing the cost of the FBR generated electricity, and will pursue an active R&D program to support the design of the next machine that will pave the way for a commercially competitive reactor.

As regards the framework within which our fast breeder development program will proceed : we have built and are operating Superphenix with our European partners (mainly Italy, West Germany). It is our intent, as far as we are concerned, to pursue FBR development in the framework of our cooperation agreements which, incidentally, provide for a possible extension to other countries, like Japan and the United States.

If difficulties were encountered by our partners that would lead them to reconsider their policies, we would have to draw the consequences of this new situation.

But one thing is sure :

Whatever the framewortk that will eventually emerge, the technological, industrial and financial stakes are such for us that we will pursue our endeavour in FWR's which are, as for Japan, an essential part of our nuclear program.

3 - Fuel Cycle

The fuel cycle has now become one of the major french industries and a net contributor to the balance of payments. It is therefore absolutely essential that we keep up with the international competition.

The prerequisite of that ambition is a vigorous R&D program focused on enrichment and reprocessing.

a) - Uranium enrichment

As regards uranium enrichment after several years of exploratory work, we have recognized that the only new technique that appears to offer important technological and economic advantages in laser isotope separation.

That is why countries with a large nuclear program, have launched very active R&D programs to develop commercial laser isotope separation facilities.

In our view, laser isotope separation,

- should reduce the cost of uranium enrichment by a very significant factor,

- can be performed in small modular units, with a vastly improved flexibility,

- would allow a much easier recycling of the reprocessed uranium.

The first phase of our program was completed in 1986, when all scientific and technological options we had taken were successfully tested on a reduced scale at SACLAY. A second global experiment, using full scale components, is expected to take place in 1992-1993. Finally, the prototype of a production module should start operating in the second half of the next decade.

b) - Plutonium recycling

An optimized management of our fuel resources calls for recycling the plutonium recovered through the reprocessing of the spent fuel, in the form of MOX fuel for PWR's until fast breeders are commercially developed.

This was the conclusion of a long and far-reaching study conducted by EdF, which is the owner of the plutonium reprocessed form its 42 PWR's now in operation. The cumulated savings generated by a strategy of plutonium recycling are estimated to be in the ordrer of magnitude of 3 billion francs until 1995.

The technical feasibility of such a strategy has been demonstrated years ago, since the first experimental MOX assemblies were loaded into a french PWR back in 1974. The implementation of the program has now started after approval by the safety authorities : this year, two PWR's will be loaded with MOX assemblies and, in the coming years, up to 12 units will use the same fuel.

To supply the large quantities of MOX fuel, COGEMA has associated itself with BELGONUCLEAIRE to form a 60/40 joint venture, named COMOX.

c) - Reprocessing

As regards reprocessing, our short term priority is obviously the successful completion and start-up of the UP3 and UP2-800 plants in LA HAGUE. Each of these plants will have a design capacity of 800 metric tons per year. The construction work is proceeding on schedule.

SGN is the architect-engineer for the whole project which is now one of the largest construction site in EUROPE. The experience accumulated will be used in the design, construction and start-up of the japanese reprocessing project, where SGN will be a partner of JNFS. COGEMA will contribute its operating experience, while CEA, the owner of the technology, will conduct R&D work in support of the design options chosen.

For the longer terme, we must begin to prepare the next century, and the main directions of our R&D are :

- improvements in the efficiency of the process,

- further reduction of the releases in the environment,

- improved automation, the ultimate goal being a fully automated plant, this involves on-line chemical measurements, and newly designed teleoperation equipments and telehandling. Qualification of the corresponding equipments in active operational conditions will take place in a pilot facility located in MARCOULE.

d) - Waste management

The early choice we made to rely on a closed fuel cycle was consistent with a waste management progam and a minimal impact on the environment. We have now to proceed with implementation in a timely manner.

As regards short-lived, low activity wastes, the first repository, near the LA HAGUE reprocessing plant, is in operation since 1969 and will be full at the beginning of the 90's. The site of a second repository has been selected in SOULAINES, 150 km east of PARIS. The environmental impact studies and licensing procedures have been successfully completed and construction work is starting this year.

The SOULAINES repository should be operational in 1990 and have a useful life of 30 years.

As regards long-lived, high level wastes and transuranian wastes that require long term geologic storage,

a temporary facility is in use in MARCOULE and another is under construction in LA HAGUE, close to the vitrification plant.

It is now necessary to select an appropriate site for the permanent repository. For that purpose, ANDRA, the french waste management agency, has just anounced the identification of four potential sites in four different geological formation :

- *PARTHENAY, in granite,*

- *SEGRE, in shales,*

- *SISSONE-MONTCORNET, in clay,*

- *MONTREVEL, in salt,*

In each of these sites, deep drillings and series of measurements will start later this year to assess its geological characteristics. By 1990, the best site will be selected for the construction of an under ground laboratory, where in situ experiments will be carried out until 1995. If the results are satisfactory and the relevant authorizations are obtained, construction of the repository could then begin for completion by the year 2001.

IV - CONCLUDING REMARKS

The French nuclear development policy, as appears from this presentation, is based on :

- *a steadfast political will supported by a national consensus,*

- *technological capabilities, continously maintained and developed in order to face present and futur challenges, either technical or economic,*

- *a dense network of international cooperations, which have a dual beneficial role,*

- *they help make our own effort more efficient and fruitful,*

- *they show the achievements of other countries and the challenges we must face,*

A sound nuclear development policy is also based on openness and on a persistent effort for an ever better information, internationally as well as domestically, covering all apsects of nuclear energy, especially safety, and health and protection of the public.

As far as we are concerned, we have always made this effort, both because ours is an open society and because the case for nuclear energy has always appeared a worthy case to us, opennes is the only possible attitude, concealment injustified and self-defeating.

In our endeavour, we are encouraged to see that a great industrial country like Japan, achievements of which in high technology fields are praised internationally, has embarked on an ambitious nuclear energy development strategy which presents many similarities with our own.

ソ連における原子力発電発展の展望

ソ連原子力発電相
N．F．ルコーニン

ソ連における原子力発電にかかわる戦略的方向はチェルノブイリ原子力発電所事故にもかかわらず変更していない。１９８６年の原子力発電による年間発電量は１６２０億ｋＷｈ、熱供給は２９百万Ｇcalであった。ソ連原子力発電における外販用暖房熱及び電力の量は１９８５年に比し１９９０年で２倍、１９９５年で３倍以上、２０００年で５倍に増加する。

今日のソ連における社会的経済的進歩の促進は労働のエネルギー装備率の一層の上昇を要求し、就中工業プロセスの電化が求められる。ソ連における原子力発電発展の３０年は原子力の技術的万能性を証明し更に発電において化石燃料需要を原子力燃料によって経済性のある代替を行うことが可能であることを証明した。

８７年１月１日現在、ソ連では１７の原子力発電所が稼働しその合計出力は３１千ＭＷである。現在ソ連では原子力発電の発電総量に占めるシェアは９分の１であるが、１９９０年迄にはこのシェアは２倍になる筈である。

１１の原子力発電所が建設中である。第１２次５ヶ年計画における原子力発電出力増加の課題は既存のプラント拡大を含む。この第１２次５ヶ年計画の出力増加はヨーロッパ地区の発電所の稼働開始によるものである。ロシア共和国ではカリーニン及び第二次スモレンスク原子力発電所の建設が終了しバラコフスク、タタール及びロストフ発電所が稼働開始、コストロムスクの建設が継続する。ウクライナ共和国ではクリミア及びザポロジエの建設が完了し、フメルニツク、ロヴェンスク、南ウクライナ発電所が稼働開始する。いくつかの原子力発電所では電気出力が５～６千MWに達する。

このように原子力発電の加速的発展は東方地区からの送電と共にソ連ヨーロッパ地区の電力需要充足の基本と見なされている。質的に見ると、ソ連原子力発電の発展は２つのタイプのリアクターをベースとする。即ち、ＶＶＥＲと呼ばれる Water-Water 型とＲＢＭＫと呼ばれる Water-graphite 型である。技術的相違の外にこのリアクターは製作過程においても異った特性を要求する。Water-Water 型のリアクターは大型リアクター本体の製作に特別の機械工場設置としたのに対し、Water-graphite

型では既存の工場での製作が可能であった。原子力発電の広範な導入はノボボロネジ発電所の４４０MWの第３、第４号機の稼働により開始された。現在ソ連製ＶＶＥＲ－４４０型のリアクターを持つ発電プラントはコラ、アルメニア、ロヴェンスク発電所、更にブルガリア、ハンガリー、東ドイツ、チェコスロバキア、フィンランドで成功裡に稼働している。これと並行して Water-graphite 型ＲＢＭＫ－１０００の建設及び稼働開始が行われた。このタイプはＶＶＥＲと比べ一基あたりの出力が大きい為、経済性のある単位あたりの資本コストが確保された。現在ＲＢＭＫ－１０００型の発電機はレニングラード、クルスク、スモレンスク、チェルノブイリ発電所で稼働中である。ソ連における原子力発電の発展は、発電及び建設の両面で労働生産性向上のための１つのサイトへの発電能力の集中及びリアクター１基あたりの出力増加の道を辿っている。１９８０年にはノボボロネジ発電所で電気出力1,０００MWのＶＶＥＲ－１０００の第１号機が稼働開始した。この発電ユニットの単位あたり資本コストはＲＢＭＫ－１０００に比べ少なく、更にヴォルゴドンスクの原子力機器専門工場“Atommack”の操業本格化の後はＶＶＥＲ－１０００が２０００年迄に導入されるソ連の原子力発電の基本となった。

イグナリア原子力発電所では電気出力１５００MW迄高められたＲＢＭＫ－１５００リアクターを持つ２基の発電ユニットが建設された。しかしこのような１基あたり出力の増加は期待されたような技術的経済的指標の一層の改善につながらず、ＲＢＭＫ－１５００を予定していたコストロムスク原子力発電所ではＶＶＥＲ－１０００を採用すべく設計変更が行われた。８７年１月１日現在で原子力発電の構成は次の通り。

Water-Water 型リアクター	１４.９千MW
チャンネル water-graphite 型リアクター	１５.３５千MW
ナトリウム熱媒体高速増殖炉	０.７５千MW

現在の５ヶ年計画期間中にＶＶＥＲ－１０００リアクターベースの発電ユニットの完成化のための科学技術及び設計上の作業が継続されるが、その目的はその信頼性と安全性の向上のためである。炉心メルトダウンのような場合でも環境に対する放射性物質の放出を防止する対策が開発されつつある。これは

－ リアクター本体の下に cooling式捕捉設備の設置、この設備は溶融燃料の制御不可能核反応の可能性を阻止する技術手段を有する。
－ リアクターシェルからの蒸気・気体の熱放出の確保、これにはこの蒸気・気体が放射能で汚染された場合、特殊フィルターであらかじめ浄化することを含む。
－ リアクター壁下の水素の燃焼、又は爆発性ガスの除去を伴った水素のベンチレー

ジョン。

更にソ連では、現在核燃料利用改善を伴った新世代 Water-Water リアクターや安全が保証された将来型のリアクターの開発の作業が進められている。原子力発電の安全性に対する要求の高まり、これに対応した設備、建設費の上昇、追加時保安システム及びその複雑化に伴いソ連の原子力発電の単位あたり資本コストは過去５年間で１３％上昇した。この為、新世代の原子力発電所に要求される安全性の外にソ連燃料・エネルギーバランスの諸条件のためにも又原子力発電所の競争力維持のためにも単位あたり資本コスト低下の必要性が同じく重要である。

チェルノブイリ原子力発電所の事故とその後につき述べたい。チェルノブイリ発電所第４号機の事故は発電所員が技術的規則の諸要件に極めて粗暴な形で違反したため起ったものである。この事故は高度熟練要員の養成の質向上のための対策を講ずることを求め、又原子力発電の国家監督の強化を求めた。

１９８７年ソ連においてはノボボロネジ発電所付属の教育トレーニングセンターでＶＶＥＲ発電オペレーターの養成が、又、スモレンスク発電所のセンターではＲＢＭＫオペレーター養成が更に拡大される。現在その他の原子力発電所でも教育トレーニングセンターないし拠点が設置されつつある。原子力発電所員の質の向上ならびに再教育のための特別なシミュレーターのより完全化に大きな注意が払われている。オペレーターの心理的・生理的資質に対する義務的管理が導入されつつある。

１９８７／８８教育年度に全国高等教育機関に共通の質的基準が、原子力発電の専門分野の標準的カリキュラムに導入される。又これら教育機関の教育研究施設が強化される。このようにして人間対機械の相互関連で human factor に対する注意がより高められる。チェルノブイリも含めすべての原子力発電所でオペレーターの完全資格再検査が行われ、それには義務的な心理生理チェックも含まれた。

既に周知の通り事故の技術的原因としては、発電機の励磁の新しいシステムの実験テストを行うにあたりリアクターの事故防御システムの幾つかが作動しない状態となり、移行状態における核安全性の順守に関わる基本的要求に違反したことがあげられる。このため組織上又技術上様々な対策が開発され実施されている。これは炉心の物理的特性の変更、安全システムの状況管理の改善、リアクター機器の構造的状況管理の改善、リアルタイムの技術パラメーター管理の改善、事故防御システムの作動スピードの向上等である。特に炉心の物理的特性の変更に関する対策の実行はＲＢＭＫ型リアクターを内部的に安全なものとしている即ち事実上セルフ・コントロールタイプとなっている。稼働中のＲＢＭＫ型原子力発電所の安全性向上に少なからず貢献し

たのは計画的 preveative メンテナンスの際の定期的停止時及び稼働中にこの機器の製作工場の専門家が設計ビュローの専門家の参加を得て発電所機器の総合的インスペクションを行ったことである。特にすべての溶接部分の特別１００％検査が行われた。上記の如き対策を講じた結果ＲＢＭＫリアクターは様々な国で稼働している他のタイプのリアクターと同じよう操業安全性が確保され、同じようなレゾン・デートゥルを有している。ＲＢＭＫ発電所の安全性向上対策についてはＩＡＥＡ事務局長 ブリックス博士に詳細報告され、同博士はＩＡＥＡはチェルノブイリにおける対策に満足している旨表明された。

チェルノブイリ発電所の第１，２，３号機の稼働再開問題又これらにおける必要復旧作業の実施は事故の影響除去計画でも最も重要なものであり、第４号機の封じ込め作業と並行して行われた。第１，２，３号機の現実的状況、放射能汚染程度、復旧作業量を考慮して当初は第１号と第２号機の稼働再開対策が実施された。この復旧作業はまず主建屋及び補助建屋諸施設その中にある機器ならびに隣接する地域の放射能除去から開始された。この除去作業は１９８６年第３四半期の初めに完了した第３号機の施設・機器の汚染除去はまもなく終了する。第１、第２号機が長期間停止状態にあったこと又更に放射能ならびに汚染除去物質の影響により全機器及び自動システムの詳細点検と診断を必要とし、修理ならびに総合的調整作業を必要とした。復旧作業の完了後上記ＲＢＭＫ原子力発電所安全向上対策完了後第１，第２号機は物理的稼働、炉心 load の増加、更に電気的稼働が行われ、段階的に設計出力稼働へと進んだ。第１，第２号機の物理的稼働が開始されたのは１９８６年９月から１０月、設計出力到達は８６年11月であった。その後の operation の過程でチェルノブイリ第１，第２号機の高度の信頼が確認された。第３号機では汚染除去終了後構造物、リアクター、パイピング及びすべてのプロセス機器の情況がチェックされ、システム及び機器の封鎖解除が始まり、修理復旧作業が行われるが、これには破壊されたり機能を失ったシステムの改造等を含む。復旧作業の完了後物理的、電気的稼働が行われ、第３号機の設計出力到達が行われる。封鎖されたチェルノブイリ第４号機では温度ならびにリアクター隣接区域のガンマ・バックグラウンドのレベルにより燃料体の安定化した状況の継続的チェックが行われる。放射能から要員と環境を保護するため４号機の遮蔽が行われ、フィルターシステムつきの流入・流出ヴェンチレーションを使用して燃料体残余発生熱の放出が行われる。チェルノブイリ発電所の地域では事故のエコロジーに対する影響検出のための大規模な科学研究が行われ、特に、例えば環境の放射能健康増進にかかわる様々な生物体の効果が研究されている。

ソ連の原子力発電発展の展望問題に戻ると、コンデンセーション型原子力発電所以外の他の可能性のある分野での核燃料使用の技術的、経済的側面を検討し、更に原子力発電が広範にわたり国民経済に導入された場合核燃料確保を如何に行うかを検討する必要がある。この為以下機動性のある原子力発電開発、核燃料の暖房及び工業熱供給用利用、fast breeder 発電所開発の問題を解明したい。

原子力発電の経済性に関連し電力システムで一日のロードのダイヤグラムにおける原子力発電所利用システムにつき触れたい。現在のソ連の諸条件では年間６～７千時間以上稼働すれば原子力発電は経済的に成り立つ。これより少ない稼働時間では火力発電と競争出来ない。更にソ連では電力需要の一日の変動幅が毎年拡大している。夜間の電力需要は減少し、企業の昼休みは生産の電化が進んでいる背景で日中でも電力需要が急減することにつながっている。専門家の評価によれば、我国では２０００年迄に load の変動を cover するためは１億ｋＷのピーク及びセミ・ピークの発電能力が必要となる。原子力発電の経済的競争力につき前に述べたことはこれらの機動性のある設備は必然的に化石燃料を必要とするのだろうか。必ずしもそうではない。ソ連では原子力発電所と結びついた形での揚水発電所建設の計画が作成され実行に移されている。揚水発電所は夜間 pump-upの為原子力発電からの電力を使い昼間消費者に電力を供給することになり、この為揚水発電はピークカット時化石燃料を核燃料に置き換え原子力発電の一昼夜を通じての定格出力を確保することにより経済的に正当性のある方法となる。

しかし原子力発電の建設が予定されているソ連のヨーロッパ部のどこにでも揚水発電建設の条件が整っているわけではない。この為ソ連では現在コメコン諸国と共同で蓄熱式原子力発電の初期設計が進められている。このような原子力発電はサーモダイナミックロスが少ないため揚水発電とリンクした原子力発電よりも経済的であり、エコロジーに対する影響も少いことが期待されている。

長期にわたるソ連のエネルギープログラムは発電のみならず熱エネルギー生産、これに伴う化石燃料の大巾削減を目ざした原子力発電の集中的発展を予定している。苛酷な気象条件とソ連の発達した産業は大量の熱エネルギーの生産を要求している。第１１次５ヶ年計画ではボイラー用燃料消費の５分の２がこの目的のためであった。集中化熱供給に核燃料が使用されるには様々な方法がある。

－ 原子力発電所の調節されない除去蒸気の利用
－ 混合式熱供給・コンデンセーティング原子力発電（ＴＫ－４５０／５００－６０／３０００ type のタービン）

－　熱エネルギーのみを生産する熱供給原子力ステーション

－　特別の原子力熱併給発電所の開発、これは放射能安全性により工業集積地に近接して建設可能なもの。

上記の４つの可能な熱供給実現の方向のうちソ連エネルギープログラムは第一段階即ち１９９０年迄は電力及び熱エネルギーの混合生産を優先し、熱供給のスケールを増大させることになっている。原子力発電所の熱供給システム機から熱を払い出す場合の経済性は次のように説明出来る。即ちタービンから熱供給システムに蒸気を払い出した結果生じた電力生産不足を補完するためには、消費者に払い出された全数量の３分の１以下の量のリアクター熱を追加的に消費すればよいということである。残りの熱は環境中への熱放出減少により消費者に払い出される。リアクターより直接熱を払い出す場合は３倍即ち消費者に払い出される分そのままが増加する。現在我が国では熱供給システム機は１３の原子力発電所の３５ユニットで稼働し熱払い出し総量は３０００ G cal/hr 以上である。

コンデンセーションタービンの非調節払い出し蒸気の、ソ連における熱供給への利用の開始は２０年以上前ベロヤルスク発電所で行われた。ここで世界の経験では初めて熱供給システム機の稼働が始まりサイト内の直接ユーザーみならず一部居住地の消費者も対象となった。ノボボロネジ発電所も初めの発電ユニット稼働開始よりタービン払い出し蒸気利用により発電所の熱需要を賄ってきた。これら発電所の熱供給システム機稼働の長年の経験は核燃料による熱供給システムの高い安全性と operation 上の信頼性を立証した。

ベロヤルスク及びノボボロネジ以外でも過去数年来他の原子力発電所でもタービンの熱供給能力は程度の差はあるが利用されるようになった。１９８６年原子力発電所からの熱払い出しは２９３百万ＧＣａｌであった。１９９０年の熱払い出し量は１９８５年に比し５倍以上に増加する筈である。

ヨーロッパ地区以外でもソ連では遠隔地で原子力熱・電力供給が活用されている。ビリビノ村では電気出力各１２MWの４基の熱供給発電所が１９７４年稼働開始し、今日迄成功裡に操業継続している。

原子力ステーションと巨大産業人口集積地に近づけ、又熱電力消費者を原子力ステーションに近づけることは経済的合理性にかなったものだが、放射能安全性条件により稼働中の又建設中の原子力供給源は、産業・人口集積地よりかなり離れた立地を余儀なくされている。このためソ連では原子力発電所からの様々な遠隔熱輸送システムの技術的経済的検討が行われている。（one pipe サーモ・ケミカル）この他大都

市の複雑化した構築物の条件下で熱供給網を設置する困難さを考慮し更にこのような大都市地域には相互のpotentialityのある熱が環境に対し大量に放出されることを考慮し、各種のヒートポンプ使用による核暖房の技術・経済的研究が実施されている。

熱供給の特殊核熱源につき触れたい。現在ソ連ではゴーリキー及びボロネジ両都市の暖房専用に熱供給原子力ステーションが２基建設中である。小型のリアクター出力（熱で５００MW）及び特別な技術対策により原子力発電所に比べ保健・保護区域がminimizeされ都市建築区域協会から間近かに設置することを可能とした。このような熱供給ステーションの安全性を高めた対策のうち特に次の点を指摘したい。

1. 一次系熱媒体のパラメーターが低く、自然循環であること
2. リアクター本体を密閉式金属保護容器に収め、リアクター本体の破損のcaseも含むいかなる事故の場合でも炉心の水没状態が確保される。
3. Cooling systemの特別な熱交換機を通し中間ループの熱媒体の自然循環によりcooling systemの作動が確保される。

熱供給用原子力ステーションのlayout及び構造は安全性についての追加的要求を勘案して開発された。特に飛行機の墜落と衝撃波の影響である。この他すべて原子力発電所に考慮されている他の影響についても設計段階で配慮されている。原子力発電所の熱払い出しと同様リアクター熱媒体から給熱システム媒体への熱伝達は二次系の中間熱媒体により行われる。この場合供熱システム熱交換器では暖める側の媒体の圧力はシステム側媒体の圧力より低くなければならない。ゴーリキー及びボロネジ熱供給ステーションのオペレーションによりこのような原子力エネルギー供給の経済的又エコロジー面での優位性が確定されるはずである。更にソ連では安全性の高いリアクターを持つ工業用・暖房用原子力熱供給ステーション開発のための科学技術、予備設計作業が進められている。このようなステーションの開発は暖房用及び工業用熱供給の分野で化石燃料の核燃料による代替を大きく進めるものである。このような高度の安全性を持つリアクターとして、モジュールタイプのヘリウムガスcoolingリアクターの適用の可能性が検討されている。高温ヘリウムリアクターの基本的特性及び長所は周知のように炉心要素の構造物としてのグラファイトと結びついたヘリウムの高い物理・化学的特性によるものである。二次ループではより高度のパラメーターを持つ蒸気を作ることが出来る。この機器の高い放射能安全性は周知のように放射性の大きなネガティブ温度効率、更に放射能漏れを防ぐより多くのバリアーが存在することによるものである。蒸気発生器を炉心をインテグラルに配置したモジュール構造の特徴はどのようなsystemでもoperationの安全が確保される。この他重要な点としてこ

のようなステーションには核分裂による放射性廃棄物の残留量が少なくて済むというのはＶＶＥＲや通常の原子力熱ステーションに比べ廃棄物のリアクターからの払い出しやステーションからの輸送をよりひんぱんに行えるからである。

燃料資源消費の大きな分野での原子力エネルギーを大規模に導入することは核燃料のより高度な使用問題を提起する。就中 fast breeder にかわってくる。現在我が国ではシェフチェンコ市用淡水化と併用の電気出力１５０MWのＢＮ－３５０パイロットステーションとベロヤルスク station の電気出力６００MWのＢＮ－６００パイロットステーションが稼働中である。これらのリアクター構造は産業的規模で設計上の諸問題及びこのような発電所の経済性についてのチェックを可能としている。現在設置中のＢＮ－８００リアクターのユニットは特に熱・機械的設備及び基本的構造上の問題解決の点で今後シリーズ生産が予定されるＢＮ－１６００のプロトタイプとなる。

最後に次の点に注意を払って頂きたい。即ちソ連においては、ソ連共産党中央委政治局決定及び中央委書記長ゴルバチョフの演説の中で次の点が再三強調されている。

チェルノブイリの大きな教訓は、科学技術革命の今後の更なる展開のもと技術の信頼性、安全性の問題、複雑な技術の操作に際しての規律、秩序、組織性の問題は第一義的意義を持つことである。その規模においてチェルノブイリ原子力発電所事故はその影響において如何なる核爆発とも比較されるものではないが、コントロールのきかなくなった原子のエネルギーが如何に危険か全世界に示した。この重大な影響は核の脅威防止に対するすべての国の責任性を思いうかばせる。周知のようにソ連はヨーロッパにおける核弾頭つき中距離ミサイルの全廃とアジアでの大巾削減を自己のイニシアチブで提案している。しかしこれは第一歩にすぎず、最後の目的は地球上の総ての核兵器の廃絶である。

ПЕРСПЕКТИВЫ РАЗВИТИЯ АТОМНОЙ ЭНЕРГЕТИКИ СССР

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Стратегическая линия в отношении к атомной энергетике в СССР, несмотря на аварию на Чернобыльской АЭС, остается без перемен. Годовая выработка электроэнергии в 1986 году на АЭС в СССР составила 162 млрд.кВт.ч, теплоэнергии - 2,9 млн.Гкал. Предполагается, что объем производства товарной продукции (отопительного тепла и электроэнергии) в атомной энергетике СССР увеличится по сравнению с 1985 годом почти в два раза в 1990 году, более чем в три раза в 1985 году и в пять раз в 2000 году.

Ускорение социально-экономического прогресса в СССР сегодня требует дальнейшего повышения энерговооруженности труда и в первую очередь за счет электрификации технологических процессов. Тридцать лет развития атомной энергетики в СССР показали ее техническую доступность и возможность экономически приемлемого в нашей стране замещения потребления органического топлива ядерным при производстве электроэнергии.

На 01.01.87 года в СССР действовало семнадцать атомных электростанций суммарной электрической мощностью 31,0 тыс.МВт.

На долю атомной электроэнергии в СССР сейчас приходится девятая часть всей вырабатываемой в стране электроэнергии, а к 1990 году эта доля должна быть удвоена.

Одиннадцать атомных электростанций находятся сейчас в стадии строительства. Задание по вводу мощностей АЭС в XII пятилетке будет выполняться также путем расширения действующих АЭС. Весь

прирост мощности в XII пятилетке намечается осуществить путем ввода в эксплуатацию энергоблоков в европейской части страны. В европейской части РСФСР будет завершено строительство Калининской и второй очереди Смоленской АЭС, будут введены в действие мощности на Балаковской, Татарской и Ростовской АЭС, развернуто строительство Костромской АЭС. В Украинской ССР намечено закончить сооружение Крымской и Запорожской АЭС, будут введены в эксплуатацию энергоблоки на Хмельницкой, Ровенской, Южно-Украинской АЭС. Мощность отдельных АЭС возрастет до 5-6 тыс.МВт(эл.).

Таким образом ускоренное развитие атомной электроэнергетики по-прежнему рассматривается совместно с передачей электроэнергии из восточных районов страны как основа для удовлетворения потребности в электроэнергии европейской части СССР. Качественно развитие советской атомной энергетики базировалось на двух типах реакторов: водо-водяных (ВВЭР) и водно-графитовых (РБМК). Кроме технических отличий эти реакторные установки имели разные требования к машиностроительной базе для их изготовления. Реакторы водо-водяного типа нуждались в создании специализированной машиностроительной базы для изготовления корпусов мощных реакторов, а оборудование водно-графитовых реакторов можно было изготавливать на уже имеющихся заводах. Широкое внедрение ядерной энергетики в электроэнергетику страны началось с вводом в эксплуатацию III и IУ промышленных энергоблоков электрической мощностью 440 МВт каждый на Нововоронежской АЭС. В настоящее время энергоблоки с отечественными промышленными реакторами типа ВВЭР-440 успешно эксплуатируются на Кольской Армянской, Ровенской АЭС, в НРБ, ВНР, ГДР, ЧССР, Финляндии. Параллельно осуществлялось строительство и ввод в эксплуатацию энергоблоков с водно-

графитовыми реакторами РБМК-1000. Их большая единичная мощность по сравнению с реакторами ВВЭР обеспечивала экономически приемлемые удельные капитальные затраты на сооружение таких энергоблоков. В настоящее время энергоблоки с реакторами РБМК-1000 эксплуатируются на Ленинградской, Курской, Смоленской, Чернобыльской АЭС. Развитие атомной энергетики в СССР шло по пути концентрации электрогенерирующих мощностей на одной площадке и увеличения единичных мощностей реакторов с целью обеспечения роста производительности труда как в энергетике, так и в энергетическом строительстве. В 1980 году был введен в эксплуатацию головной энергоблок с реактором ВВЭР-1000 на Нововоронежской АЭС единичной мощностью 1000 МВт(эл.). Удельные капитальные затраты на сооружение этого энергоблока были меньше удельных затрат на сооружение энергоблоков с реакторами РБМК-1000, и после освоения производственных мощностей Волгодонского завода атомного машиностроения "Атоммаш" энергоблоки с реакторами ВВЭР-1000 стали основой вводимых до 2000 года электрогенерирующих мощностей на АЭС в СССР. Надо сказать, что на Игналинской АЭС были сооружены два энергоблока с реакторами РБМК-1500, на которых электрическая мощность форсирована до 1500 МВт(эл.). Однако такое укрупнение единичной мощности не привело к ожидаемому дальнейшему улучшению технико-экономических показателей и Костромская АЭС, где ранее предполагалось установить реакторы РБМК-1500, также перепроектирована на применение реакторов ВВЭР-1000. По состоянию на 01.01.87 года структура электрогенерирующих мощностей на АЭС в СССР следующая:

АЭС с корпусными водо-водяными реакторами	- 14,9 тыс.МВт
АЭС с канальными водно-графитовыми реакторами	- 15,35 тыс.МВт

АЭС с реакторами на быстрых нейтронах с натриевым теплоносителем - 0,75 тыс.МВт

В текущей пятилетке продолжаются научно-исследовательские, конструкторские и проектные работы по усовершенствованию энергоблоков с реакторами ВВЭР-1000 с целью дальнейшего повышения их надежности и безопасности. Разрабатываются мероприятия, предусматривающие исключение радиоактивных выбросов в окружающую среду даже при расплавлении активной зоны реактора. Это:

- сооружение под корпусом реактора охлаждаемого улавливающего устройства, оснащенного техническими средствами, исключающими возможность неконтролируемой ядерной реакции расплавленной массы топлива;

- обеспечение отвода тепла от паровоздушной среды из-под оболочки реактора, в том числе в случае загрязнения ее радиоактивными элементами с предварительной очисткой через систему специальных фильтров;

- организация сжигания водорода под оболочкой реактора или ее принудительная вентиляция с удалением взрывоопасных газов.

В СССР также разворачиваются работы по созданию для АЭС реакторов водо-водяного типа нового поколения с улучшенным использованием ядерного топлива и перспективных реакторов гарантированной безопасности. В связи с повышением требований к безопасности атомных электростанций и соответствующим повышением стоимости оборудования, строительно-монтажных работ, оснащением станции дополнительными системами безопасности и их усложнением удельные капиталовложения на единицу вводимой мощности в атомной энергетике СССР возросли за прошедшую пятилетку на 13%. Поэтому кроме требований по безопасности, предъявляемых к АЭС нового поколения, для условий топливно-энергетического баланса СССР, для

сохранения конкурентоспособности АЭС не менее важной является необходимость снижения удельных капитальных вложений в их сооружение.

Об аварии на Чернобыльской АЭС и ее последствиях. Авария на IУ энергоблоке ЧАЭС произошла в результате грубейших нарушений персоналом АЭС требований технологического регламента. Авария выявила неудовлетворительное состояние технологической и производственной дисциплины на атомных электростанциях. Она потребовала принятия мер по улучшению качества подготовки высококвалифицированного персонала и усиления государственного надзора в атомной энергетике.

В I987 году в СССР будет расширена подготовка эксплуатационного персонала для энергоблоков с реакторами типа ВВЭР в учебно-тренировочном центре на Нововоронежской АЭС и подготовка персонала для энергоблоков с реакторами типа РБМК в учебно-тренировочном центре на Смоленской АЭС. Сейчас сооружаются учебно-тренировочные центры и пункты при других АЭС. Большое внимание уделено дальнейшему совершенствованию специальных тренажеров для повышения квалификации и переподготовки кадров атомных станций. Вводится обязательный контроль за психофизиологическими характеристиками эксплуатационного персонала. В I987/88 учебном году будут введены единые для всех ВУЗов страны квалификационные требования к типовым учебным планам по номенклатуре специальностей для атомной энергетики, укрепляется учебно-исследовательская база этих ВУЗов. Тем самым в цепи взаимодействия человек-машина повышено внимание к человеческому фактору. На всех АЭС, в том числе и на Чернобыльской, была проведена полная переаттестация эксплуатационного персонала с обязательной психофизиологической проверкой.

Как теперь уже известно, техническими причинами аварии послужило то, что при проведении экспериментальных испытаний новых систем возбуждения электрогенератора был выведен из работы ряд аварийных защит реактора и нарушены основные требования по соблюдению ядерной безопасности в переходных режимах. Поэтому разработаны и внедрены организационные и технические мероприятия, направленные на повышение безопасности АЭС с реакторами РБМК путем изменения физических характеристик активной зоны, улучшения контроля состояния систем безопасности, состояния конструкций реакторной установки, улучшения контроля текущих технологических параметров, повышения быстродействия аварийной защиты. В частности, выполнение мероприятий по изменению физических характеристик активной зоны делают реактор РБМК внутренне безопасным, т.е. он становится практически саморегулирующимся. Повышению безопасности работы действующих АЭС с реакторами РБМК в немалой степени способствовало комплексное обследование оборудования во время очередных остановов на планово-предупредительный ремонт и в процессе эксплуатации специалистами заводов - изготовителей этого оборудования при участии специалистов конструкторских и проектных институтов. В частности, проведен внеочередной 100%-ный контроль всех сварных соединений. В результате всех перечисленных мероприятий реакторы РБМК становятся такими же безопасными в эксплуатации и имеют такое же право на жизнь, как и другие типы реакторов, используемых в атомной энергетике различных стран. О мерах по повышению безопасности АЭС с РБМК подробно было сообщено Генеральному директору МАГАТЭ доктору Х.Бликсу, который отметил, что МАГАТЭ удовлетворено мерами в Чернобыле.

Вопросы возобновления эксплуатации I, II и III блоков Чернобыльской АЭС, проведения на них необходимых восстановительных работ были важнейшими в плане ликвидации последствий аварии и решались параллельно с работами по консервации IУ блока. Исходя из реального состояния I, II и III блоков, степени радиоактивного загрязнения и объема восстановительных работ, первоначально были выполнены мероприятия по возобновлению эксплуатации I и II блоков. При этом восстановительные работы были начаты с дезактивации основных и вспомогательных зданий и сооружений энергоблоков, находящегося в них оборудования, а также прилегающей территории. На I и II блоках работы по дезактивации были завершены в начале третьего квартала 1986 года. Дезактивация сооружений и оборудования III блока будет завершена в ближайшее время. Длительное пребывание I и II блоков в остановленном состоянии, воздействие при этом радиационного облучения и дезактивирующих веществ потребовали тщательной ревизии и диагностической проверки всего оборудования и систем автоматики, проведения ремонта и комплекса пусконаладочных работ. По окончании восстановительных работ и упомянутых выше мероприятий по повышению безопасности АЭС с РБМК были осуществлены физический пуск и формирование загрузки активной зоны, энергетический пуск I и II блоков ЧАЭС и поэтапное освоение их проектной мощности. Физический пуск I и II блоков осуществлялся в сентябре-октябре 1986 года, освоение проектной мощности было завершено в ноябре 1986 года. В процессе последующей эксплуатации подтверждена высокая надежность работы I и II блоков ЧАЭС. На III блоке по окончании дезактивации будут проведены обследование состояния строительных конструкций, реактора, трубопроводов и всего технологического оборудования, на-

чнутся расконсервация систем и оборудования и ремонтно-восстановительные работы на блоке, включая воссоздание или реконструкцию разрушенных или утративших свои функции систем. По окончании ремонтно-восстановительных работ будут осуществлены физический и энергетический пуски и освоение проектной мощности Ш блока ЧАЭС. На законсервированном IУ блоке ЧАЭС ведется постоянный контроль за стабилизировавшимся состоянием топливной массы по температуре и уровню гамма-фона в прилегающих к реактору помещениях. Сооружено укрытие IУ блока для защиты персонала и окружающей среды от проникающего излучения, ведется теплоотвод остаточного тепловыделения от топливной массы с помощью приточной и вытяжной вентиляции с системой фильтров. В регионе расположения Чернобыльской АЭС ведется большой комплекс научно-исследовательских работ по выявлению экологических последствий аварии. В частности изучается, например, эффективность различных биологических культур по радиационному оздоровлению окружающей среды.

Возвращаясь к вопросу перспектив развития атомной энергетики СССР, необходимо рассмотреть технические и экономические аспекты использования ядерного топлива в других возможных областях, кроме атомных конденсационных электростанций, а также вопросы ядерного топливообеспечения в случае широкомасштабного внедрения атомной энергетики в народное хозяйство. Поэтому ниже будут освещены проблемы создания маневренных АЭС, использования ядерного топлива для отопительного и промышленного теплоснабжения, проблемы создания АЭС на быстрых нейтронах с реакторами-размножителями ядерного топлива.

В связи с экономичностью атомной энергетики несколько слов о режиме использования АЭС в суточном графике нагрузки энергосистем. Сейчас в условиях Советского Союза атомная электростан-

ция является экономически приемлемой, если она работает не менее 6-7 тыс.часов в году. При меньшем годовом числе часов использования АЭС не сумеет отстоять свою конкурентоспособность по сравнению с ТЭС. Вместе с тем суточные колебания электропотребления в СССР растут из года в год. Продолжает падать потребность в электроэнергии в ночное время, обеденный перерыв в работе предприятий на фоне растущей электрификации производства приводит к углублению провала электропотребления и днем. По оценкам специалистов к 2000 году в СССР для покрытия переменной части графика нагрузки потребуется до 100 млн.кВт пиковых и полупиковых электрогенерирующих мощностей. Означает ли вышесказанное об экономической конкурентоспособности АЭС, что эти маневренные мощности обязательно потребуют использования органического топлива. Нет, не обязательно! В Советском Союзе разработана и реализуется программа строительства гидроаккумулирующих электростанций (ГАЭС) в сочетании с АЭС. ГАЭС, потребляющая ночью для своего заряда электроэнергию от атомной станции, а днем выдающая эту энергию потребителям, и является тем экономически оправданным средством, которое замещает органическое топливо ядерным в переменной части графика электропотребления, обеспечивая при этом круглосуточную работу АЭС на номинальной электрической мощности.

Но не везде в европейской части СССР, где предполагается строительство атомных электростанций, есть благоприятные условия для строительства ГАЭС. Поэтому в настоящее время в Советском Союзе совместно со странами - членами СЭВ ведется поисковое проектирование АЭС с тепловыми аккумуляторами. Ожидается, что такие АЭС будут более экономичными, чем АЭС в сочетании с ГАЭС, в связи с меньшими термодинамическими потерями при таком аккумулировании, а их строительство будет оказывать меньшее экологическое воздей-

ствие на окружающую среду, чем строительство ГАЭС.

Энергетическая программа СССР на длительную перспективу предполагает форсированное развитие ядерной энергетики в СССР не только для производства электроэнергии, но и для производства тепловой энергии и высвобождения на этой основе значительного количества органического топлива. Достаточно суровые климатические условия и развитая промышленность СССР требуют значительного производства тепловой энергии. В XI пятилетке на это тратилось около 2/5 всего расходуемого в стране котельно-печного топлива. Использование ядерного топлива для целей централизованного теплоснабжения может быть реализовано различными путями:

использованием нерегулируемых отборов пара на атомных электростанциях;

сооружением смешанных теплофикационно-конденсационных атомных электростанций (с турбинами типа ТК-450/500-60/3000);

сооружением атомных станций теплоснабжения (АСТ), вырабатывающих только тепловую энергию;

созданием специализированных атомных теплоэлектроцентралей (АТЭЦ), которые по условиям радиационной безопасности можно было бы располагать в непосредственной близости от промышленно-жилищных агломераций.

Однако в любом случае ядерные источники теплоснабжения должны удовлетворять специальным требованиям, сформулированным в качестве дополнения к действующим в СССР "Общим положениям обеспечения безопасности атомных электростанций при проектировании, строительстве и эксплуатации". Из четырех названных выше возможных направлений реализации теплоснабжения страны Энергетическая программа СССР на первом этапе, т.е. до 1990 года, отда-

от предпочтение комбинированному производству электрической и тепловой энергии с возрастанием масштабов атомной теплофикации. Экономическая эффективность отпуска тепла из теплофикационных установок АЭС предопределяется тем, что для компенсации недовыработки электроэнергии на АЭС, происходящей в результате отборов пара из турбин на эти установки, требуется дополнительно затратить реакторного тепла в количестве не более одной трети от всего отпущенного потребителю. Остальное тепло отпускается потребителю за счет уменьшения сброса тепла в окружающую среду. При отпуске же тепла непосредственно от реактора, как в случае с АСТ, требуется затратить реакторных мощностей в количестве втрое большем, т.е. столько, сколько отпускается тепла потребителю. В настоящее время в нашей стране работают теплофикационные установки (ТФУ) на тридцати пяти энергоблоках тринадцати действующих АЭС общей установленной мощностью по отпуску тепла более 3000 Гкал/час.

Начало использованию нерегулируемых отборов пара конденсационных турбин АЭС для целей теплофикации в Советском Союзе было положено более двадцати лет назад на Белоярской АЭС, где впервые в мировой практике были введены в эксплуатацию теплофикационные установки, снабжающие теплом не только абонентов непосредственно на площадке, но еще и часть потребителей жилпоселка. С начала работы первых энергоблоков использованием пара отборов турбин обеспечивала свои собственные нужды в тепле и Нововоронежская АЭС. Многолетний опыт эксплуатации ТФУ этих станций показал высокую безопасность и эксплуатационную надежность систем теплоснабжения с ядерным источником. У различных турбин, применяемых в настоящее время на АЭС, возможности по отпуску теплоты

для теплофикационных нужд различны.

Тип турбины	Количество турбин в блоке с атомным реактором	Гарантированная мощность отборов на теплофикацию, Гкал/час
К-220-4	Две с ВВЭР-440	25 х 2
К-500-65/3000	Две с РБМК-1000	75 х 2
К-750-65/3000	Две с РБМК-1500	100 х 2
К-1000-60/1500-2	Одна с ВВЭР-1000	200
К-1000-60 /3000-6	Одна с ВВЭР-1000	200
К-1100-60/1500-4	Одна с ВВЭР-1000	450
КТ-1070-60/1500-3	Одна с ВВЭР-1000	1200
ТК-450/500-60-3000	Две с ВВЭР-1000	750 х 2

За прошедшие годы кроме Белоярской и Нововоронежской АЭС теплофикационные возможности турбин в той или иной степени стали использоваться и на других АЭС. В 1986 году отпуск теплоэнергии от АЭС в отрасли составил 2,93 млн.Гкал. В 1990 году отпуск тепла в отрасли должен увеличиться более чем в 5 раз по сравнению с 1985 г.

Кроме европейской части страны в СССР ядерное тепло- и электроснабжение нашло применение и в изолированных районах страны. В поселке Билибино в 1974 году была введена и успешно эксплуатируется по настоящее время АТЭЦ в составе четырех энергоблоков по 12 МВт(эл.) каждый.

Несмотря на экономическую целесообразность приближения атомных станций к крупным промышленно-жилищным агломерациям (ПЖА), а потребителей тепловой и электрической энергии к атомным станциям, действующие и строящиеся атомные энергоисточники по условиям радиационной безопасности вынуждены размещаться на

значительном удалении от крупных ПЖА. Поэтому в СССР ведутся технико-экономические исследования различных систем дальнего транспорта тепла от АЭС (однотрубных, термо-химических). Кроме того, учитывая трудность прокладки транзитных теплосетей в условиях сложившейся застройки в крупных городах и наличие в районах размещения таких городов мощных сбросов в окружающую среду тепла достаточного потенциала, ведутся также технико-экономические исследования по ядерному электроотоплению от АЭС с использованием теплонасосных установок различного типа.

Несколько слов о специализированных атомных источниках теплоснабжения. В настоящее время в СССР строятся две опытно-промышленнеы одноцелевые атомные станции теплоснабжения (АСТ) для отопления городов Горького и Воронежа. Меньшая единичная мощность реакторов - 500 МВт(т) и специальные технические мероприятия, реализованные в АСТ, позволяют ограничиваться существенно меньшей санитарно-защитной зоной по сравнению с АЭС и располагать АСТ в непосредственной близости от границы застройки городов. Среди технических мероприятий, обеспечивающих повышенную безопасность АСТ, следует отметить:

низкие параметры теплоносителя первого контура и его естественную циркуляцию;

размещение корпуса реактора внутри герметичного металлического страховочного корпуса, обеспечивающего сохранение активной зоны под заливом при всех авариях, включая разгерметизацию корпуса реактора;

обеспечение работы системы расхолаживания за счет естественной циркуляции теплоносителя промконтура через специальный теплообменник системы расхолаживания.

Компановка и конструкция АСТ разработаны с учетом дополнительных требований ее безопасности, в частности, падения самолета и воздействия ударной волны. Кроме того при проектировании АСТ учитывались другие воздействия, общепринятые для всех атомных станций. Как и при отпуске тепла от АЭС передача тепла от реакторного теплоносителя к сетевому теплоносителю осуществляется через промежуточный теплоноситель второго контура. В сетевом теплообменнике при этом давление греющей среды должно быть ниже давления сетевого теплоносителя. Эксплуатация Горьковской и Воронежской АСТ должна определить экономические и экологические преимущества таких атомных источников теплоснабжения. В СССР ведутся также научно-исследовательские и опытно-конструкторские работы по созданию промышленно-отопительных атомных теплоэлектроцентралей с реакторными установками повышенной безопасности. Создание таких АТЭЦ позволит кардинально увеличить замещение потребления органического топлива ядерным как в сфере отопительного так и промышленного теплоснабжения. Рассматривается возможность в качестве реакторных установок повышенной безопасности для таких АТЭЦ применить модульные газоохлаждаемые гелиевые реакторы. Основные характерные особенности и преимущества высокотемпературных гелиевых реакторов определяются, как известно, хорошими физико-химическими свойствами гелия в сочетании с графитом как конструкционным материалом элементов активной зоны. Это позволяет получить во втором контуре таких установок и водяной пар более высоких параметров. Высокая радиационная безопасность этих установок, как известно, определяется большим отрицательным температурным коэффициентом реактивности, наличием большего ряда барьеров, предотвращающих утечку радиоактивности. Особенностью

же модульной конструкции при интегральном расположении парогенератора и активной зоны является обеспечение безопасности эксплуатации в любых режимах. Немаловажным обстоятельством является и то, что единовременно на такой АТЭЦ может находиться значительно меньшее количество радиоактивных осколков деления ядерного топлива, так как выгрузка из реактора и отправка со станции отработанного топлива могут производиться значительно чаще, чем в АТЭЦ с реакторами типа ВВЭР или в АСТ.

Широкомасштабное внедрение атомной энергии в наиболее емких по потреблению топливных ресурсов отраслях ставит вопрос о наиболее полном использовании ядерного топлива, в частности, в результате применения реакторов на быстрых нейтронах. В настоящее время в нашей стране эксплуатируются опытно-промышленная АЭС с реактором БН-350 электрической мощностью 150 МВт с опреснением морской воды для нужд города (г.Шевченко) и опытно-промышленная АЭС с реактором БН-600 электрической мощностью 600 МВт (Белоярская АЭС). Конструкции этих реакторов обеспечивают возможность проверки в промышленных масштабах инженерных решений и экономичности таких АЭС. Сооружаемый в настоящее время энергоблок с реактором БН-800 в части тепломеханического оборудования и основных конструктивных решений является прототипом серийного энергоблока с реактором БН-1600.

В заключение хочу обратить Ваше внимание, что в СССР в решениях Политбюро ЦК КПСС и выступлениях Генерального секретаря ЦК КПСС М.С.Горбачева неоднократно подчеркивалось: непререкаемый урок Чернобыля состоит в том, что в условиях дальнейшего развертывания научно-технической революции вопросы надежности техники, ее безопасности, вопросы дисциплины, порядка и организованности

при эксплуатации сложной техники приобретают первостепенное значение. Хотя по своим масштабам авария на Чернобыльской АЭС не идет ни в какое сравнение по последствиям с любым ядерным взрывом, она показала всему миру, насколько опасна энергия атома, вышедшая из-под контроля. Ее тяжелые последствия напомнили об ответственности всех государств за предотвращение ядерной угрозы. Как известно, Советский Союз выступил сейчас с инициативой полной ликвидации ракет средней дальности с ядерными боеголовками в Европе и значительного их сокращения в азиатской части. Однако это - первые шаги, конечная цель - полная ликвидация ядерного оружия на Земле!

INTERNATIONAL CO-OPERATION IN NUCLEAR POWER DEVELOPMENT AND NUCLEAR SAFETY: THE POST-CHERNOBYL IAEA PERSPECTIVE

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It is a great honour for me to address this twentieth Annual Conference of the Japan Atomic Industrial Forum. I have been asked to talk about international co-operation in nuclear power development and nuclear safety after Chernobyl and particularly about the role of the International Atomic Energy Agency. I appreciate this opportunity because there is a good deal to report.

Many of the lessons to be drawn from the Chernobyl accident were specific to the type of reactor that was destroyed and these lessons are now being drawn in the form of technical modifications and changes in operator routines and supervision in the Soviet Union. However, it was realized for the first -- and hopefully last -- time that a nuclear power accident in one country could have physical consequences through radioactive fall out in other countries. And Chernobyl confirmed the experience from the Three Mile Island accident that a serious nuclear accident anywhere has strong psychological repercussions everywhere. As

a result, the accident has, on the one hand, triggered some increase in resistance to nuclear power development and, on the other, prompted an expanded international co-operation to ensure that the level of nuclear safety is high everywhere.

Some political leaders and political parties -- especially in countries which have no nuclear power -- proposed the phasing out or freezing of nuclear power. The predominant reaction, however, was that nuclear power remains a vitally needed source of electricity. That reaction is not surprising considering that nuclear power is economically advantageous and ecologically much less problematic than fossil fuels even when these are equipped with environment protecting measures. Nuclear power presents a high level of safety, but it can and must be made even safer. Let me illustrate this.

Shortly after the Chernobyl accident, the leaders of the seven industrially most advanced countries in the world, meeting at a summit here in Tokyo, stated that "properly managed" nuclear power will continue to produce an increasing share of the world's electricity. In the same period, the Soviet leader, Mr. Gorbachev, said that it was unthinkable to envisage a world economy without nuclear power. Here in Japan, the report "Nuclear Energy Vision" was published last year by the Ministry of International Trade and Industry describing the expansion of nuclear power to more than double by the year 2000 and giving scenarios to 2030 when it would supply 58% of Japan's electric energy - compared to 25% now. More recently, the British Energy Secretary, Mr. Peter Walker, announced that planning permission had been given for the Sizewell B nuclear power plant. Coming after years of public controversy and

inquiry into the economy and safety of the proposed plant, the decision is highly significant. Very recently, too, the United States Department of Energy reaffirmed the U.S. government's commitment to nuclear energy and stated that "it would be natural to expect the use of nuclear energy to grow as worldwide use of electricity increases".

These firm positions of leadership are encouraging to the nuclear power industry, but we should note that the support is not unconditional. Invariably, it is combined with demands that safety be further strengthened and that a variety of other concerns be met, e.g., regarding waste disposal, protection against terrorist attacks and non-proliferation. Further, although recent opinion polls in some countries have registered attitudes to nuclear power which are similar to those which prevailed before Chernobyl, there is no doubt that the public acceptance of and confidence in nuclear power still suffers from the Chernobyl effect.

There is sometimes a tendency to lay people's anxiety at the door of the media and their often exaggerated and sensationalist reporting of things nuclear. There is some justification for this, but I am inclined to think that the attention of the media to the most trivial nuclear problem or mishap is mostly not caused by an anti-nuclear bias, but rather by the circumstance that the media find people interested in reports even about trivial problems that arise in nuclear power operation. Seen in this way, the media attention is only a reflection of people's attention to events connected with nuclear power.

One may, of course, then ask oneself why so many people who accept gas and gas explosions, who accept coal and coal mine accidents, who accept hydro power and dam catastrophes, why so many of these people are nervous about nuclear power, whose overall safety record is excellent.

I think we have to acknowledge that modern man has not yet finished the process of filing nuclear power in his mind, as he has done with hydro power and dam catastrophes and other modes of generating electricity and the risks connected with them. Although he has long accepted the X-raying of his body and irradiation treatment of cancer, his mind is still wrestling with the nuclear power stations, nuclear accidents and nuclear waste disposal.

This reasoning leads to several conclusions. First, we must simply accept that uranium fuelled generation of electricity is subjected to more severe conditions for public acceptance than fossil fuelled generation of electricity. This calls for a sustained record of excellence in nuclear power operation. Second, the public must be provided with correct and understandable information so that people have adequate material for a rational processing of the nuclear questions in their minds and are not referred to patchy information and anti-nuclear slogans.

Let me first develop the information problem somewhat.

Of the media we can demand that they try, to the best of their ability, to give an accurate image of nuclear events; that the facts should be correct but also that the proportions should be right. Time pressure will explain and excuse many errors but it hardly excuses the publication of vague, sensationalist, unverified rumours, of which there was too much in the wake of Chernobyl. Absence of hard facts is not, in my view, an excuse for the publication of flimsy and alarmist rumours.

Of all those engaged in nuclear science and technology, in the operation and administration of nuclear power -- i.e. scientists, engineers, civil servants, administrators -- we can demand that they provide available information, that they speak up and speak plain language.

An important information requirement is that nuclear power must be placed in a proper perspective. All forms of energy production have some risk for health and the environment. It is simply not meaningful to discuss the acceptability of one form of electricity generation without discussing the alternatives. You may then end up rejecting one mode of producing electricity only to find that you have forced yourself to accept another, even more problematic.

Nuclear power, as we know, is not without some risk of accidents, but its overall safety record is extremely good. A highly toxic waste results from normal nuclear power operation, but methods of safely managing and disposing of this long-lived waste now exist. I shall come back to this later.

Fossil fuels, whether coal, gas or oil, are not exploited without serious accidents. The mining of coal has taken many lives and gas explosions have killed many people. Moreover, burning fossil fuels causes problems even in normal operation through the sulphur and nitrogen oxides produced, and there is an even more serious problem for the longer term through the contribution of carbon dioxide to the greenhouse effect. These serious problems will not mean that we will stop burning coal and oil. This is not possible, but we must be aware that as environmental protection requirements are imposed -- as they will have to be -- the cost of using fossil fuels will go up. In this economic and environmental perspective, it will be more easily seen that nuclear power is badly needed for our energy future. The more so as solar cells for large scale electricity production and fusion energy are far away, more hydro is not available in most industrialized countries, and various other sources, like wind, make only insignificant contributions.

Another information requirement at the present time is that we must present the facts about the Chernobyl accident so that an image emerges which is true to the reality. The IAEA has played an important role in this. Apart from the two visits which I and two expert colleagues of mine paid to Chernobyl and which helped to produce a good deal of factual information, the IAEA arranged a post-accident review meeting in Vienna, which drew some 600 experts from 62 countries and more than 230 journalists from nearly 30 countries. The very frank report given by the Soviet experts at this meeting undoubtedly gave a wealth of facts to the world and helped to explain what had really happened at Chernobyl -- and

why it happened. It was vital that so many specialized scientists and media people from all over the world were given hard facts and an opportunity to ask questions and to discuss.

The origin and course of the accident are now reasonably well established and I need not go into them. I should rather report to you that the situation is now -- less than one year after the accident -- beginning to go back to normal. All those who were hospitalized after the accident have been released. Many villages within a distance of 10 to 30 km from the plant have been decontaminated and people will be able to move back to them. Two units of the Chernobyl nuclear power plant are in operation again after decontamination, and the third is expected to be restarted soon. The fourth damaged unit is encased in concrete and is being monitored. There is some concern about risks connected with the spring flood, but a system of dykes and dams has been built to prevent contaminated water from reaching the Pripyat and Dniepr rivers.

The consequences of the accident outside the Soviet Union were certainly costly, because of precautionary measures taken, primarily regarding foodstuffs, but we can see now that the radiation doses received by the public during the first year after the accident were not greater than the variations which exist in the natural background radiation. The health consequences will thus be so small outside the Soviet Union that they will not be measurable.

In the media there have been many reports about the number of cancer deaths that could be caused in the Soviet Union by the accident. I am advised by the best authorities that such calculations are very uncertain and meaningful only as maximum estimates to be used for planning of emergency measures. Only the long-term medical follow-up of the population in the Western part of the Soviet Union can give reliable answers to what the effects really will be. Under all circumstances, the number of cancers that may be induced by the Chernobyl accident will be very small compared with the number of cancers from other causes in the same population.

An accurate public image of the Chernobyl accident, though highly important, will not be enough to restore damaged confidence. A number of other actions must be taken for nuclear power to earn the public confidence which it needs. We must everywhere have the readiness to cope with and mitigate the consequences of a nuclear accident. Even more important is to take steps to further improve nuclear safety so that serious accidents do not occur. Regulation and control must be effective. The highest standards must be set for quality in operations so that they become as free as possible of accidents and disturbances and a new record of excellence is established. Work must also be done to bring about for the future even more forgiving technology than is at present available. In addition, we must show to the public that the nuclear waste issue is manageable, and that more nuclear power will not lead to more nuclear weapons. I shall now discuss these matters.

The Chernobyl accident pointed to the need for effective mechanisms for prompt information about any accident that may occur and on emergency assistance. The IAEA was able to respond to this need with remarkable speed. A convention on early notification of nuclear accidents and another on emergency assistance were negotiated within four weeks last summer and they have now both entered into force. We are now setting up a small emergency response unit and organizing the procedures and the telecommunications system which are needed. We hope, of course, that we shall never have to use them.

An IAEA Convention on Physical Protection of Nuclear Material entered into force in February this year after ratification by 21 States -- not yet including Japan. It lays down useful standards of protection of material in international transport. However, in view of the terrorist problem, there is now discussion whether there should not be some international agreement about the level of physical protection to be given to nuclear facilities, in particular power reactors. This is still an open question.

Another open question is the prohibition of armed attacks against nuclear installations. With the same aim of protecting nuclear installations against physical violence, there have for several years been discussions about this matter. There have been no results whatever, whether in the IAEA or in the Conference on Disarmament in Geneva. Even attacks with conventional means on a nuclear installation could have very serious consequences and this is an argument sometimes invoked against nuclear power programmes. Since all great powers have such

installations, one would have thought that they should have a mutual interest in prohibiting attacks against them. Such a rule might have a good chance of being respected, considering the risk of retaliation in case of a violation. Regrettably in this field, we are even witnessing a retrograde evolution, for the prohibition of attacks on nuclear electric generating stations, dams and dykes which was unanimously approved in Article 56 of the 1977 Additional Protocol I to the Geneva Conventions is no longer universally accepted, as it was in 1977.

The precautionary measures taken by different governments in Western Europe to protect the public from foodstuffs contaminated by the fall-out from Chernobyl differed widely from one country to another. For iodine in milk, Sweden, Finland and the UK tolerated a maximum of 2000 Bq/l, Hungary 1000, Austria 185 and Land Hesse in the Federal Republic of Germany 20 Bq/l. Such variations, of course, had no scientific basis and some of them led to food being unnecessarily discarded. They also complicated trade in foodstuffs and led to significant economic losses. Differences still persist as regards rules for radioactive caesium in milk and meat products. This experience shows that there was a lack of readiness in this field and harmonization is obviously necessary. The actual setting of intervention levels must remain a national responsibility but they can and should be harmonized on a common scientific basis. This is now being done through IAEA, FAO and WHO.

Let me now turn to the international actions taken to strengthen nuclear safety. Most of these build on and strengthen existing international measures.

After the Chernobyl accident some political voices, noting that nuclear clouds do not respect national frontiers, proposed that universally binding safety standards should be enacted. Governments will not go that far, but they might give a stronger commitment to the international nuclear safety standards -- NUSS -- which the IAEA has been issuing since 1974. These standards are already being used extensively in Member States and are often included as basic safety requirements in international contracts. Some countries have even adopted them in part as national regulations. They are now being reviewed in the light of lessons from Chernobyl and there is a suggestion that Member States should more explicitly signal that they accept and respect these international standards. Such action would have the merit of demonstrating to the world that States operating nuclear power plants all accept some common international safety standards.

A second radical proposal in the wake of Chernobyl was that nuclear power installations should be subjected to mandatory international safety inspections. Again such a system would go too far. There is no doubt that the enactment of safety standards and the verification of their observance will remain national responsibilities. However, rather than trying to institute safety inspections, the Agency has created a service under which Member States may invite a team of international experts to visit a nuclear power plant and examine its operational safety. The team spends several weeks at the plant before reporting to the plant operator and the authority which issued the invitation. Operational Safety Review Teams (OSARTs) have been sent to a number of plants around the world since 1983. Since Chernobyl, the requests have increased drastically and this year we expect to carry out 10-12 of these visits. The reason for

the increase in demand is simple. OSARTs will give governments an independent check on the safety of their nuclear power plants. If made public -- and if positive -- OSART reports might help to increase the public's confidence in nuclear power plants and may even help to allay possible concern in neighbouring countries. To the Agency it is, of course, a challenge to maintain this service at the highest level of competence. I can assure you that the reviews are not cosmetic. If they were, they would be worse than useless, for they would then create a false feeling of confidence. Our experience is that critical advice has led to prompt remedial action and we have even been requested to verify that such action has been taken.

One subject area to which the nuclear community must give more attention is the man-machine interface. There has been significant progress, for instance, in the design of control rooms to provide the operator with the information he needs in each situation and with help to diagnose and master abnormal situations. However, there has been surprisingly little international information exchange on this essential subject and we have seen how very different paths have been pursued in different countries. I am grateful to the Japanese authorities for their offer to host a major conference on the man-machine interface in February next year. Against the background of the major achievements made in this area here in Japan, this conference will discuss improvements in the man-machine system which could be introduced everywhere. The conference will be a significant part of the Agency's programme of information exchange, which has the ultimate aim of providing guidance on the optimal balance between automatic control and manual operator action in a nuclear power plant.

The second part of this problem relates to the qualifications and training of plant operators. We must remember that in both Three Mile Island and Chernobyl, operator errors and infractions of procedures played the major role. It is essential to ensure that plant operators are highly qualified everywhere. While there can be no question, of course, of international procedures for the licensing of operators, it has been suggested that the IAEA could work out standards for operator training programmes to help ensure that they are at appropriate levels.

The international exchange of experience from nuclear power accidents and incidents is a useful way of broadening knowledge and improving readiness to cope with problems and thus of improving peformance and safety in operation. For this purpose the Agency has set up an international incident reporting system -- or IRS -- to which safety significant events are reported. Thereafter, they are analysed by an international group for the lessons that can be learnt. Regrettably, so far too few incidents have been reported. After several years of operation, the system has information on only about some 350 incidents, a number that could reasonably have been expected to be the annual input. To obtain the full benefit of this system we need to get more complete reporting from our Member States.

I have talked only about international measures to strengthen nuclear safety. At the national level, reviews and other measures are also being undertaken, post Chernobyl, to improve safety further and to mitigate consequences of possible accidents. Thus, in the Soviet Union, all RBMK reactors have been fitted with new automatic limits for control

rod withdrawal and operating procedures have been revised. Over the next years, fuel enrichment will be increased to improve physical parameters. In Sweden and in the Federal Republic of Germany, power plant containments are being equipped with pressure relief systems, which will vent overpressures through a filter so that radioactive elements will be trapped and not released to the environment.

Technical improvements in existing plants is a familiar way to improve nuclear safety. It is natural that there is also a serious discussion in many countries about the next generation of nuclear power reactors. One school of thought maintains that our presently proven reactors can be developed and simplified to achieve a higher level of safety. The goal would be highly standardized plants which could give a greater assurance of being built within a tight time schedule and budget. Some would like these plants to be smaller than the currently most common types. Safety, of course, is a primary objective in all this development work.

The other school favours the development of a new generation of power reactors with a greater degree of inherent safety, i.e. in which passive safety features would ensure that there can be no power surges or core melts. Promising concepts of quite different types are being developed -- not least here in Japan. Finding the capital to design and build the first prototypes for such plants may be a problem, however. One possible way could be to pool resources through international co-operation. An obvious model which comes to my mind at the present moment is the co-operation which took place in fusion research under the

auspices of the IAEA in the so-called INTOR project, and which is now being followed by a major international effort for the conceptual design of an International Thermonuclear Experimental Reactor (ITER) -- again under the IAEA umbrella.

I would hope that both development paths to new power reactors, the evolutionary and the revolutionary, will be pursued. The evolutionary improvement of our present power reactors is taking place within the existing structures of power plant development and manufacture although with a higher degree of international information exchange and co-operation than has been the case in the past. For the revolutionary line of new safer plants, international co-operation may be even more essential and it will be necessary to find an appropriate form for this. This line of development might also turn out to be very interesting, if it results in designs for smaller power plants which would be easier to build and operate in developing countries.

Major efforts are now naturally being devoted in many countries to establishing and maintaining a record of excellence in operation, which is a prerequisite for public acceptance. A major conference on nuclear power experience will be held at the IAEA in Vienna this coming fall to review the situation world-wide. The impressive operating results of Japan with very few forced outages and extremely low unplanned unavailabilities of less than 1%, I am sure, will be carefully studied. The way in which Japan has achieved this should serve as inspiration to plant owners in other countries.

Improvements in nuclear power operations have had results also in areas other than availability, e.g. the radiation dose which maintenance and operations staff receive. In spite of plants getting older and the systems more contaminated with cobalt-60, it has been possible to reduce the occupational doses very significantly, and many plants now have 200-300 manrems as annual objectives, a level which many could not even have dreamed of ten years ago. These results do credit to the nuclear power industry.

I have mentioned these examples to show what can be achieved. The improvements can be easily seen in the IAEA's Power Reactor Information System (PRIS), to which performance data from more than 80% of all power reactors in the world are reported. By far the most important factor for performance improvement and excellence appears to be the competence of the operating organization and the measures which it takes to maintain a high level of quality in operations. This is also the focus of the information exchange and guidance which the IAEA sponsors internationally. There is no doubt that nuclear plant operators have much to learn from each other. Yet, traditionally, utilities have not indulged to any great extent in this kind of exchange of experience. They sell their product on a defined, limited market, and are not engaged in co-operation with peers, especially not peers abroad. There would be advantage in breaking this isolation. In my view an exchange of experience between nuclear power plant owners and operators in industrialized as well as in developing countries, market economy countries and centrally planned countries should be established. The aim would be to spread good operating practices.

When I said earlier that nuclear power is environmentally benign in normal operation, I naturally include nuclear waste. Scientists and engineers are confident that present technology is adequate for safe disposal of these wastes. Of course, we cannot guarantee that in a thousand years' time no-one will drill through the rock and find a nuclear waste disposal site. However, the risks and quantities involved are small and -- above all -- they must be compared with the risks that we run if we produce the electricity by coal, which for many countries is the major alternative to nuclear generation. In our environmental concern it would really be more appropriate for us to examine the alternative wastes than the alternative energies. If we do that I am confident that the small amounts of highly active wastes from nuclear plants will be preferred to the alternative immense amounts of wastes from coal-fired plants. I am not ignoring the fact that it is possible to remove most sulphur dioxide and nitrogen oxide from the atmosphere emissions of coal plants and that Japan has done precisely this. It is an example to be emulated by other countries. However, these measures do not protect us from the so-called greenhouse effect -- the warming of the earth's atmosphere -- to which the carbon dioxide from fossil fuel burning will be a main contributor.

In order to demonstrate that nuclear waste disposal technology is viable, actual demonstration is needed. In Sweden a large disposal plant is now being built for low-level wastes, and off-site interim storages for spent fuel are being constructed in several countries. The adoption of a set of international standards for safe underground disposal may also help to convince public opinion that nuclear waste handling is by no means an open issue. The Agency has recently brought out the first of these standards and work is going on to complete them.

Actions related to safety are not the only ones that are needed to make nuclear power more generally acceptable to the public. In some people's mind the growth of nuclear power raises fears about the further spread of nuclear weapons and guarantees are needed against proliferation of nuclear weapons. Assurances are also needed regarding the safe supply of, for instance, nuclear fuel, to create confidence in the reliability of nuclear power as a source of energy. In the present buyers' market, in which a growing diversification of suppliers provides considerable assurances against supply interruptions, an international agreement on supply assurance may not have any great urgency. At present, nuclear power can be relied upon to contribute to a greater measure of energy independence for most of the countries which see this as one of their objectives. The small amounts of fuel needed have permitted many countries to stockpile enough for many years' needs. In the longer term the restructuring of the supply industry, which now seems inevitable because of the present overcapacity, may again raise a need for closer international co-operation regarding assurances both of supplies and demand.

The present situation in the non-proliferation area is one of some uneasiness. Governments and public opinion in many countries understandably attach great importance to assurances that international trade does not promote proliferation of nuclear weapons. Against this background, non-proliferation conditions in bilateral supply agreements have been made stricter. The cornerstone of the non-proliferation regime still remains the Non-Proliferation Treaty. It is complemented by the treaties on nuclear-weapon-free zones, notably the Latin American Tlatelolco Treaty and the recently concluded Rarotonga Treaty on the

South Pacific. The verification provided by Agency safeguards is a fundamental part of any non-proliferation scheme for it provides greater confidence in non-proliferation commitments. An added merit is that it constitutes a breakthrough in showing that international on-site inspection can be accepted and can work. The shortcomings of the safeguards system lie, of course, above all in the lack of universal coverage. In this context, the recent decision by the Government of Spain to sign the NPT must be welcomed. The decision of the Chinese Government to place some nuclear facilities under IAEA safeguards should also be welcomed. This will mean that the on-site inspection system will have been accepted by all recognized nuclear-weapon States.

These positive acceptances do not mean that the safeguards work of the Agency is always easy. For one thing the safeguards budget is kept within rigid limits. I cannot help mentioning in this connection that last year power plants under Agency safeguards produced some 700 TWh and the safeguards budget was less than $35 million. The cost of the safeguards system to Member States was thus less than 5 thousandths of a cent per kWh! This does not appear to be much when related to the assurance it gives. For next year, we have had to request an increase in the safeguards budget of 2.9%, which is to help meet expected safeguards obligations at several new bulk handling facilities and an increase in power reactors under safeguards of almost 10%. There are, however, also other problems relating to safeguards than budgetary ones. For instance: governments have the right to reject individual inspectors who are designated. When extensive use is made of this right, it becomes more difficult to use the Agency's personnel resources efficiently.

Objections have also been raised to the introduction of new and more effective safeguards techniques and this again will have a negative impact on the quality of verification. The system needs constructive and dedicated attention and above all, close co-operation from Governments, authorities and plant operators, if it is to maintain the desired confidence and to operate at optimal cost.

I have tried to describe many measures which, taken together, may be said to constitute an evolving international nuclear safety regime and which may be expected to result in greater public acceptance of nuclear power. The Atoms for Peace programme and the establishment of the IAEA thirty years ago was built on a basic philosophy of a transfer of technology linked with non-proliferation assurances. Thus from the outset there was a regime of international interdependence. We have to acknowledge that today the regime of interdependence extends to other areas, notably safety, in which international assurances are extremely important for the further development of nuclear power.

In Japan, there are plans to more than double the present nuclear capacity within the next 13 years. I am sure that you will agree with me that advances in waste disposal, confidence in safeguards, better information about the nuclear power option as compared to other energy options, and a stronger international nuclear safety regime, giving better guarantees of nuclear safety everywhere, will make it easier to obtain the general public support which Japan's impressive programme deserves.

(1)

20th JAIF Annual Conference

THE ENERGY STRATEGY OF THE UNITED KINGDOM

THE SIZEWELL 'B' PWR

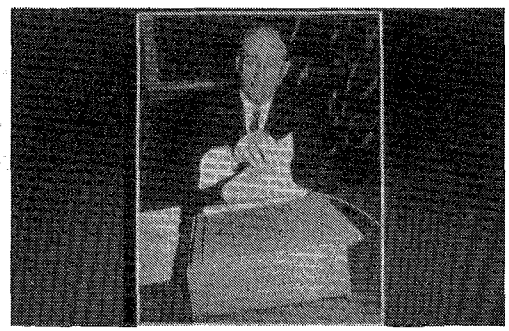
Lord Marshall **14 April 1987**

1

On 12 March 1987, the UK Government gave its consent and planning approval to the construction of a PWR nuclear power station at Sizewell on the east coast of England, and the CEGB are making an immediate start on site. The construction of Sizewell 'B' will fulfill an ambition to build PWRs that the Board has held for many years.

The decision follows a long pause in power station construction in the UK. The Sizewell PWR project was actually initiated by the British Government in 1979 but its approval was subject to a wide ranging public inquiry, following the precedent of the Windscale Inquiry on reprocessing. The Inspector for the Sizewell Inquiry was Sir Frank Layfield.

The length of the Sizewell public inquiry set an all time record in the UK and (**2**) the final report was also long and comprehensive.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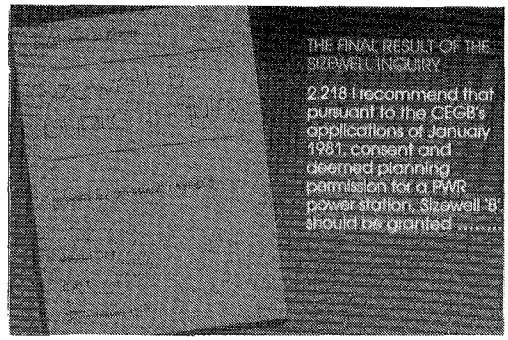
(**3**) It ended with an unambiguous recommendation that the project go ahead:



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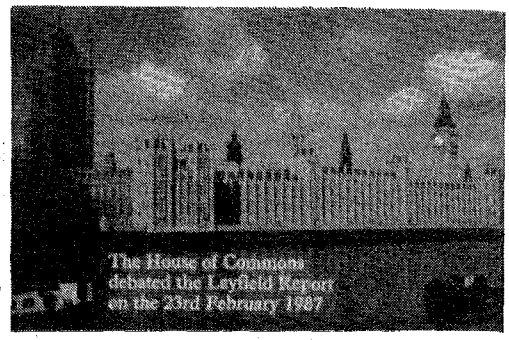
> 'I recommend that, pursuant to the CEGB's applications of January 1981, consent and deemed planning permission for a PWR power station, Sizewell 'B', should be granted' . . .

You will note that the language is old fashioned because it follows the form and protocol of British Law, in this case the Electrical Lighting Act, 1909.

(**4**) Following the publication of the report the House of Commons debated it on 23 February 1987.



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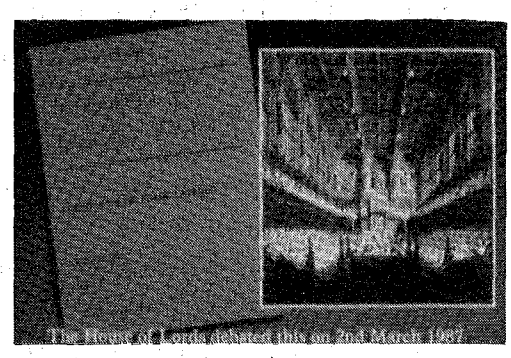
(**5**) and the House of Lords on 2 March 1987.



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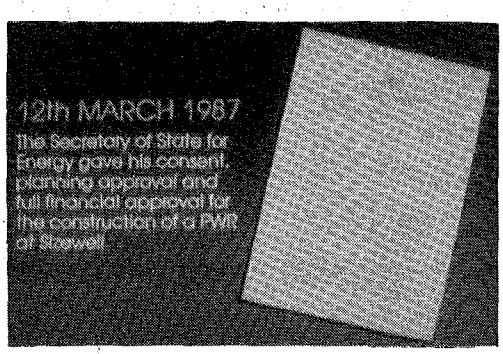
(**6**) Formal consent for Sizewell 'B' to go ahead came in a letter from the Secretary of State on 12 March 1987.



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(**7**) On 1 April 1987 the Board of the CEGB met and authorised the expenditure of 1550 million pounds and this triggered the manufacturing contracts which will be placed this month.

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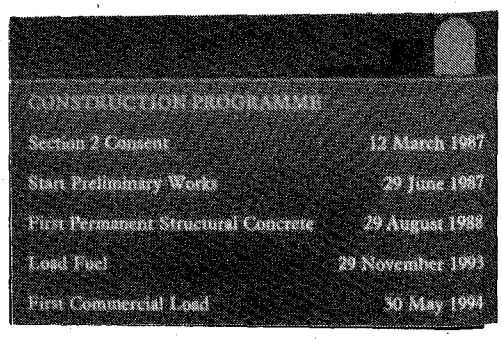
(**8**) The key construction programme dates are:

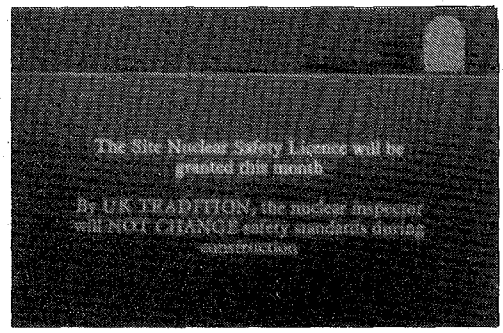
Start Preliminary Works	29 June 1987
First Permanent Structural Concrete	29 August 1988
Load Fuel	29 November 1993
First Commercial Load	30 May 1994



8

This is a slow construction compared to Tsuruga 2; but this is our first PWR so we are being very cautious.

(9) In addition to the consent of the Secretary of State we also require a site nuclear safety licence and the Chief Inspector of Nuclear Installations has indicated that there are no outstanding safety issues of substance. We expect a site licence during April and the project should proceed smoothly because by UK tradition, the nuclear inspector will not change safety standards during construction.



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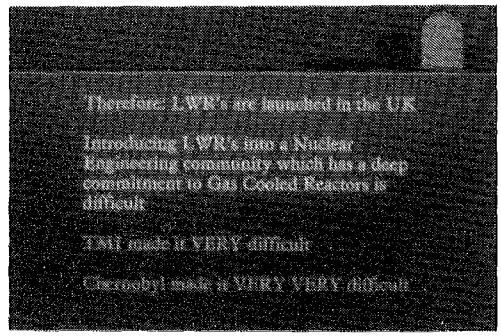
(10) The introduction of light water reactors into a country with a highly developed nuclear power programme with a deep commitment to gas cooled reactors has been difficult. The position was made more difficult following the accident at Three Mile Island, and more recently by the Chernobyl accident, which had a profound impact on the acceptance of nuclear power by the British public. This made the launching of a reactor system new to the UK a very difficult task. However, we have succeeded and the way is now open to the building of further light water reactors.



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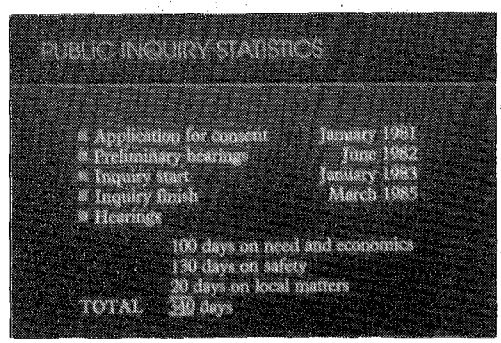
THE PUBLIC INQUIRY

(11) The Public Inquiry into Sizewell 'B' was the most wide ranging and longest carried out in the UK. The application for Consent was made in January 1981; the Inquiry started in January 1983; and the Inquiry closed in March 1985.



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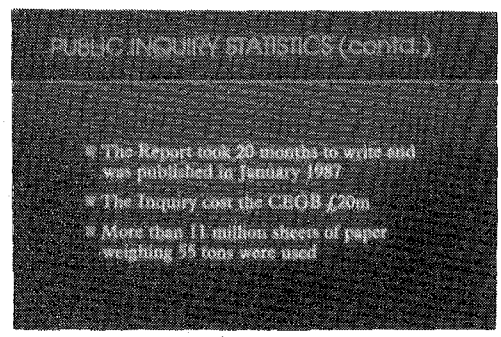
The Inquiry dealt with planning issues, addressed public concern about nuclear energy and ranged over economics, safety and environmental aspects. The scale of the Inquiry can be judged by the statistics: The hearings spent 100 days on need and economics, 130 days on safety, 20 days on local matters, and sat for 340 days.



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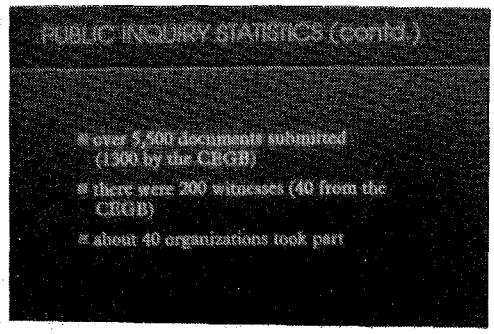
(12) The Inquiry cost the CEGB 20 million pounds. More than 11 million sheets of paper weighing 55 tons were used.

(**13**) Over 5500 documents were submitted, 1300 by the CEGB. There were 200 witnesses, 40 from the CEGB. About 40 organisations took part. The verbatim transcript of the proceedings ran to sixteen million words.



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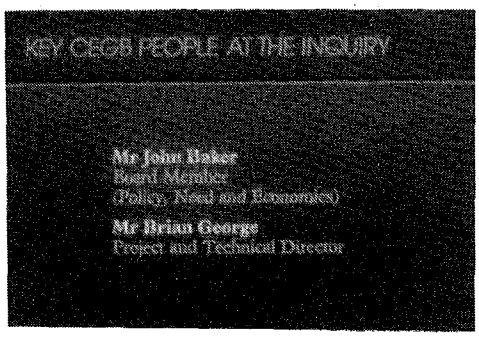
The scale of the Public Inquiry meant that the CEGB has to commit a very (**14**) substantial effort in making its case at the Inquiry.



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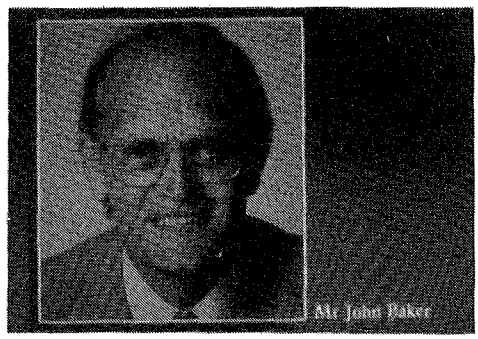
The two key witnesses of the CEGB who deserve a large part of the credit for our success (**15**) were John Baker the Board Member who led for the CEGB at the Inquiry,



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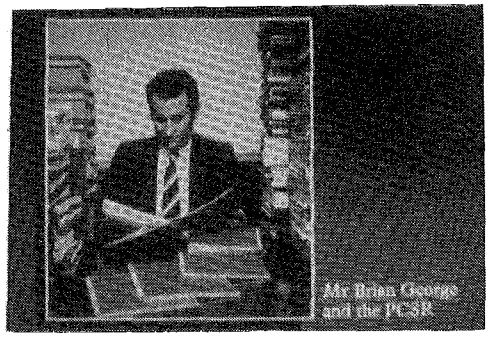
and (**16**) Brian George, the Sizewell 'B' Project, and Technical Director who was the Board's lead witness on technical matters.



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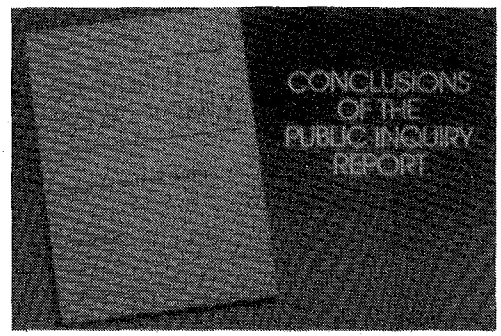
THE PUBLIC INQUIRY REPORT



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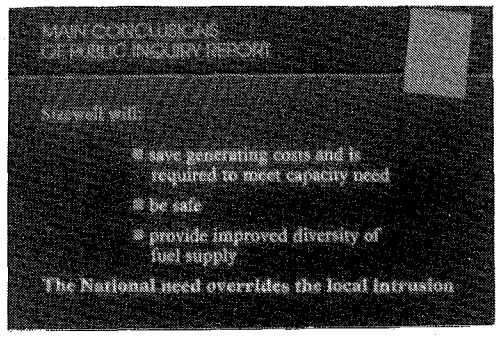
(17) Sir Frank Layfield took 20 months to prepare his report which ran for over 3000 pages. The report is of a very high quality.



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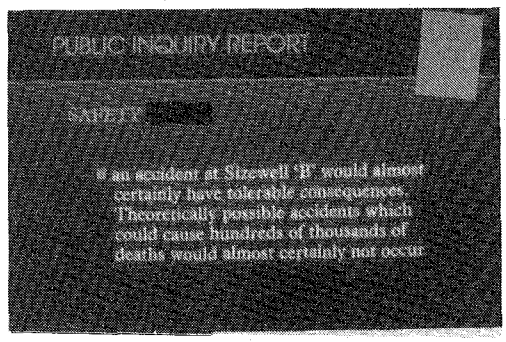
(18) It came to the broad conclusion that 'the benefits of Sizewell to the nation in the form of overall generation cost saving, contribution to meeting capacity need, and the reduction of the reliance on coal outweighed the risks'. The national need overrode the local inconvenience that would be caused.

In reviewing Sir Frank Layfield's Report, I propose to concentrate on those matters of general interest which have a wider impact than simply Sizewell 'B'. In particular I think you would like to hear what the report had to say about safety and emergency plans.



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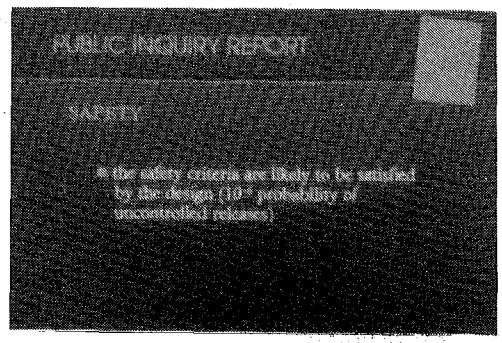
(19) The topic of safety occupied more time at the Public Inquiry than any other subject, and the report rejected the arguments put forward by the objectors on subjects like pressure vessel integrity, loss of coolant accidents, human error and external hazards. The report concludes that an accident, 'would almost certainly have tolerable consequences. Theoretically possible accidents which could cause hundreds or thousands of deaths would almost certainly not occur'.

(20) In arriving at this very satisfactory conclusion the Inspector paid great attention to the safety criteria set by the CEGB as targets and guidance to designers, and to the NII safety assessment principles which guide its nuclear inspectors in their assessment of the safety case. The criteria are comprehensive and cover both normal operation and accident situations. For serious accidents the criteria is that the total frequence of all accidents leading to an uncontrolled release should be less than 10^{-6} per reactor year. The Inspector considered that the Sizewell 'B' design would come close to achieving this target. He concluded that the overall safety criteria of the CEGB and NII are satisfactory and that they are likely to be generally satisfied by the Sizewell 'B' design.



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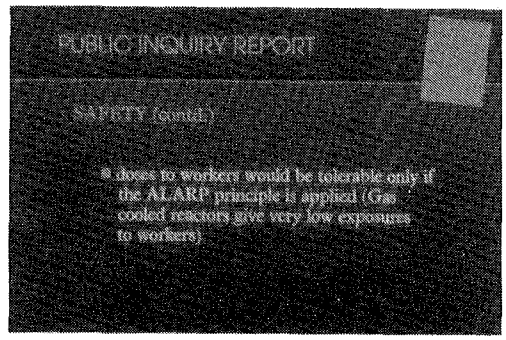
(21) The limit for the annual dose to workers set by the CEGB is based on the ICRP recommendations and our criteria set a stringent target for the designers in limiting the radiation dose to the operators. These are easily met on our gas cooled reactors, but international operating experience of light water reactors shows that the doses on this type of reactor can be high unless particular attention is paid in the design and operation of the plant. On this subject the Inspector cautions that doses to workers would be tolerable only if there is a rigorous application of the ALARP principle. However, on Sizewell 'B' the commitment to reduce doses to 'as low as reasonably practicable' forms a fundamental part of the design process and we are confident that the dose targets will be met.



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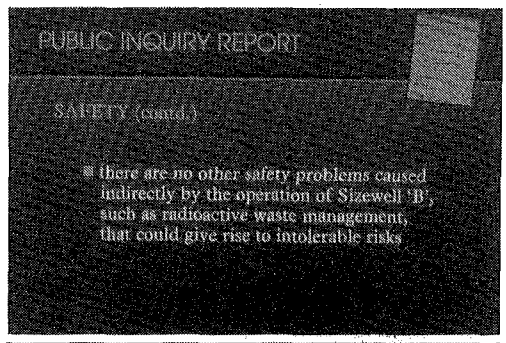

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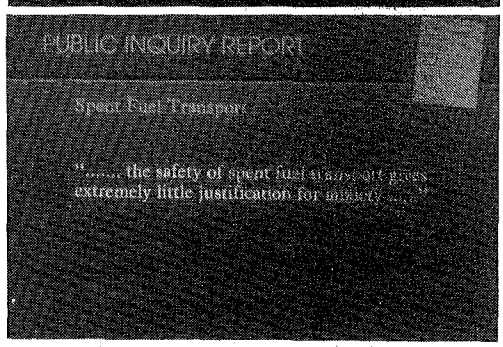
(22) Sir Frank Layfield concludes that there are no other safety problems caused indirectly by the operation of Sizewell 'B', such as radioactive waste management, that would give rise to intolerable
(23) risks. Further, although many objectors were concerned with the transport of spent fuel for reprocessing at Sellafield, he dismissed these fears as unfounded. He concluded that 'the safety of spent fuel transport gives extremely little justification for anxiety'.



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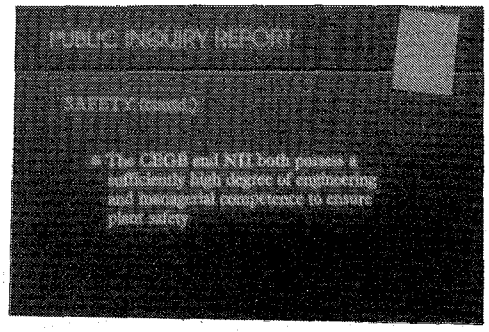
(24) In arriving at these conclusions on safety the Inspector stressed that he placed a great deal of reliance on the engineering and management competence of the CEGB and the NII.



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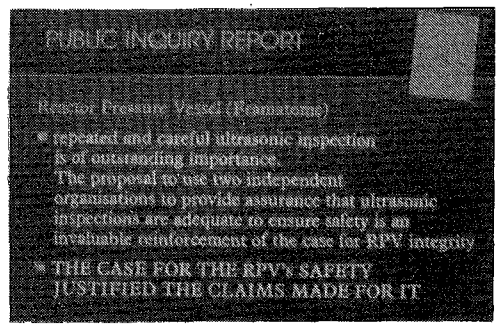
THE REACTOR PRESSURE VESSEL

(25) On Sizewell 'B' it was recognised at the outset that the integrity of the Reactor Pressure Vessel was of fundamental importance to safety and the engineering standards employed in its design have necessarily been of the highest order. Significant developments undertaken in the UK included the development of pressure vessel steels with improved mechanical properties; the use of large forgings as an alternative to plate; improvements in stress analysis and fracture mechanics; and developments in non-destructive testing — particularly ultrasonic inspection. The specification and inspection requirements set by the CEGB for the forgings and the vessel fabrication for the Sizewell 'B' pressure vessel were formidable, but the challenge has been met. This approach of using perfect forgings; inspection; and then double inspection, to ensure that we have a safe vessel has met with the approval of Sir Frank Layfield who concluded that, 'Repeated and careful ultrasonic inspection is of outstanding importance. The proposal to use two independent organisations to provide assurance that ultrasonic inspections are adequate to ensure safety is an invaluable reinforcement of the case for RPV integrity'. His overall conclusion that 'The case for the RPV's safety justified the claims made for it' was very gratifying.



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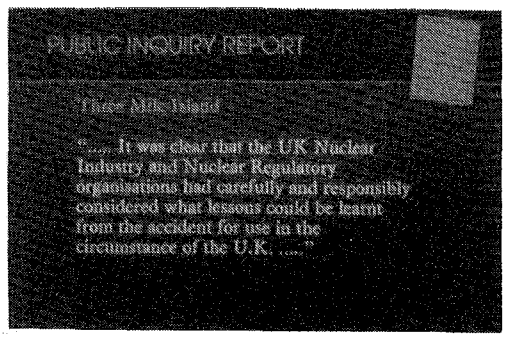
HUMAN FACTORS

At the Public Inquiry one of the most widely held anxieties expressed by the objectors was the possibility that accidents might be caused or aggravated by human error. They argued that human error had contributed to many past accidents at nuclear power stations, including the Three Mile Island accident, in which a fault caused by human error in maintenance was incorrectly diagnosed and then exacerbated by incorrect operator action (**26**). However, the CEGB evidence on this matter convinced the Inspector that 'the UK Nuclear Industry and Nuclear Regulatory organisations had carefully and responsibly considered what lessons could be learnt from the accident'.



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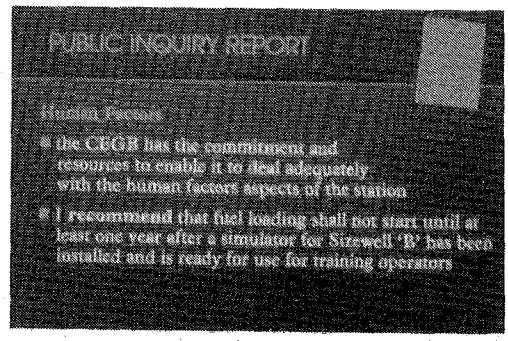
In the UK our safety practices recognise that human factors enter into almost every aspect of the design, construction and operation of a nuclear power station, and on Sizewell 'B' human factors are systematically addressed to ensure that human errors are taken fully into account in the safety of the station. The Sizewell 'B' design team includes ergonomics experts and particular emphasis is placed on the design of the Main Control Room and the development of the very best operating instructions.

(27) The Inspector concluded that: '— the CEGB has the commitment and resources to enable it to deal adequately with the human factors aspects of the station;'.



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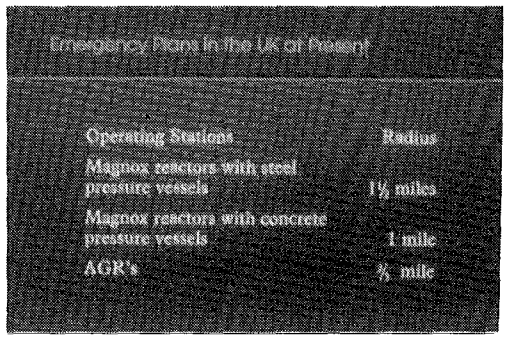
The CEGB places great emphasis on operator training, and relevant to TMI, we emphasise the importance of the operator understanding how the plant works — not merely following rules and instructions. This is essential in dealing with unexpected situations. Simulators play an important role in the Board's operator training and for Sizewell 'B' we plan to commission the simulator six months before the control room is finalised and two years before fuel is loaded into the reactor. The Inspector gave full endorsement of this approach and commented on the CEGB's good record in the selection, training and supervision of operators. He made it a condition of the consent that fuel loading would not start until at least one year after the simulator for Sizewell 'B' had been installed and was ready for use for training operators.

EMERGENCY PLANS

(28) Following the Chernobyl accident there has been a heightened interest in emergency plans for nuclear power stations, and I believe the Inspector's views on the plans for Sizewell 'B' are of some interest. I will begin by reminding you of the present arrangement on CEGB stations. As one of the conditions of the Site Licence the CEGB has to have an emergency plan, which is approved by the NII, drawn up for each of its nuclear stations. For the Magnox reactors with steel pressure vessels the emergency plans extend to a radius of 1½ miles. For Magnox reactors with a concrete pressure vessel the emergency plans extend to a radius of 1 mile. The emergency plans for the AGR's extend to a radius of ⅔ mile.



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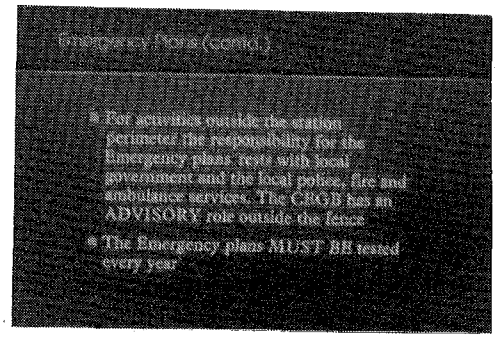
In the case of Sizewell even on pessimistic assumptions, there is no design based accident which would require evacuation of any permanent resident. However, as Sizewell 'B' shares the site with a Magnox station we propose to use the Sizewell 'A' emergency plans, with modifications for both stations. The plan therefore assumes a possible evacuation to the distance of 1½ miles, but can be readily extended to deal with a 'beyond design base accident' should it occur.



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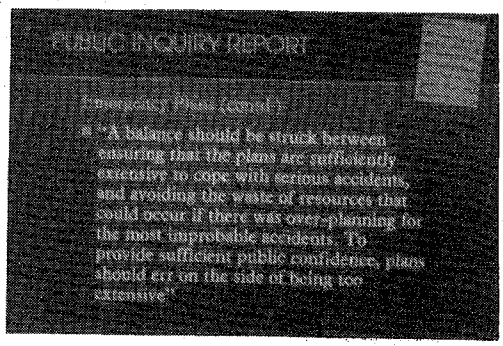
(29) In the event of an emergency the CEGB remains fully responsible for the nuclear site and for bringing the incident under control and ensuring the restoration of safe conditions at the site. The emergency plan would be initiated by the power station manager. Outside the site boundary the responsibility for the emergency plans would rest with local government and the local police, fire, and ambulance services. The role of the CEGB would be to advise them on what immediate steps should be taken to protect the public. The emergency would be controlled from an Operational Support Centre located remote from the power station. The emergency plan is rehearsed by an annual emergency exercise at each of the CEGB's nuclear power stations.



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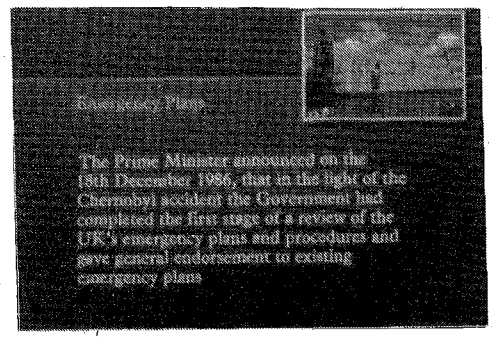
(30) In his report Sir Frank Layfield gave general endorsement of the Board's emergency plans and recommended that 'A balance should be struck between ensuring that the plans are sufficiently extensive to cope with serious accidents, and avoiding the waste of resources that could occur if there was over-planning for the most improbable accidents. To provide sufficient public confidence, plans should err on the side of being too extensive'.

(31) Following the Chernobyl accident the UK Government instigated a review of the arrangements for dealing with nuclear emergencies, and the Prime Minister on 18 December announced that the first stage of the review had been completed and that the existing plans continue to provide a valid basis for a response to any nuclear accident in the UK.



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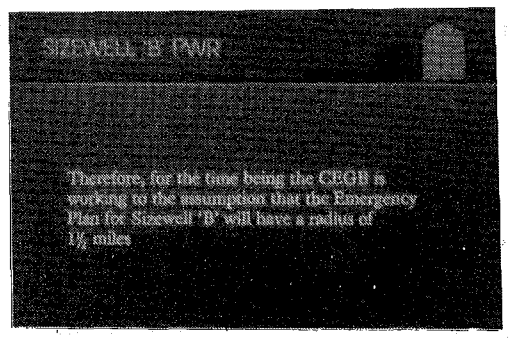
(32) Therefore the CEGB is working on the assumption that the emergency plan for Sizewell 'B' will be for a 1½ mile radius, with the ability to extend the evacuation distance to deal with an accident beyond the design basis should it occur.



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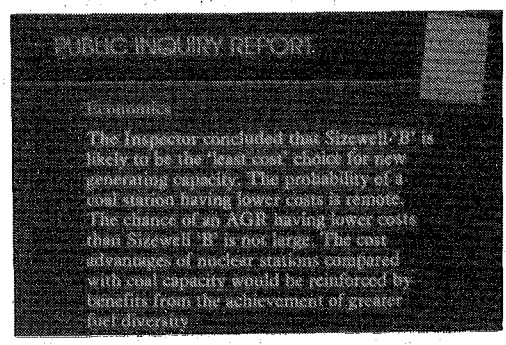
ECONOMICS

(33) The examination of the economic case for Sizewell 'B' at the Public Inquiry was wide ranging and was made difficult by the need to justify our projections of future development and trends well into the twenty-first century. Such forecasts cannot be precise and are necessarily subject to considerable uncertainty. Nevertheless Sir Frank Layfield was satisfied with the economic case that we made at the Inquiry. He concluded that:

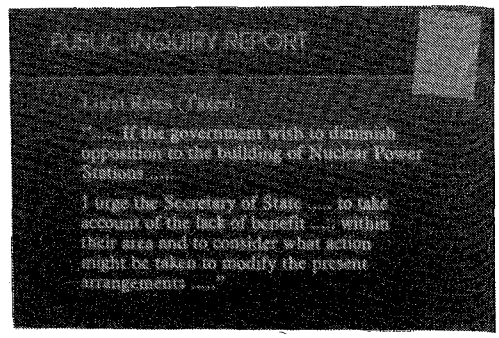


33

> 'Sizewell 'B' is likely to be the least cost choice for new generating capacity. The probability of a coal station having lower costs is remote. The chance of an AGR having lower costs than Sizewell 'B' is not large. The cost advantages of nuclear stations compared with coal capacity would be reinforced by benefits from the achievement of greater fuel diversity'.

It is worth pointing out that the economic case for Sizewell 'B' is based on a capital cost which includes a major part of the costs of launching the PWR in the UK. For follow-on stations many of these costs would not be incurred and the economics would benefit accordingly.

34) Finally, a local economic issue which was raised at the Inquiry. In the UK when a utility pays local taxes, the benefit goes to Central Government and the local people get no financial benefit. Sir Frank Layfield considered this grossly unfair. He commented '. . . If the Government wish to diminish opposition to the building of Nuclear Power Stations . . . I urge the Secretary of State . . . to take account of the lack of benefit . . . within their area and to consider what actions might be taken to modify the present arrangements . . .'



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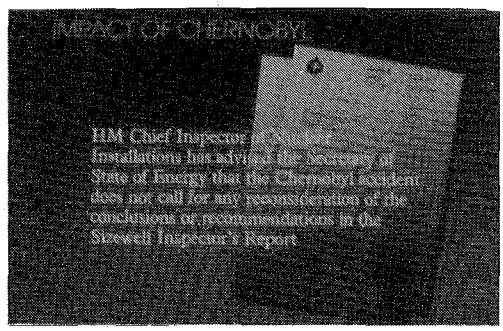
IMPACT OF CHERNOBYL

(35) The decision to proceed with Sizewell 'B' was made very much more difficult by the Chernobyl accident which occurred less than twelve months before the UK Government gave consent for the project to go ahead. However, due to the full and frank presentations made by the Russians on what had happened at Chernobyl we now know why the accident happened, how it happened, and how it should have been prevented. This allowed the Chief Inspector of Nuclear Installations to give the UK Government the assurance that:

> 'the Chernobyl accident does not call for any reconsideration of the conclusions or recommendations in the Sizewell Inspector's Report'.



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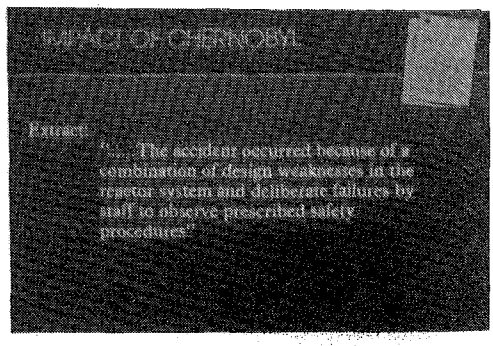
The reasons given by the NII in support of this advise were:

(36) the accident occurred because of a combination of design weaknesses in the reactor system and deliberate failures of staff to observe prescribed safety procedures.



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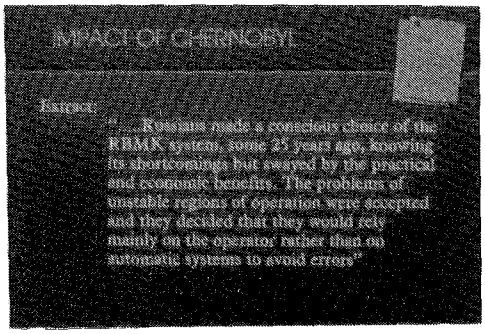
(37) The Russians made a conscious choice of the RBMK system, some 25 years ago, knowing its shortcomings but swayed by the practical and economic benefits. The problems of unstable regions of operation were accepted and they decided that they would rely mainly on the operator rather than on automatic systems to avoid errors.



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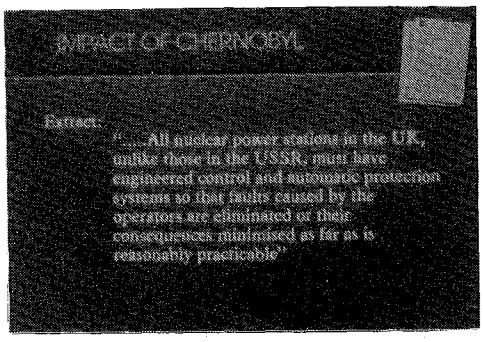
(38) All nuclear power stations in the UK, unlike those in the USSR, must have engineered control and automatic protection systems so that faults caused by the operators are eliminated or their consequences minimised as far as is reasonably practicable.



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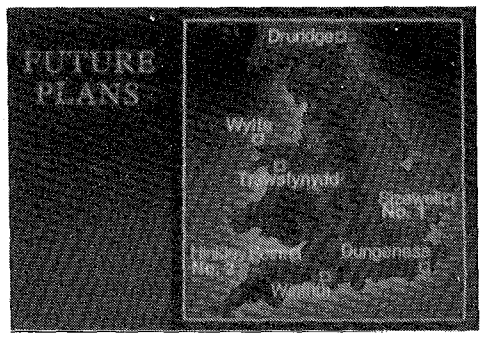
FUTURE PLANS

(39) The UK Governments' decision to give the go-ahead for Sizewell 'B' is important as it paves the way for the further development of nuclear energy in Britain. Our immediate priority is to launch the construction of Sizewell and build it to time and cost. Later this year we will be making a planning application for a follow-on PWR power station at Hinkley Point in South West England, and for two coal fired stations. Depending on growth in electricity demand, we plan to build further PWRs in subsequent years. The nuclear construction programme will be partnered by a parallel coal-fired station programme.



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Each time we apply to build a nuclear power station we have to hold a Public Inquiry, but because the discussions of Sizewell 'B' were so detailed and extensive we have good hopes that future inquiries will be shorter. We hope they will mostly concentrate on matters which are of interest to local people. Therefore we see the decision on Sizewell 'B' as an extremely important step in the evolution of nuclear policy in the United Kingdom.

THE EVOLVING STRATEGY FOR NUCLEAR POWER DEVELOPMENT IN INDIA

BY

Dr.Raja Ramanna*

I consider it a great honour to my country and myself for being invited to address this distinguished audience at the 20th Annual Conference of the Japanese Atomic Industrial Forum (JAIF). It is appropriate that our participation in this conference comes at a time when the installed nuclear power generation capacity in Japan has now gone upto being the fourth largest in the world. As this session is expected to focus primarily on the role of nuclear energy towards the 21st century, I have chosen to share with you, some of my thoughts on how the strategy for nuclear power development in India has evolved over the years, and the directions it is expected to take, as we approach the 21st century.

HISTORY OF NUCLEAR SCIENCES IN INDIA:

While organised studies in nuclear sciences began in India in 1945 with the establishment of the Tata Institute of Fundamental Research (TIFR), the formalisation of the country's policy on nuclear energy was done by the Atomic Energy Act of 1948 which established the Atomic Energy Commission. The prime objective of our programme as defined in this act, is valid even today, which is: "the development, control and use of atomic energy for peaceful purposes, namely generation of electricity, applications in research, agriculture, industry, etc; the establishment of appropriate facilities, infrastructure, and manpower to support the programme, and; to make the country totally self-reliantg in this field".

Looking back over the past 39 odd years, I feel that one can in all modesty, claim that the above objectives have been attained to a very large degree. The successful commissioning of the two 235 MWe power reactors and a Fast Breeder Test Reactor (FBTR) at Kalpakkam and the research

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* Till recently Chairman, Atomic Energy Commission, India.

reactor DHRUVA at Trombay, are in a way, landmarks in crossing the first phase of our strategy towards self-reliance in the field of nuclear energy.

NUCLEAR ENERGY AS A SOURCE FOR POWER GENERATION

As early as in the 1950s, India's political and scientific leadership recognised the crucial role that nuclear energy could play in the industrial and economic growth of a developing country. Being aware that electric power5 generation would be the primary tool for this purpose, they felt that the potential of nuclear energy cannot be left untapped, more so given the large population and the limited availability of natural fossil fuel reserves. Ours is a developing country. Per capita electricity consumption is still very low. The demand for electrical energy is therefore expected to be on the rise in coming years, as can be seen from Fig.1. Although we have some quantity of coal, and a major share of our current electricity production is based on coal, they envisaged the need to develop nuclear power as an additional source for bulk electricity production to meet the increasing electricity generation demands and ensure energy independence in the next century when coal resources start depleting. They were also aware that this was a field into which only a few developed countries alone had ventured. Given the limited resources of a developing country, India first gave priority to establishing a strong indigenous R & D base by setting up the multi-disciplinary centre for R & D at Trombay, which is today universally known as the Bhabha Atomic Research Centre (BARC). This centre has been and continues to be the nucleus for carrying R & D in nuclear energy in the country. That such an approach was successful is proved by the fact that India has now the complete expertise covering the entire nuclear fuel cycle, that is; from mining of uranium ores, manufacturing nuclear fuel, producing heavy water, designing and commissioning nuclear power stations, to the reprocessing of the spent fuel and finally disposing of radioactive nuclear wastes. Today, the Department of Atomic Energy with over thirty-two constituent units and an annual budget exceeding $ 1 billion, is poised to take up a large nuclear power programme that is expected to be implemented by the early part of the next century.

STRATEGY ADOPTED FOR THE INDIAN NUCLEAR POWER PROGRAMME

The strategy for nuclear power development is based on availability of uranium resources within the country and the prospect of tapping the abundant thorium reserves in the long run.

The farsighted decision over two decades back, to opt for the natural uranium fuelled Pressurised Heavy Water type of Reactors (PHWR) instead of the then popular Boiling Water/Pressurised Water Reactors (BWR/PWR) using enriched uranium, has probably contributed most to the self-reliance which India has acquired in the field of nuclear power generation. The decision was an optimal one, in that, it took into account the objective of self-reliance and the country's financial limitations. The PHWR system has the advantages of:

- Possibility of a larger number of Indian sources for the supply of equipment/materials,
- Obviating the need for imported enriched uranium fuel,,
- Built-in safety features,
- Smaller requirements of uranium per MWe installed, and
- Higher plutonium production per MWe installed,
- The prospect of switching over from PHWRs for which the available natural Uranium reserves are limited, to Fast Breeder Power Reactors (FBRs) which could tap the abundant Thorium reserves available within the country.

PROGRESS OF THE NUCLEAR POWER PROGRAMME

Recognising that self-reliance would take some time, it was decided to order a BWR to start with, so that experience could be gained in operating a nuclear power station in the Indian electrical grid. It was only as an introduction to nuclear power that the Tarapur Station comprising of two 210 MWe reactors was built by a US firm on a turnkey basis. Since commissioning in 1969, these reactors have operated satisfactorily and have been supplying the cheapest non-hydel electric power in the country.

Simultaneously, work was also undertaken on two 220 MWe, PHWRs at Rajasthan. Most of the equipment for the first unit was imported from Canada. The first unit was commissioned in 1972 and commenced commercial

operations from December 1973. During its initial years of operation, apart from several teething problems, its performance was severely affected by the voltage and the frequency fluctuations in the grid. In 1982, a very difficult technical problem arose on one of the end-shields, which necessitated the unit to be shutdown. The reactor side face of one end shield has developed cracks. This material is currently in embrittled state on account of fast neutron irradiation. Repair works of the kind never undertaken anywhere in the world are in progress. The cracks are being mechanically sealed with the help of remote gadgets. In this respect, the first unit at Rajasthan should basically be considered as an imported prototype reactor, and the lessons learnt from it have been invaluable on our road to self-sufficiency in the design and operation of subsequent power reactors. The second unit at Rajasthan incorporated progressively a significant indigenous content. Due to export restrictions placed by some countries, a much larger indigenous content became inevitable and this could be achieved only at the expense of a slippage in its time schedule. After commissioning in October 1980, the unit commenced commercial operation in April 1981. Since then its performance has been improving every year.

As I mentioned earlier, the commissioning of the first 235 MWe unit at Kalpakkam (near Madras) during 1983 and the second unit during 1985 marks the culmination of our efforts to becoming self-reliant in the field of nuclear power (see Fig.2). Though basically the two reactors at Kalpakkam are like the units at Rajasthan, several significant changes to improve their performance and safety were incorporated. Apart from some technical problems faced last year, these units have performed very well till now, thereby demonstrating the commercial viability of the indigenously developed technology for 235 MWe PHWRs.

In order to be able to speed up installation of the reactor units, their design has been standardised. The standardised design takes into account seismic design requirements and has design features which would permit easy scaleup to larger unit sizes. Six more such units are under construction - two at Narora in U.P., two at Kakrapara in Gujarat and two more units at Rajasthan.

We are the only country still building a series of small power reactors in the 200 - 235 MWe range. At the time these units were introduced, they were the largest in our grid and we had to face some problems on account of grid fluctuations. Even currently these units are considered economically competitive and are producing relatively cheaper electricity. A comparison of costs of power from nuclear and thermal units is given in Fig.3. Design of a larger size unit (500 MWe) has been taken up and we are now well set to start constructing a series of 500 MWe units to augment the nuclear electricity production. 500 MWe unit is still considered to be the optimum size for our grids till the end of this century. Fig.4 indicates the programme of installation of power reactors currently under implementation.

The PHWR system has seen continuing evolution for improvements in its safety characteristics. A fully developed containment with passive vapour suppression pool for absorbing energy released into the containment during an accident has been developed for these reactors.

Our PHWRs have a number of other unique safety features. Some of these are availability of low temperature moderator in the reactor core with capability of providing alternate heat sink in crisis, locations of reactor shutdown system in low pressure regions, minimum excess reactivity on account of availability of on-power refuelling, low volumetric power density within the reactor core and availability of two independent and diverse shutdown systems. A review subsequent to Chernobyl accident of PHWR reactor system has concluded that a severe accident like Chernobyl cannot take place with our reactor system.

PROGRESS IN SUPPORTING AREAS OF THE NUCLEAR POWER PROGRAMME:

Apart from mastering the technology of "designing to commissioning" PHWRs, considerable progress was concurrently achieved in other areas supporting this technology. These include: uranium mining, fuel fabrication, heavy water production, spent fuel reprocessing and waste management.

The exploration for uranium was initiated over three decades back since the basic pre-requisite for any self-sufficient nuclear power programme is the availability of uranium. Initially, most of the exploration work of the Atomic Minerals Division was confined to the Singhbhum District of Bihar, but has now spread to all parts of the country. During the last three decades, various ore reserves totalling over 73,000 tonnes of U308 in grades ranging from 0.015% to 0.070% have been identified. The first mine and mill was set up during 1967 at Jaduguda, by the Uranium Corporation of India Ltd., and this is at present supplying the Uranium concentrates needed for fabricating fuel for our power reactors at Rajasthan, Kalpakkam and Narora. Work on another mine at Bhatin is in progress and plants to recover uranium from the copper tailings have been commissioned at Surda and Rakha. Despite the fact that India is not endowed with high grade uranium deposits, it has been possible to locate, mine and process even the low grade ores on a commercial scale.

Even in the early stages of the nuclear programme, indigenous capabilities were established in the crucial area of fuel fabrication. Today the Nuclear Fuel Complex at Hyderabad supplies the fabricated fuel and zircaloy components required by all the operating nuclear power stations. The expertise acquired in this field is attested by the extremely high quality production that has been maintained with respect to fabrication of all nuclear fuel and zircaloy components.

During the 1970s, it was also decided to set up scaled up versions of pilot heavy water plants that could be linked to the fertilizer plants at Baroda, Tuticorin and Talcher. The first two plants faced extended teething problems but their performances during the past two years have shown significant improvement and have stabilized to a large extent. Simultaneously, work was also initiated in developing indigenous technology for the Hydrogen-Sulphide process, and a large plant based on this process was successfully commissioned at Kota. This plant has also operated satisfactorily and we expect its production to stabilise during the current year. Based on these experiences which enabled India to have the unique distinction in possesssing expertise in all available heavy water production technologies,

work on setting up three more plants commenced during the past few years. These are at Thal-Vaishet, Manuguru & Hazira. While the first has already been commissioned and is now producing heavy water, the other two are expected to come on stream during 1988 & 1990 respectively. Consequently, one does not forsee heavy water availability to ever be a constraint on our nuclear power programme.

Reprocessing and Waste Management are the last but vital stages of a nuclear fuel cycle and here again the technology is available only with a handful of countries. Years of sustained effort by our scientists and engineers has resulted in the complete indigenisation of these operations as well. Spent fuel reprocessing provides the important link to the fast breder power reactor programme and optimises the spent fuel storage capacity at various power reactor sites. An indigenously designed plant for reprocessing spent fuel from our research reactors was built at Trombay as early as 1964. This unit has recently been refurnished and expanded. Based on this experience a large plant for reprocessing power reactor fuel was constructed at Tarapur and this is at present reprocessing the spent fuel from the Rajasthan and Kalpakkam nuclear power stations. Construction work on another 100 tonnes per year plant at Kalpakkam has commenced and it is expected to be operational around 1990.

Protection of the environment has always been recognised as an essential feature by the world's nuclear industry and it is in this connection radioactive waste management has also received high priority from the very inception of our nuclear programme. Work was started in all three areas of waste management: disposing of low, intermediate and high-level radioactive wastes. For low and intermediate level wastes, technology developed for their disposal is already in use at various nuclear facilities. All the stringent stipulations for environmental protection are being met at these locations. For the management of high-level radioactive waste, the concepts generally accepted the world over are:

- Immobilisation of thewaste in appropriate matrices (vitrification)
- Interim on-site retrievable storage of solidified waste for about 25 years in a near-surface facility to allow dissipation of the decay heat, and
- Final disposal of solidified wastes in deep geological formations specifically selected for the purpose.

The first stage of providing interim storage facilities for a Waste Immobilisation Plant has been completed at Tarapur. Efforts are also being directed to establishing an adequate degree of confidence in deep geological formations. Final repositories for solidified high-level wastes are expected to be established by the turn of the century. Though the complexity of managing high-level wastes is undoubtedly high, it should be kept in mind that its volume is very small. After all the entire quantity of high-level waste resulting from one year's operation of a 4 x 235 MWe nuclear power station will occupy a volume of just 4 cubic metres.

A LONG TERM PROGRAMME FOR SETTING UP PHWRs

The experience acquired over a period of 30 years gave us the confidence to step up our nuclear power programme so that it could contribute significantly towards the country's growing demand for electricity. It was with this aim we embarked on a programme to have atleast 10,000 MWe of nuclear power generation capacity by the year 2000. Due to the chronic problem of paucity of financial resources, there has been a slight slippage on our original schedule, but our target is still valid. Planners in our country have realised that our reserves of fossil fuels are limited and cannot meet the growing demand for energy. Projections made a few years back on the expected demand for energy during the beginning of the twenty-first century have already been revised upwards. It is estimated that India will need to have an installed capacity of atleast 1,40,000 to 1,60,000 MWe by that period and fossil fuel and hydel power can in no way match this demand. It is in this respect that the country's 10,000 MWe PHWR programme holds out the promise for taking it to the next stage of setting up Fast Breeder Power Reactors (FBRs) which can meet the entire energy needs of the country during the later years of the 21st century.

ROLE OF NUCLEAR ENERGY IN INDIA DURING THE 21ST CENTURY

With this background it is now possible for India to enter the second and third phase of our nuclear energy programme, during the 21st century. The operating PHWRs during the beginning of this period will be in a position to yield Plutonium byproduct, which can fuel the next generation of Fast

Breeder power reactors. The potential for this is estimated at about 350,000 MWe. A start can also be made on irradiating Thorium in these reactors so that the next generation of Thorium based FBRs can also come into operation. India's Thorium reserves, which are one of the world's largest, are considered so huge that they will be capable of supporting a nuclear power programme of the order of 1000 Giga watts thereby making it feasible for the country to be practically independent of fossil fuels for electric power generation. In this respect the successful commissioning of the FBTR at Kalpakkam marks a major step in this direction. This reactor uses a unique combination for its fuel - a uranium-plutonium carbide mix - and work on this has given our scientists and engineers sufficient experience to commence design of a 500 MWe Prototype Fast Breeder Power Reactor, which I expect to come into operation during the early years of the 21st century.

CONCLUSION

As a country which has to depend on imports of fossil fuel to meet its energy needs, Japan has embarked on a large nuclear power programme so as to be self-reliant as regards power generation. Despite misguided or sometimes biased views expressed occasionally in certain quarters, the general public in our country is gradually realising the importance of gene rating more electricity and the crucial role that nuclear energy can play in this direction. I often point out the example of Japan, which despite being the sole country in the world to have gone through the horrors of an atomic bomb; and despite being a densely populated country in one of the world's earthquake prone areas; has consciously gone in for a large nuclear power programme. With an installed nuclear power generation capacity that is nearly twenty times of that we have in India, I am sure we can learn a lot from our experience. On this note, I will conclude my talk by once again thanking JAIF for having given me the opportunity to address this distinguished audience..

Fig 1

PAST AND PROJECTED GROWTH OF ELECTRIC POWER GENERATION CAPACITY AND ACTUAL GENERATION/CONSUMPTION OF ELECTRIC POWER IN INDIA

	1950-51	1983-84 (Estimated)
Installed Capacity (MWe)	2300	40,000
Electricity Generation (Billion KWHrs.)	5.1	140.0
Per Capita Electricity Consumption (KWHrs.)	18	200

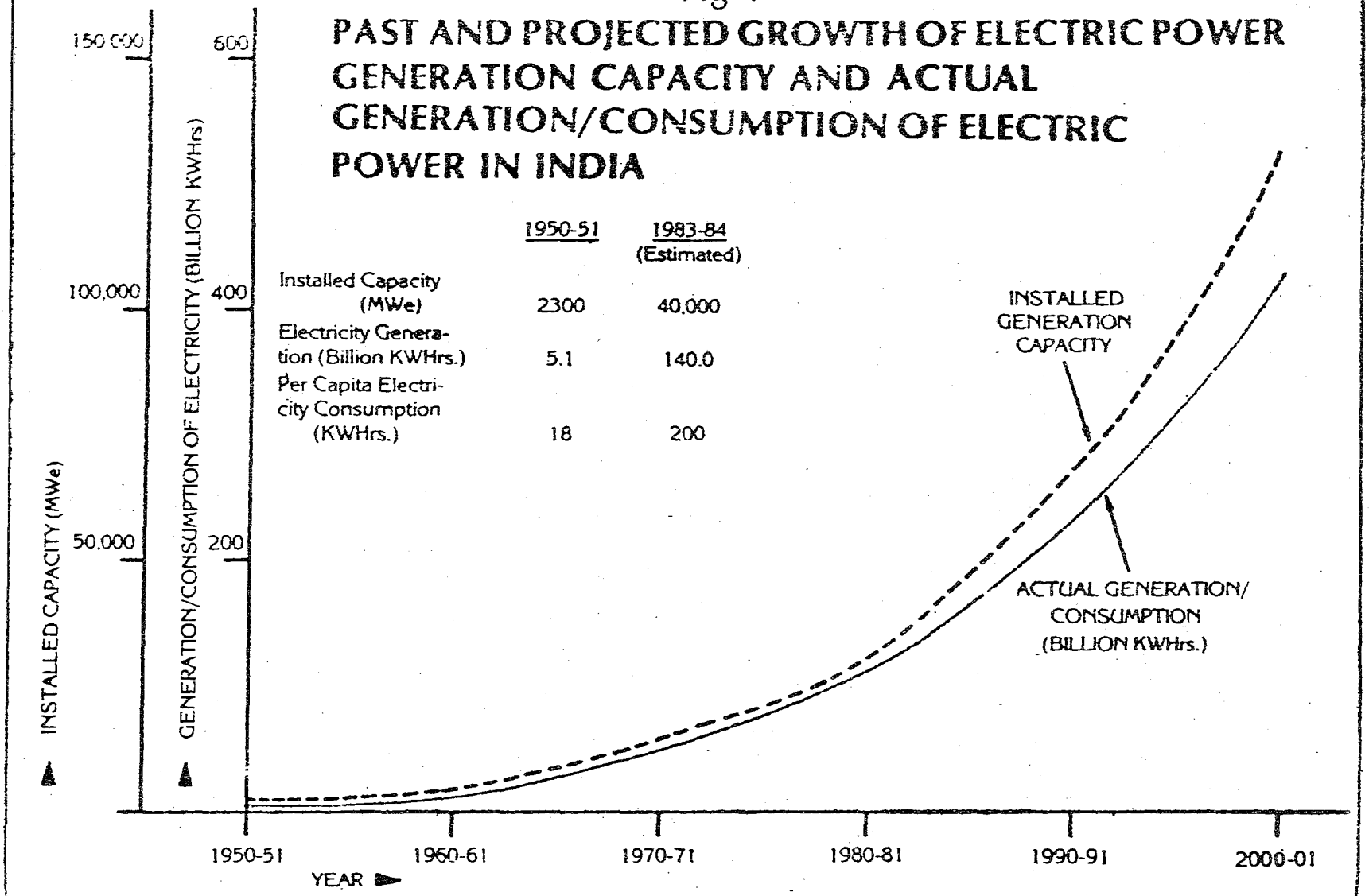

Figure - 2

Approach to self reliance
in Power Reactor Technology

Reactor	Indigenous participation
TAPS-1	Turnkey
TAPS-2	Turnkey
RAPS-1	54%
RAPS-2	75%
MAPS	88%
NAPP	90%
Subsequent projects	Above 90%

Figure - 3

RESULTS OF STUDIES ON COMPARATIVE COSTS OF COAL AND NUCLEAR UNITS COMMISSIONED IN 1983

	MAPS Unit-1 235 MWe	Singrauli S.T.P.S. 3x200MWe	
		As located at pithead	Notionally located 800 Kms from pithead
Capital cost (Rs. lakhs)	11584	30375	
Capital cost (Rs./KW)	4930	5060	
Coal cost (Rs./Te)		233	376
Unit Energy Price (p/kwh):			
(a) IDC @ 7%, ROI @ 12%			
(i) Generation 5500 Kwh/KW (Capacity factor 62.8%)	41.05 45.50* 48.06**	40.83	49.28
(ii) Generation 6570 Kwh/KW (Capacity factor 75%)	35.16 38.89* 42.16**	37.14	45.59
(b) IDC @ 7%, DCF @ 12% IRR			
(i) Generation 5500 Kwh/KW (Capacity factor 62.8%)	35.89	36.11	44.56
(ii) Generation 6570 Kwh/KW (Capacity factor 75%)	30.85	33.14	41.59

* Actual gestation period and IDC at Government borrowing rates.

** Actual gestation period and IDC @ 7%

MAPS: MADRAS ATOMIC POWER STATION
SINGRAULI STPS: SINGRAULI SUPER THERMAL POWER STATION
Rs. RUPEES LAKH: 10^5
P: Paise; one hundredth of a Rupee.

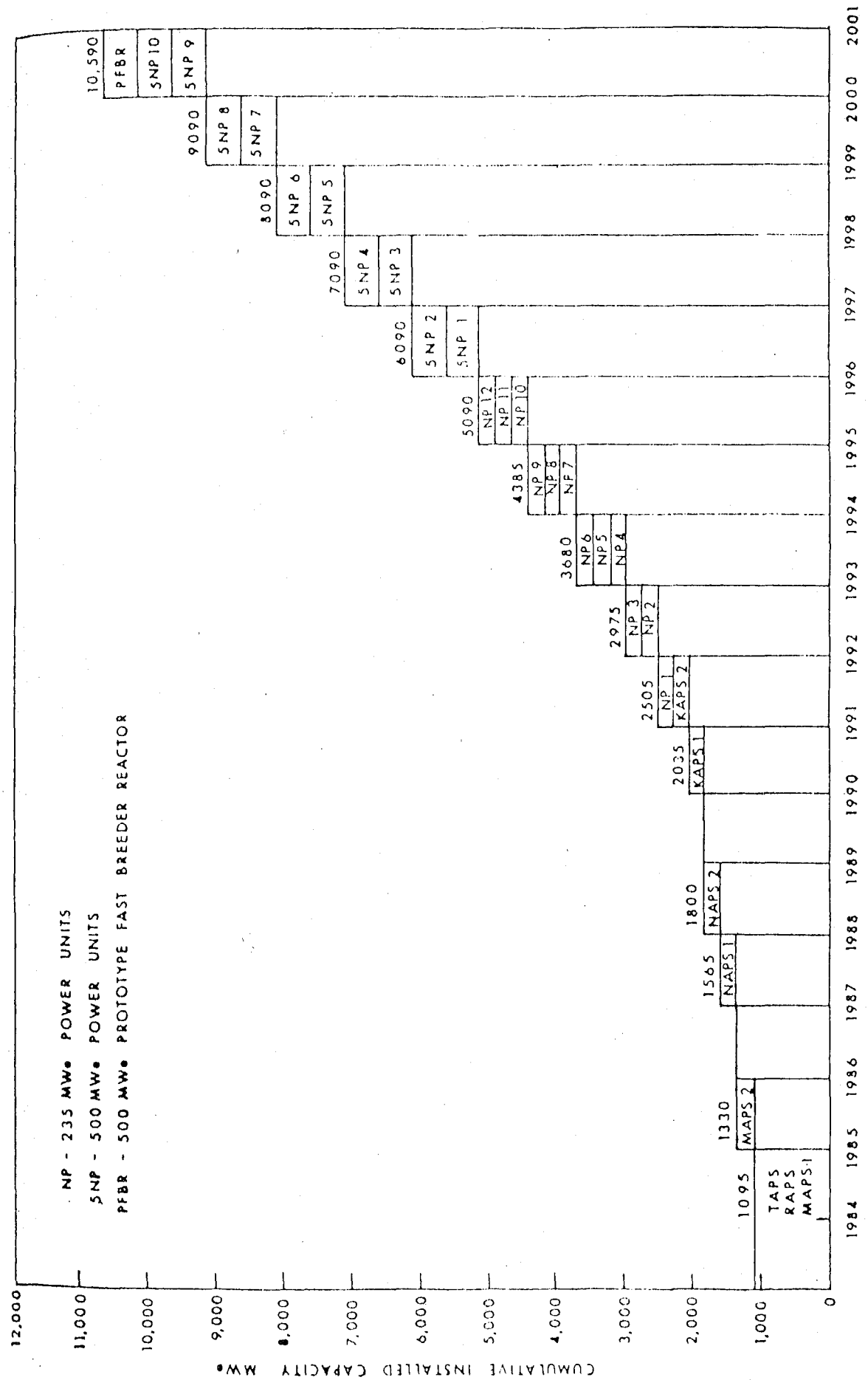

FIG.-4 NUCLEAR POWER PROFILE.

日本における原子力開発の展望
―原子力開発推進のための課題提起―

東京電力株式会社
取締役会長　平岩　外四

1．はじめに

本日は，世界各国からの有力な原子力関係者の方々の参加を得て開かれました第20回原産年次大会において，関係者の一人としてお話する機会を与えられたことを，大変光栄に思っている次第です。

さて，今回のセッションの統一テーマは「21世紀に向けての原子力の役割」ということですが，私は「日本における原子力開発の展望」という主題を与えられていますので，現在，官学民をあげて策定中の原子力長期計画に関連して，その取り纏めに関係しているものの立場から，推進のための課題を中心に述べてみたいと思います。

2．原子力開発推進の世界的意義

昨年のチェルノブイル原子力発電所事故は，当事国たるソ連はもとより，世界各国の原子力発電計画に大きな打撃を与え，さらに最近の化石燃料需給の緩和と価格低落もあって，いくつかの国々では原子力開発を後退させる動きとなってあらわれています。

原子力の利用が，万全な安全性を大前提としていることは，いまさら申しあげるまでもありません。しかし，ＴＭＩ，チェルノブイルと不幸な現実に直面してきた原子力関係者としては，事実を謙虚に受けとめると同時に，安全性，信頼性の確保に万全を期するのはもちろんのこと，原子力の役割，意義について改めて再確認し，将来に向けた原子力開発の方向と進め方を示すことが，きわめて重要であります。

私がここであえて原子力エネルギー利用の意義，必要性を問い直そうとするの

は，幾多の障害，制約があっても，それを乗り越えていくことが，真に人類にとって必要不可欠な道であるならば，われわれはあらゆる努力を通じて，それに挑戦し，課題の解決を図って，原子力に対する理解の促進と不安感の除去による国民の信頼回復を実現せねばならないと思うからです。

よく言われることですが，21世紀に向けた人類共通の課題として，食糧とエネルギーの問題が指摘されます。

これまで人類は，限られた資源をめぐって国家間の対立，摩擦，そして時には争いまで引き起こしてきましたが，今日から将来に向けても，エネルギー資源の利用機会をめぐる幾多の問題は避け難いと言えます。

エネルギー資源が政治性の高い商品といわれ，市場経済の原則を越えて，その価格が大きく揺れ動くことがあるのは，先の石油ショック時にみられた歴史的事実であり，いわゆるセキュリティーの問題として各国の重大な関心事となっています。

したがって，21世紀に向けて，人類がより一層の発展を遂げていこうとするならば，エネルギー資源の確保をめぐる対立を，長期的に解決していくことが肝要です。

たまたま今日は，世界経済の停滞に助けられて，化石系燃料を中心とする需給緩和の時代にありますが，いまのような時にこそ，将来に備えた着実な方策の積み重ねがなにより大切です。

エネルギー問題を在来の資源論的な枠組の中だけで解決していこうとすれば，いたずらに対立と摩擦を激化することは否めません。

そこで，人類の英知によって創り出されたものが，技術により生み出される新しいエネルギー資源であり，その典型的なものが原子力であると言えます。こうした技術エネルギーとしての原子力の登場によって，先進工業諸国は持てる技術力を駆使して，原子力利用への道を切り拓くことが可能となりました。そして，世界の各国はそれぞれの自己責任と努力によって，出来る限りエネルギー需給の自立化を図っていくことが，21世紀へ向けての人類共通の問題であるエネルギー問題を解決することとなり，また国際的責務となってきています。

ひるがえって日本をみると，自由世界第二の巨大なエネルギー消費国であり，しかもエネルギー資源賦存量に乏しい国であるため，エネルギー需給充足の面で国際的責任を果していこうとすれば，われわれは必然的に原子力への道を進まざるをえないわけです。

二度にわたる石油ショックを通じて，原子力は，石油代替エネルギーとしての現実性，環境への影響，資源賦存量，輸送，備蓄等の各面で優れた特性を持っていることが明らかになりましたが，化石燃料が，化学原料等としての多様なニーズに対応する付加価値の高い使い方ができることを考えると，発電用エネルギー資源としての原子力の適切な規模での活用は，人類にとって将来欠くことの出来ない不可欠な道であると言わなくてはなりません。

現在，原子力に頼らなくても他のエネルギー資源を自国内に保有する国では，差し当っては原子力計画の一時的後退の道を選択していますが，人類発展の世界的，長期的見地からみると，発展途上国での飛躍的なエネルギー需要の増大とも相まって，原子力利用の必要性に立ち帰ってくることは必定です。

そうした意味で，今日，日本が自らの置かれた立場と必要性に照らして，原子力開発の推進に先駆的な役割を果していくことは，日本にとってのみならず世界の将来にとって，非常に有意義なことであると考えます。そのためには，原子力利用における安全性の確保，信頼性，経済性の向上が必要であり，同時に，原子力の開発推進に対する社会的信頼感，コンセンサスの形成がとりわけ重要です。

3．日本における原子力安全確保への取り組み

われわれは，日本における原子力発電を推進するに当り，開発の当初から安全確保は基本的な大前提だと考えてきました。原子力技術は基本的に安全性・信頼性の技術であり，原子力の経済は安全性・信頼性の経済であると言われています。原子力は，安全性・信頼性の下で技術開発と経済性の調和を図って育てられてきた唯一の産業と言えます。われわれの経験してきた軽水炉原子力発電は，まさにこの考えを具現したものであり，その計画，設置，運転のすべての段階で安全性・信頼性が論じられ，また研究・開発設計の重点は常に安全の問題に置かれてきました。

不具合を起こさないこと，起きた場合にも事故にまでは拡大させないこと，事故になっても放射性物質を閉じ込めて環境に出さないことは，基本中の基本と言えます。言いかえれば，何かが起きたとき，核反応を止める，冷却する，閉じこめる，ということが原子力の安全確保の基本的三原則です。われわれは，このように固有の安全性の確保，ヒューマン・エラーの発生にも留意した多重防護，万

全な管理体制の確立をめざして，日本の原子力開発を進めてきました。

チェルノブイル事故は軽水炉では起きないと考えられます。しかし，とくに巨大設備，先端技術の代表である原子力の場合は，ハードの機器・設備の安全性の確保はもちろんのこと，ヒューマン・ファクターが重要な鍵になると思います。

われわれはチェルノブイル事故を他山の石とし，運転員の教育・訓練の充実，事故時対応の一層の整備などに取り組まなければなりません。私は，このように，総合的に安全を築きあげ，確保していくたゆまない努力は，原子力開発の主体である電気事業が自らの責任において高めねばならないと，決意を新たにしているところです。

また，原子力が発電用エネルギーとして適切な規模で開発されていくためには，安全性，信頼性を大前提とした上で，石油や石炭などと経済性の面で十分対抗し得るものでなければなりません。このためには，原子力発電所の建設費を下げるなど，発電所部分におけるコストダウン努力を続け，また同時に，稼動率を向上させるなどの地道な努力が必要です。それと同時に，原子力発電を，ウラン濃縮や再処理などの原子燃料サイクルを含めた一つのシステムとしてとらえ，システム全体を最適化することにより，発電コストのミニマム化をめざすことがきわめて重要であります。

４．新原子力長期計画における４つのポイント

日本の原子力開発は，これまで30年の歴史を重ねてきたなかで，今日，その発電規模は全発電量の約30％に達し，2010年～2030年には，現在の予測では，全発電量の約50～60％の大きさになると予想されます。したがって，発電のみならず，周辺の原子力燃料サイクルを含めた総合的，本格的な原子力利用の体制整備が時代の急務となってきました。

そうした背景のもとで，原子力委員会は，原子力開発利用長期計画の見直しを行っていますが，私はその専門部会の部会長として作業に携っています。現在，まとめの段階にありますので，大略をご紹介いたします。

現在進められている新長期計画の策定作業の中では，21世紀へ向けた原子力利用体系整備の第２ラウンドの課題として，次の４点が挙げられています。

第１は，ウラン資源需給の世界情勢を踏まえて，軽水炉時代の長期化は必至で

あり，この観点から，技術の一層の改善，改良による技術高度化を通じて，より高い安全性，経済性を実現すること。

また軽水炉の定着を踏まえて，発電のみならず，原子燃料サイクル全般を含めた総合的な体系整備が必要です。

第２は，原子力が人類のエネルギー問題を解決する手段として役立つためには，どうしても，プルトニウム利用の実用化をめざした技術開発に期待しなければならないということ。

日本としては，核不拡散の基本原則に立ちながら，ウラン資源の有効利用を通じて資源制約の壁を乗り越えるために，プルトニウム利用の方途を確立する必要があります。

第３は，原子力技術の研究開発に関するもの。日本は，これまで欧米で開発された技術の導入，利用に大きく依存してきました。いわゆるキャッチ・アップ型の技術開発を進めてきたわけですが，今後は，これまでの30年にわたる研究開発の進展と成果を踏まえて，わが国独自の立場から，先駆的な技術開発領域を切り拓いていかねばならないということです。それは，言葉を変えると，「創造的技術開発型」への移行をめざすということです。

第４は，世界に共通の課題であるエネルギー問題に貢献するという点から，国際的な公共財としての性格を持つといわれている，原子力技術の利用をめぐっての国際協力の推進が必要となること。

原子力の一般化，普及とともに，原子力の安全性確保と効果的利用のための努力は，国境を越えた深い相互依存関係を生み出し，いかなる国も自らの国際的責務として，積極的な協調と協力の必要性に迫られています。この領域でいかに役割を果し，貢献していくかがこれからの日本の大きな課題です。

以上のような４つの基本課題を踏まえながら，21世紀へ向けた日本の新しい長期計画策定作業が目下進められています。

将来に向けての，わが国としての炉型戦略は，「軽水炉からＦＢＲへ」という従来からの基本路線に変りはありません。現在，軽水炉は安定的に運転されており，今後もますます高度化が図られていくものと思います。

高速増殖炉については，プルトニウム利用の最も優れた炉であることから，最終的な開発目標をＦＢＲの実用化に置いていますが，原子力の本格利用は，このＦＢＲの開発実用化を通じてはじめて本来の特性が活かされるものと考えています。このため，政府ならびに産業界も一体となって，ＦＢＲの実用化を早期に実

現すべく努力しているところです。しかしながら，ＦＢＲ技術の開発見通しは当初の予定よりかなり遅れざるを得ないという状況にありますし，とくに軽水炉並の経済性を確保するという点において，まだ多くの問題を抱えています。電力需要の停滞を反映したウラン資源の需給実態等からみますと，ＦＢＲの実用化の時期は，2020年代から2030年ごろになるものと想定されます。

軽水炉と経済的に競合できるようになってはじめて，ＦＢＲの実用化が可能となるわけですが，そのためには革新的な技術を開発して設計に取り込むと同時に，安全性を実証していくことがきわめて重要になります。こうしたＦＢＲの開発に取り組んでいく一方，将来におけるＦＢＲ時代の本格到来に備えて，プルトニウム利用技術の確立，体制の整備を今から着実に進めていくことが重要だと考えています。

現行の原子力開発利用長期計画においては，ウラン資源のひっ迫が近い将来に予想されるとして，プルトニウムの利用を出来るだけ早期に実現するということになっていますが，新しい原子力開発利用長期計画においては，ただ今申し上げたとおり，原子力をめぐる四囲の情勢の変化に合わせ，若干時間的な余裕が生じていると考えています。

従って，プルトニウム利用体制の着実な整備という点においても，われわれは，ＦＢＲ実用化までの間，軽水炉およびＡＴＲにおいて一定規模のプルトニウム利用を進めることにより，プルトニウム燃料利用技術の確立を図っていくことが重要だと考えています。また，プルトニウム利用の要である再処理をはじめとして，原子燃料サイクルの確立に向けて，政府と産業界が協力して積極的に取り組んでいますが，その一環として，青森県において，再処理工場，濃縮工場および低レベル廃棄物貯蔵施設の，いわゆる原子燃料サイクル施設３点セットの建設が鋭意進められていることは，既にご承知の通りです。

ここで，原子燃料サイクルの確立に関して，重要な鍵を握っている再処理の考え方を簡単に述べてみます。

新長期計画においては，以下４つの点を基本的な視点として取り上げています。

第１は，使用済み燃料の再処理，プルトニウムの利用を国の基本戦略としていくこと。

第２は，プルトニウム利用の主体性を確立するため，国内再処理を原則とし，再処理能力を上回る使用済み燃料は適切に貯蔵・管理していくこと。

第３は，プルトニウム利用体系確立のためには，一定規模のリサイクルの早期

の実現が重要であり，青森県における年間処理量 800トンの民間再処理工場を，1995年ごろの運転開始を目途に建設を進めること。

第４は，第２民間再処理工場は，2010年を目指して，自主技術によって，より経済性の優れたものを開発していくこと。

このように，日本の原子力開発の新長期計画は，最近の原子力をめぐる四囲の情勢の変化を踏まえながら，将来におけるわが国エネルギー供給の主軸としての地位を確立すべく，プルトニウム利用を基本戦略として着実に推進していくことをめざしています。

５．原子力開発推進のための課題

日本は，これまで，原子力発電所を主体に原子力の開発利用を着実に推進してきましたが，今後は，さらに大規模化していく原子力の利用を支える原子燃料サイクルの確立に，政策の重点を注いでいく必要があると考えています。

今日，世界的にみると，原子力は厳しいアゲインストの風にさらされています。21世紀に向けて「エネルギー複合時代」の到来が予想されていますが，冒頭に申し上げたように，原子力は発電用として適切な規模で開発されるべきものだと信じています。適切な規模の原子力開発は，日本やフランスのようなエネルギー資源に恵まれない国のみの特別な問題ではなく，人類に共通するエネルギー問題の解決をめざすという，きわめて重要な意義と役割を持っていると考えています。しかしながら，そうした世界的規模での原子力利用を進めていく上では，当然のことながら核不拡散の問題をはじめとするさまざまな制約条件を克服していくことがきわめて重要となります。

私はこの点において，

第１に，原子力平和利用についての国際的および各国におけるコンセンサスづくりがきわめて重要であり，

第２に，原子力の平和利用を進める上で国際協力と連携の強化ということが非常に重要だと考えています。

原子力平和利用に関するコンセンサスづくりに関しては，世界の国々はそれぞれの風土や社会システムの違いもあり，原子力に対する考え方も様々であるかと思います。

日本においては，原子力の利用は平和利用しか意味していませんので，話は単純なのかもわかりませんが，私はここで，原点に帰って安全性，経済性を追及していけば，原子力推進に関する世界共通の普遍的な基盤が明らかになると考えています。チェルノブイルの事故が起きて，原子力利用に関する世論が厳しい折ではありますが，今日ほど原子力平和利用の積極的な推進のためのコンセンサスづくりが必要な時はないと思います。

1953年12月の原子力平和利用の呼びかけ以来，世界において原子力推進の着実な努力が積み重ねられてきていますが，そうした努力の歩みを，今途絶させてはならないと考えています。しかしその一方で，なお漠然たる原子力への不安が各国国民の中に存在することも事実です。しかし，原子力発電ほどクリーンで，環境に与える影響の少ない，安全な商業用のエネルギーはないということもはっきりした一つの事実と言えます。原子力発電について一般公衆に正しく理解してもらう努力を，世界各国が地道にやっていかねばならないと思います。

例えば卑近な例ですが，原子力関連の用語にしても，一般の人にとってはきわめてなじみにくいものであります。特に放射線の影響に関しては，わかり易い用語を用いて説明することが非常に重要です。本会議にご出席の，ＣＥＧＢ総裁マーシャル卿が申されております，「放射性廃棄物処分にかかわる健康上へのリスクは，裏庭の自然放射線のリスクに比べてもはるかに小さい」とのご指摘は，きわめて身近な比喩として，原子力のＰＡを進める上で大いに役立つものだと思います。もっとも，日本の住宅のほとんどはイギリスのようなバックヤード（裏庭）をもっていませんので，何かほかのものと比較する必要がありますけれども。

原子力に関する国際会議にしても，単に原子力に携わる人達だけのものではなく，もっと一般の人々にも浸透していくような工夫はないかという検討も必要です。そのためには，各国のＰＡ活動を結集できる場をつくり，その成果を生かすことが必要ではないかと思います。

また，一般公衆の原子力に対する信頼の向上とコンセンサス作りにとって重要な点は，今回の新長期計画において取り上げられているところの，原子力をめぐる技術開発の重要性であります。

これまでも，軽水炉原子力発電所を中心とする技術開発の成果は非常に大きなものでしたが，今後はさらに，こうした原子力発電所はもとより，原子燃料サイクル関連の技術開発において，幅広い各方面での技術的成果を最大限に取り入れ，これを安全性・信頼性の面に成果として結集させていくことがきわめて重要です。

私から改めて申しあげるまでもありませんが，原子力技術は，それ自体がきわめて巨大技術で，そしてさまざまな極限的な技術，システム技術，あるいは先端技術の利用に支えられています。

過去において，原子力技術は総合的な技術として発達を遂げてきました。物理学，化学，電気工学，機械工学，材料工学，情報工学，生物学をはじめ，きわめて広範な科学領域の技術が総合的に活かされて今日に至っています。その点では，今話題となっている超電導の技術も，その他の分野の成果と合せて，やがては，例えば，核融合などの研究開発を一層促進させることにもなると期待されます。

また，こうした原子力の開発を通じて達成された技術が，原子力以外の広い分野に亘って利用され，また活かされていく可能性が秘められているということです。ここに，原子力をめぐる研究開発の新しい時代的な展開が求められており，またその可能性は非常に大きいものがあると考えています。

次に，わが国の国際協力と連携を通ずる国際社会への貢献という点について言及したいと思います。

冒頭にも述べましたように，エネルギー問題は，21世紀に向けた人類最大の課題の一つであります。この問題解決のためには，世界レベルでの共通した取り組みがきわめて重要となります。わが国は原子力開発利用の先進国として，その技術発展に大きく貢献すると同時に，この成果を国際的に役立てるような協力関係を確立していかねばならないと思います。

原子力の国際利用は，まさに公共財としての原子力を広く国際的に普及させていくという意味において，我々の果たすべき役割は非常に大きいわけです。もちろんその場合にも，わが国の原子力国際利用に関する基本的な視点として，平和利用と核不拡散の両立を基本的な立場としていることは今更申すまでもありません。その意味で，この度の新長期計画においても，原子力分野における国際協力の進め方について，われわれは積極的にその必要性を認め，推進方策を検討している次第です。

昨今，日米の原子力協議が進展し，わが国が自主的に原子力開発利用を進めていく環境が整いつつあります。なかんずくプルトニウム利用については，国際的に核拡散の懸念が依然として問題視されている状況の下で，これを進めていくわけですので，わが国としては十分な配慮が必要です。

平和利用に限定したプルトニウム利用ではありますが，その道は国際的にもき

わめてパイオニア的事業であるため，わが国のプルトニウム利用の必要性と有効活用について関係諸国の理解を得る努力がきわめて重要であり，またわが国の国際的責務だと考えています。

また，現在，原子力の開発利用を進めていくには，どの分野をとっても，一国だけでできるものは一つもないと言っても過言ではありません。とりわけ，原子力開発推進の大前提となる安全確保に関しては，国際的な協力の下ではじめて達成できるものであり，それには政府と民間がそれぞれのレベルでしっかり連系していかねばならないと考えます。

原子力災害時における通報・援助に関する協定は勿論重要ですが，各国が事故を起こさないようにするための安全技術の交流が今後ますます重要になってくるものと思います。

6．おわりに

最後に，再度，重ねて次の点を強調しておきたいと思います。

それは，今日，日本が置かれている立場についてであります。経済の領域において，日本の存在は世界の注視の的であり，多くの点で新しい道を求められていることは，皆さまもご承知の通りです。この点では，エネルギーの領域，なかんずく原子力開発においても同様の立場に立たされていると言わざるを得ません。日本のあり方，行動の方向が世界の注目を集めています。私は，いまや，わが国の原子力利用のあり方がどのように世界の発展に貢献し得るかが問われていると思っています。

その意味で，日本としての原子力開発の基本哲学が明らかにされる必要があります。したがって，国際国家としての日本の原子力開発利用の方向を示すものとして，政府はもとよりここにご列席の原子力関係者の方々と力を合わせて，新原子力長期計画を作りあげていかねばならないと考えています。またそれが国民の原子力への信頼を高める所以であると信じています。

こうした原産会議のような会合が，明日の原子力のために大きな推進力となっていくことを切に期待して，私の話を終らせていただきます。

以　上

The Outlook for Nuclear Power Development in Japan

-Promotional Issues to be Faced-

Gaishi Hiraiwa

Chairman

Tokyo Electric Power Co., Inc.

(1. Introduction)

It is a great pleasure to have this opportunity to address my colleagues from around the world, at this 20th Annual Meeting of the Atomic Industrial Forum.

This year's theme is the "role of nuclear power as we move towards the twenty first century", and I have been asked to speak on the outlook for nuclear power development in Japan. As I am an executive member of the joint government and private sector long term planning committee, I would like to deal specifically with the issues involved in promoting further nuclear power development.

(2. Global Aspects)

Last year's accident at Chernobyl nuclear power plant had a major impact on nuclear power programs in both the U.S.S.R. and other countries around the world. In addition, the recent decline in the demand and price of fossil fuels has resulted in a slow down in nuclear power development in some countries.

I need scarcely point out that absolute safety is essential in

the utilization of nuclear power. The accidents at Chernobyl and Three Mile Island, however, indicate that greater efforts need to be made to maintain safety. Furthermore we need to clarify our methods and policies in developing nuclear power, while re-emphasising its role as well as its safety and reliability.

If, on reconsideration, nuclear power ultilization, despite its problems and limitations, is seen to be indispensible for mankind as a whole, then we must make every effort to solve those problems, and to restore public confidence in nuclear power by dispelling anxieties and argumenting public knowledge of this energy source.

Food and energy requirements are forecasted to become the major issues facing people throughout the world in the twenty-first century. In the past, there have been frictions, conflicts and wars between nations over limited natural resources, and similar confrontations over access to energy resources are inevitable in the future.

Energy resources are very political in nature, and their price fluctuates greatly, with no regard to market principles, as illustrated by the oil crises in the 1970's. National governments have now become very aware of energy resources as a major aspect of national security.

Long term solutions to confrontations over access to energy resources are crucial to the prosperity of mankind in the twenty first century. The present slump in the world economy has brought about a decline in the demand for fossil fuels but we should use this

period to work out substantive measures for the future. Trying to solve energy issues within the traditional theoretic framework of energy resources, will only serve to aggravate confrontations and frictions. Mankind has used his knowledge and intelligence to devise technologies to produce new energy sources, the most major example being nuclear power. The discovery of this technological energy has allowed modern industrial states to forge ahead with the development of nuclear power utilization technologies. Each country has the responsiblity to make efforts necessary to become as energy independent as possible, as a contribution to the solution of world wide energy problems in the twenty-first century.

Japan is the second largest energy consumer in the free world, but is very poor in energy resources. Nuclear power is consequently an inevitable choice, if we are to carry out our responsibility to raise our energy self-sufficiency.

The two oil crises revealed nuclear energy to be an attractive alternate source of energy, because of its availability, abundant reserves, ease of transport and storage, and minimal impact on the environment when properly handled. As fossil fuels have a variety of higher-value-added applications, the use of nuclear power, as an energy source especially for electric power generation, will be indispensable in the future.

Countries which possess other energy resources do not need to rely on nuclear power, and so most of them have temporarily suspended their nuclear power development programs. However, the expanding

energy demand in the developing countries, makes it certain that the necessity of nuclear power once again become obvious in the long term interests of global prosperity. If Japan, recognising her present position and needs, were to take a leading role in promoting nuclear power development, this would contribute greatly not only to her own future prosperity, but to that of the world as a whole. To do this we must thoroughly upgrade the safety, reliability, and economy of nuclear power and at the same time it is vital to build a public consenus of support for continued nuclear power development.

(3. Safety Maintenance Measures at Nuclear Power Stations in Japan)

Safety has always been considered the keystone of nuclear power development in Japan. Nuclear power technologies as well as the economics of nuclear power utilization are basically concerned with safety and reliability. The nuclear power industry is the only industry to have been developed out of technical research oriented to safety, reliability, and economical efficiency. Power generation using light water reactors is a concrete result of such research. Maintaining safety was the focal point in the research, developement and designing of these reactors, and their safety and reliability were primary concerns at each stage of planning, installation, and operation. Our basic targets were: to avoid malfunctionings, and to minimize any which did occur. In the case of an accident, we were concerned to devise measures to confine radioactive materials to prevent leakages to the surrounding environment. In other words, the

three basic principles of safety maintenance in nuclear power plants are, in the event of an accident, to stop the nuclear reactor, cool down, and seal up radio-active materials. In promoting nuclear power development in Japan, we have been careful to observe stringent safety measures, institute multiple safeguards against human error, and endevour to establish a fail-safe management system.

The Chernobyl accident is not likely to occur in a light water reactor. The large scale facilities, and advanced technologies of nuclear power stations mean that the safety of equipment and facilities is unquestionably important, yet, however, the human factor still remains the most critical element.

The Chernobyl accident teaches us that we need to improve staff training methods and the overall measures to be implimented should an accident occur. Given its leading role in nuclear power development, the electric power industry has a clear responsibility to redouble its efforts to create a safe operating environment, and we have renewed our resolve to do so.

Nuclear power should be developed to an appropriate scale as an energy resource for electric power generation, on the premise, of course, of its safety and reliability, To achieve this, nuclear power must be cost competitive with oil and coal. We are continuing to aim at reducing construction costs of nuclear power plants and increasing the cost effectiveness of the generation processes, and at the same time raising the plants' operating levels. Furthermore, it is important to minimize generation costs by optimizing the total

system for nuclear power generation , including the nuclear fuel cycles such as uranium enrichment and reporcessing.

(4. Four Issues in the New Long Term Plan for Development of Nuclear Power)

Nuclear power development in Japan is thirty years old, and presently supplies 30 percent of all the electric power generated. We estimate that this figure will reach about 50 to 60 percent by 2010 or 2030. Thus we urgently need to improve our systems for nuclear power generation and the nuclear fuel cycle, to allow full-scale, comprehensive utilization of nuclear power.

The nuclear power committee is currenty reviewing its long-term nuclear power development plan, and I am the chairman of the specialists subcommittee. As we have almost completed our review, I would like to give you a brief outline of it here.

The new long term plan sets out four issues to be considered in the second stage of improving the system of nuclear power utilization as we move into the twenty-first century.

1. Light water reactors can be expected to remain in use for some time, in view of the international supply and demand for uranium. Therefore, technological inovations to increase safety and economical efficiency must be pursued, and the nuclear fuel cycle reorganized into a more comprehensive system.

2. Technologies for the practical utilization of plutonium must be developed, to ensure that nuclear power is able to solve the

energy problems of the future. Japan, while observing non-proliferation principles, should work towards establishing methods for plutonium utilization, and overcome energy resource constraints by effective use of uranium resources.

3. Japan has been very dependent on new technologies from the U.S. and Europe in the research and development of nuclear power, as we have been concerned to catch up with the West in this area. However, Japan must now build on the research and development of the past thirty years to pioneer new fields in technological developments. In other words, Japan must become more creative in its research and development.

4. In order to contribute to solving the energy problems of nations around the world, Japan should promote international cooperation in sharing nuclear power technology, which is often refered to as international public property.

Increased utilization of nuclear power has fostered strong interdependence beween nations, as each country has been compelled to actively cooperate with other countries to upgrade the safety and effectiveness of nuclear power utilization. A major task for Japan today is to work out her role and the contributions she can make in this area.

These four points are our basic considerations in devising a new long term stragety for nuclear power development as we move

into the twenty-first century. Our basic plan to switch from light-water reactors to fast breeder reactors (FBR) remains unchanged. At present, light water reactor operation is very stable, and I expect that they will be even further improved in the future. Our final research and development goal, however, is the practical use of fast-breeder reactors, as these are the most efficient plutonium users. Commercial operation of FBRs is the key to full scale utilization of nuclear power, and both the government and private sector are cooperating to achieve this as soon as possible. Unfortunately, however, the timetable for the development of FBR technologies is running behing our original schedule, and there are still many problems to be solved before FBRs can be made as economically efficient as light water reactors. We estimate that FBRs will not be up and running fully until about 2020 or 2030, given the present uranium supply and demand balance, which reflects the slump in electric power demand.

Commercial operation of FBRs will not be viable, until they are able to rival light water reactors cost competitively, and this can only be achieved by developing new and inovative FBR technologies, which do not sacrifice their safety aspects. At the same time it will be important to prepare for the coming age of FBRs by mastering the technologies of and establishing the foundation necessary for efficient and effective plutonium utilization. The current long term nuclear power development plan estimates that uranium shortages will occur in the near future, and proposes plutonium utilization at the

earliest possible date. However the nuclear power situation has changed somewhat, and so the new plan's timetable is much less urgent. Full scale plutonium utilization calls for the development of new plutonium fuel technologies, starting with the utilization of limited amounts of plutonium in light water reactors and ATRs until FBRs are operating commercially. The government and private sector in Japan are also cooperating to set up a nuclear fuel cycle including reprocessing capacity, which is essential for plutonium utilization. As you know, we are now in the process of constructing three nuclear cycle facilities-- a reprocessing plant, an enrichment plant, and a low-level nuclear waste storage facility--in Aomori Prefecture.

The new long term plan sets out the followings as key points in establishing a nuclear fuel cycle.

1. Designation of spent fuel reprocessing and plutonium utilization as basic national strageties.
2. Guidelines for plutonium utilization, domestic-only reprocessing, and appropriate storage and management of spent fuel that cannot be reprocessed in the domestic reprocessing capacity.
3. To establish a plutonium utilization system, it is important to be able to reprocess fairly large volumes of spent fuel from the very begining. As I mentioned earlier, plans are presently underway to construct a private sector reprocessing plant in Aomori Prefecture, with an annual capacity of 800 tons.
4. We also plan to construct a second more economically efficient

private sector reprocessing plant by 2010.

In short, Japan's new long term nuclear power development plan, while taking into account the changing circumstances, aims to establish nuclear power as a major energy source in the future--the key to achieving this being plutonium utilization.

(5. Issues in Promoting Nuclear Power Development)

Japan has been taking steady action to promote the development and utilization of nuclear power, but to expand that utilization further, we must now place greater emphasis on establishing a nuclear fuel cycle

Today, strong opposition to nuclear power exists at the international level, but with the arrival of "a multiple energy era" before the turn of the century, as I mentioned earlier, I believe that nuclear power for electric power generation should be developed to an appropriate level. This consideration does not only apply to countries, such as Japan or France which are poor in energy resources, but will be important in solving the common energy related problems of mankind on a global scale. However, restrictions such as the issue of non-proliferation will have to be overcome, if we are to promote nuclear power internationally.

In this connection, I believe that it is crucial to create a consensus within each nation regarding the peaceful use of nuclear power, and secondly to set up an international network to cooperate in promoting peaceful nuclear power utilization.

In the process of building such an international consensus, we will encounter various obstacles such as different social organizations, customs and attitudes toward nuclear energy. In Japan, nuclear power utilization implies peaceful usage only, and so the situation is quite simple. But by analysing the safety and economic efficiency of nuclear power, we may be able to identify a common basis for promoting its utilization. The Chernobyl accident triggered social critism of nuclear power utilization, but we must now start to build a consensus so as to actively promote peaceful nuclear power utilization.

Steady efforts have been made throughout the world to promote nuclear power since calls for its peaceful use were first made in December, 1953, and such efforts should not be abandoned now. Admittedly, people in many nations throughout the world have vague feelings of anxiety about nuclear power, but it is also true that no other commercial energy source is as clean and safe with a minimal impact on the environment as nuclear power. Each country should make efforts to ensure a correct understanding of nuclear power amongst its people. For example, the general public are not familiar with the jargon used in the nuclear power industry, and it is essential to explain everything in easily understood language, especially when it comes to the effects of radioactivity. The Chairman of the Central Electricity Generating Board, Lord Marshall, who is with us today, has said that the effects of handling radioactive waste is less detrimental to the health than handling natural radioactive

substances that could be found in the backyard of a house. This statement is a simple illustration, and will help promote public understanding of nuclear power, but perhaps a different example would be needed in Japan, as most Japanese houses do not have a backyard like they do in Great Britain. International nuclear power conferences should also discuss how their forums can be opened wider to the general public, and to do this, we need to create a forum to link up activities in each country, and then make use of those results.

Our new long term plan also places major emphasis on the importance of developing nuclear power technologies in increasing public confidence and creating a concensus regarding nuclear power.

Many successful technologies have been developed up to now especially in the area of nuclear power generation using light water reactors, but our task now is to take as many of these technologies as possible, and incorporate their safety and reliability aspects into further research and development of the nuclear fuel cycle and of course nuclear power generation technologies. I need scarcely repeat that nuclear power generation technologies are in themselves very complex, and are supported by a variety of very advanced, systemized technologies.

Nuclear power technology is an interdisciplinary field, and developed over the years using technologies from a range of sciences such as physics, chemistry, biology,and electrical-,mechanical-, materials- and information-engineering. The recent superconductive

technology, and other scientific achievements will contribute in future to further research and development of, for example nuclear fusion. There is now a need to open up new avenues of research and development in the area of nuclear power, and I believe that there is great potential in that area.

Next, I would like to talk about Japan's contribution to international cooperation. As I mentioned earlier, energy will become a major issue for all mankind by the time we reach the new century, and mutual efforts at the international level will be needed to solve these problems. As a leading nation in the development and utilization of nuclear power, Japan should both contribute to improving those technologies, as well promoting international cooperation, so that these technological achievements can be shared with other nations. Nuclear power generation technologies are said to be the common property of all mankind, and Japan should play a major role in promoting them throughout the world. Our basic premise for this, however, is peaceful utilization of nuclear power, and adherence to the non-proliferation principle. In our new long term plan, we recognize the necessity to promote international cooperation, and measures to achieve this are now under consideration.

Recently there has been progress in U.S.-Japan nuclear power discussions, and the situation is gradually becoming more conducive for Japan to independently pursue nuclear power development. However, especially in utilizing plutonium, we need to take into consideration the concerns about nuclear proliferation that still exist at an international level.

Although our plutonium utilization is confined to peaceful purposes only, we should make efforts to obtain the understanding of other nations vis-a-vis the necessity and efficiency of plutonium utilization in Japan, as this field is still in the pioneering stage, even at the international level.

At present however, one country can not possibly promote the development and utilization of nuclear power by itself. Safety is a basic condition for such development and utilization, but it can only be achieved through international cooperation, by strengthening inter-governmental and private sector ties at all levels. Agreements to notify and give assitance in the event of a nuclear accident are of course very important, but international exchange of safety related information to prevent accidents is even more important.

(6. Conclusion)

In conclusion I would like to re-emphasise that Japan is presently the object of international attention economically, and that new approaches to many issues are expected of her. This is also true in the field of energy, especially nuclear power development, and the world is watching with great interest to see what course of action she will take. The contribution Japan can make to international progress in such areas as nuclear power utilization is now under scrutiny.

Japan should clarify her basic principles of nuclear power development, and with the help of the government and the nuclear power specialists gathered here today, work out a new long term plan

for nuclear power development. This will also serve to renew public confidence in nuclear power.

In closing, I would like to express the hope that the Atomic Industrial Forum and other similar conferences will serve to stimulate nuclear power utilization in the future.

Setting the Course to Maintain the Nuclear Option in the United States: The U.S. Industry's Program to Revitalize Nuclear Power

Presented to the
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Tokyo, Japan
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by
Frank W. Graham
Vice President,
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I am very pleased to be in Japan, to participate in the 20th JAIF Annual Conference, and to take part in the session on the role of nuclear energy toward the 21st century. The topic I will discuss is the U.S. industry's program to revitalize nuclear power. But first, I want to thank Mr. Mori for inviting me here today. It is personally a particularly symbolic time. This is my first return to Japan in almost forty years, having spent two years in Tokyo following the end of World War II. And in June I will retire as an officer of the Atomic Industrial Forum as that organization is merged with the U.S. Committee on Energy Awareness in the restructuring of the industry's representation in Washington. So it is a time of change for me and the pleasure of looking back. For the U.S. industry, it is a time for looking ahead and positioning for a stronger role as we move toward the 21st century.

Before I discuss the steps the U.S. industry is taking to revitalize the nuclear option, I would like to review with you where the U.S. nuclear power program stands today. It is the world's largest program and is expanding at a near record rate. In 1986 seven new plants achieved commercial operation. Almost without notice since 1980, a new nuclear plant has entered service on the average of every 10 weeks bringing to 106, the number of plants in the U.S. program. U.S. nuclear electrical generation reached 414 billion kwh last year, a 7.9 percent increase over the 1985 total.

To put the topic of the U.S. nuclear program in perspective, let me note that at the end of last year it represented 31% of the world's total nuclear plant capacity. In actual terms, U.S. nuclear plant capacity is greater than the combined total in France (44,968 MWe) and the Soviet Union (33,223 MWe), the countries with the second and third-largest civil nuclear power programs.

After three decades of development and over 1,000 cumulative reactor years of operating experience, nuclear power has become an integral component of U.S. electrical supply providing almost 17% of the total electricity generated. It is now second only to coal in supplying electricity to the U.S. grid.

For the next several years nuclear power in the U.S. will continue to expand. In addition to the 106 plants licensed to operate there are 19 plants under construction scheduled to come on line by the end of this decade--13 of these plants this year. When all of the 19 plants reach commercial operation, nuclear power will represent more than one-fifth of U.S. electrical generation, and will provide as much electricity as the total produced in the entire country in 1953 when President Eisenhower opened nuclear

power for civil use in his "Atoms for Peace" plan. At that time it was hoped that energy derived from splitting the atom would provide the world with another energy resource that would be competitive with fossil fuels. That hope has been largely realized and we are witnessing the benefits of the foresight and planning done over 30 years ago.

However, at the end of this decade, growth in the U.S. nuclear program will end and U.S. utilities, faced with excess reserve capacity, are not ordering new central-station generating plants. In light of this, it is the purpose of my paper to examine the outlook for nuclear power in the U.S. and discuss with you what the U.S. industry is doing to strengthen the nuclear option so that it will be the energy choice when new generating capacity is ordered.

To grasp what the future role of nuclear power in the U.S. will be, it must be recognized that nuclear power, in today's interdependent world, does not exist in a vacuum. The central energy concern of the past 15 years has not been nuclear power, but the price and supply of oil. In the U.S. it began with gasoline lines and soaring prices. At that time, however, there were 49

nuclear power plants operating in the U.S., 98 with construction permits, and 57 on order. It is the nuclear plants from that backlog which produced over 414 billion kilowatthours in 1986. Producing the same amount of electricity with oil-fired plants would have required burning more than 700 million barrels of oil. This nuclear power contribution to U.S. energy demand, along with increased efficiency in the use of energy, reduced U.S. oil imports from almost 9 million barrels of oil per day in 1977 to just over 5 million barrels per day in 1985.

Other oil importing countries reacted to their concerns about the security and cost of energy supply in much the same way by seeking to reduce their energy use and to increase the use of nuclear power and other none petroleum fuels.

Today, oil importing countries including the U.S. are enjoying the benefits of the actions taken in response to the oil supply crisis of the 1970's. The drastic decline in oil prices that started in 1985 is directly attributable to the Organizations of Petroleum Exporting Countries (OPEC) loss of market share, to the point it could no longer artificially control oil prices. At its high point in 1977, OPEC delivered some 31 million barrels of oil

daily to to importing countries. This had dropped to 16 million barrels in 1985 creating a daily over capacity of at least 15 million barrels. This loss in market share and the decline in world oil prices which followed paralleled the world's growth in the use of nuclear power to generate electricity. OPEC concluded that by mid-1985, global nuclear power had permanently eliminated the market for approximately 6 million barrels of oil daily. Since then, new nuclear plants around the world have displaced the equivalent of another million barrels of oil daily.

The most drastic example of how nuclear energy has been used to displace oil consumption is in France, where oil has been almost totally backed out of the electric utility sector. In 1973, France used oil to generate almost two-thirds of its electricity. Today, nuclear power provides almost 70% of the electricity in France while oil is virtually eliminated. This represents an oil displacement that is approaching a million barrels of oil a day.

In 1973, oil was used to generate 17% of the electricity in the United States. That same year nuclear power provided 4.5%. Today, those numbers are reversed with a savings of the equivalent of almost 2 million barrels of oil per day.

Throughout the world, nuclear power now produces a significant part of electricity supply (15%) enabling oil importing countries to moderate their demand. President Eisenhower had not anticipated that his "Atoms for Peace" plan would play such an important role in providing lower costs for today's oil.

These lower costs however, are increasing demand for oil and reducing exploration. In the U.S., there is concern over the increase in oil imports up almost 20% in 1986 over 1985, and the U.S. oil industry predicts oil imports could reach the 50% level by 1991 making the U.S. even more vunerable than it was in the 1970's.

Response options too are fewer -- and more painful than during the oil crisis of the 1970's, because many of the easiest steps have already been taken, and there is no longer a back-log of nuclear plants in the pipeline as the U.S. had in 1973.

The U.S. electric utilities are now working off a surplus generating capacity that has occurred from slower than

anticipated demand. Unfortunately, almost 70% of the excess capacity is oil-fired, and as demand for electricity increases, oil use will also increase. Last year the nation's electric utilities increased their consumption of oil by more than 36 %, the largest single year percentage increase since the 1973 Arab oil embargo.

However, higher oil prices, and most experts agree that there will be higher prices for oil, will hasten the time new nuclear capacity will be ordered.

There is significant potential market for new nuclear plants in the U.S. There are 32 million new workers already born who will enter the labor force by the year 2000. They are expected to create 24 million new households. This coupled with the sheer size of the U.S. electrical grid -- approaching 700,000 MWe of generating capacity and the need to replace existing facilities as they retire will create a demand for significant amounts of new capacity.

Even if demand for electricity grows at a moderate 3% per year rate -- which is less than half of the pre-oil embargo days when

demand regularly grew at 7% annually, the U.S. will need to add over 20,000 MWe of new capacity each year, not counting the need for additional capacity to replace aged or uneconomic units. This is equivalent to at least 20 large 1000 MWe generating plants needed each year.

Recognizing this potential market for new nuclear plants, the U.S. nuclear industry is well aware of the need to keep the nuclear option strong and competitive. Toward this end, much is being done to position nuclear power to be the energy option of choice for new generating capacity.

The first and foremost goal is to ensure the safe and reliable operation of the current generation of reactors. The industry has in place, several institutions designed for this purpose.

One institution, the Institute for Nuclear Power Operation (INPO) was formed after the 1979 accident at Three Mile Island. The industry recognized as the result of the accident the interdependence of nuclear plant operations. If one plant had an accident it effected the operations of all the plants. No owner of a nuclear plant wanted to face a reactor shut-down because of opera-

tions at another plant. The Institute of Nuclear Power Operations was the answer for assuring excellence at all plants. It provides "hands-on" evaluations of nuclear power plants and makes the best operating procedures found at any one nuclear power plant the standard for all. INPO also provides the conduit for sharing information. It analyzes every incident for accident potential and makes its findings available to all operating plants. For nuclear plants falling short of INPO's standards, even if meeting federal requirements, INPO provides support and if required peer pressure on senior management to improve operations.

In keeping with its goal to promote excellence, INPO has established performance indicators for operating U.S. nuclear plants. It has been recognized that nuclear plants with high equivalent availability, small numbers of forced outages, few unplanned scrams, few significant events, and low personnel radiation experience, are generally well managed overall. Such plants are more reliable and can be expected to have higher margins of safety. Today, in the operation of U.S. nuclear plants, improving trends in these performance indicators are evident and demonstrate the potential for continued improvement in the years ahead.

Another institution helping improve nuclear plant performance is

the National Academy of Nuclear Training. Created in 1985 to focus and unify efforts at upgrading training for nuclear plant personnel it provides the framework to coordinate training activities. As part of the accreditation process, an independent National Nuclear Accrediting Board determines whether training programs meet established industry standards. The Board is comprised of 20 scholars and executives from four groups: senior utility management, non-nuclear industrial training, post-secondary education, and nominees from the U.S. Nuclear Regulatory Commission.

When a nuclear plants' first training program is accredited, it becomes a branch of the Academy and is eligible to issue certificates to graduates of accredited programs. Accreditation of the ten training programs for key operations, maintenance and technical support personnel in nuclear plants is the condition for full membership in the Academy.

But, accreditation and full academy membership comes only after solid commitment and hard work. Using a model with procedures established by INPO, training programs must have a systematic performance-based approach. INPO's model reflects the state of

the art in training design, with modern programs and curriculum development, tieing the training directly to performance-based objectives.

The National Academy of Nuclear Training is like a university with campuses at each U.S. nuclear plant.

A third institution is the Nuclear Safety Analysis Center(NSAC). It was established in the days following the Three Mile Island accident to make an in-depth analysis of the accident sequence and the long term implications. Its present and continuing purpose is to supply the nuclear industry with technical advice and support on safety-related matters such as designs, performance, and analysis of nuclear power plant behavior.

NSAC's programs identify the major areas of safety risks in engineering and equipment, and the effectiveness of safety measures. The objective is to achieve and maintain a high level of nuclear safety.

Further evidence of the industry's commitment to maintaining the nuclear option is the restructuring of the organizations which

represent the industry in Washington. It was recognized that additional resources were needed to resolve important issues in nuclear licensing and regulation. To meet this need the Nuclear Management Resources Council (NUMARC) is being established under the control of the electric utilities operating nuclear power plants, to assume the day to day responsibility for working with the U.S. Nuclear Regulatory Commission on reactor operations and technical issues. NUMARC will work within the industry and with the U.S. Nuclear Regulatory Commission to develop non-regulatory solutions to nuclear operational issues. It will coordinate the work of all nuclear utilities in solving problems in the operation of nuclear plants and will help ensure that corrective actions are taken.

To enhance and combine industry communications, the Atomic Industrial Forum, Inc. and the U.S. Committee on Energy Awareness will merge into a single organization. In addition to its communications role, the merged organization will be responsible for the industry trade association activities including international services. It will also encompass a number of technical issues such as the nuclear fuel cycle, advanced reactors and fusion, and promotion of the future of the nuclear option.

A third organization, the American Nuclear Energy Council (ANEC) will handle the industry's lobbying activities. In doing so, it will advocate the legislative objectives of the nuclear industry with Congress.

The restructuring is scheduled to be completed on July 1, 1987. Each of the organizations will be independent with its own Board of Directors, President and full-time staff.

Through this restructuring, industry representation should be even more effective in continuing the operating excellence of nuclear plants, and in meeting the growing U.S. demand for electricity.

The Soviet-Chernobyl accident in April 1986 also gave rise to an intensive industry analysis of nuclear power to determine if the lessons of that accident could enhance the safety of U.S. reactors. A 31 member panel released its findings in February culminating more than eight months of analysis. The panel's conclusions reaffirm Soviet reports to the International Atomic Energy Agency (IAEA) in Vienna last August. That is, the design of the Soviet Chernobyl-type reactors are so unique that last

year's accident offers no major lessons that would require immediate changes in U.S. reactors.

This conclusion was supported by the U.S. Nuclear Regulatory Commission's analysis which concluded that the Chernobyl accident reinforces some aspects of the NRC regulatory program and "no immediate regulatory action" is needed to assure U.S. nuclear plant safety.

The industry group pointed out that the Chernobyl accident presents an opportunity to improve public understanding with respect to the safety of U.S. reactor design.

However, nuclear power will not be an energy choice for generating electricity in the U.S. unless it is economically competitive with other energy options. The current generation of high cost nuclear plants have suffered from an unusual combination of well-documented economic and socio-political forces. A lower than predicted growth in electrical demand and post-Three Mile Island regulatory changes stretched construction schedules and made efficient management almost impossible. The effects of these delays were further heightened because they occurred during a

period of high inflation and high interest rates on borrowed construction funds.

However, this doesn't need to be the case for the future. The industry has looked hard at controlling nuclear construction schedules and costs. In the late 1960's and early 1970's, nuclear plants were built in the U.S. in five years or less, a far cry from the 10 to 14 years for plants coming on line today. These early nuclear plants with reasonable construction schedules were built at a cost competitive with other energy options.

In a wide ranging industry study completed last year by an AIF Study Group, it was concluded that under current economic trends, standardized nuclear plant designs in the U.S. would significantly reduce construction schedules and cut the cost of building new nuclear plants. The analysis shows that a standardized nuclear plant with commercial operation in 1992 can be built in six years for 55% less than the best cost experience model of recent years.

As an example of cost saving, the study pointed out that if a standardized nuclear plant had been ordered in the U.S. in 1980, it would have reached commercial operation in 1986 at a capital

cost of $932 per kw, assuming the same factors applied as were used in the analysis. With a 70% capacity factor for this hypothetical nuclear plant, first year capital costs would be 3.2¢ per kwh (or 2.4¢ per kwh levelized over 30 years). If the current nuclear plant average operation and maintenance cost of 0.9¢ per kwh, fuel costs of 0.6¢ per kwh and other costs of 0.1¢ per kwh are added to these capital costs, total first year generation costs for the plant would be under 5¢ per kwh (or under 4.0¢ per kwh levelized over 30 years). This 1986 cost of electricity from a standardized nuclear power plant is believed to be competitive with , or cheaper than, any other energy resource for providing new electric generating capacity.

At the same time, both the industry and government are moving ahead to maintain U.S. nuclear technology at the cutting edge. As an example, the Electric Power Research Institute (EPRI) has a cooperative research program underway to advance the state of light water reactor technology. Taking advantage of the experience that has been gained from the research, design, construction and operation of today's nuclear plants, the program is developing future designs with the following characteristics:

- simplified and reduced numbers of systems and components,
- use of more passive safety features,
- lower accident probabilities,
- easier to construct, operate and maintain,
- higher availability.

Another example is the research and development program for an advanced reactor. This program is designed to develop modular liquid metal-cooled and modular gas-cooled reactor systems that can meet evolving market needs while providing a path to long term resource extension and energy security.

In summary, the U.S. nuclear industry has confidence in the future of the nuclear option. Orders for new base load generating capacity are expected around the end of this decade.

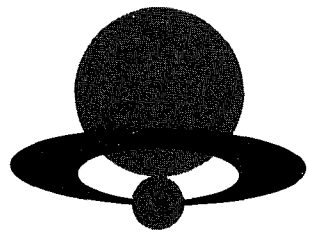
Through the commitments outlined in this paper;

- o the safe and reliable operation of today's nuclear plants supported by the institutions now in place,
- o the restructuring of the organizations which represent the industry,
- o standardization and reduced costs,
- o and, research to advance the state of today's technology;

the industry is positioning nuclear power as a safe, reliable and economically competitive choice for new base load generating capacity in the United States.

セッション2

原子力研究開発の新しい展開



原子力研究開発の長期展望と問題点

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大　島　恵　一

原子力研究開発に関する規制側のイニシアチブ

米国原子力規制委員会（NRC）委員
K．カー

原子力研究開発の進め方と国際協力

西ドイツ連邦研究技術省（BMFT）
エネルギー・バイオロジー・エコロジー局長
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石　渡　鷹　雄

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(株)東芝副社長
(社)日本電機工業会原子力政策委員会委員長
青　井　舒　一

東京大学教授
田　畑　米　穂

原子力研究開発の長期展望と問題点

東京大学名誉教授
大　島　恵　一

今回の原産年次大会は「国際経済社会の発展に果たす原子力の役割」を基調テーマとして開かれました。このような観点から、本セッションにおきまして、わが国の原子力研究開発の新しい展開について、私の考えを申し述べる機会を与えられましたことは、この上ない光栄に存じます。

わが国においては、総合エネルギー調査会の「原子力ビジョン」の報告書や現在ほぼ最終段階のとりまとめに入っている原子力委員会の「原子力開発利用長期計画の改定」などをはじめ、各方面で２１世紀へ向けての原子力の将来計画の討議が行なわれております。

これらの基本的な一致した結論は、わが国にとって原子力開発の重要性は依然として変らず、将来、ますます原子力の役割が大きくなるということであります。しかし、重要なことは、今日の原子力をめぐる国際情勢とわが国の現状から考えて、原子力が明らかに新しい時代を迎えたということであります。いわば、わが国の原子力開発は第２ラウンドに入ったのであります。

国際的に見れば、ＴＭＩやチェルノブイリの事故の影響、また原油価格の下落もあって、各国において原子力計画の低迷がみられております。その間にあって、原子力先進国のなかでも、わが国はフランスなどとともに最も順調に原子力発電計画が進行している国であるといえます。

このような世界各国の原子力開発の進み方の違いは、原子力産業の実用化の進展にともなって、各国にとっての原子力産業の重要性と発展の形態が異なってきたからであると考えられます。

それぞれの国のエネルギー資源条件、社会的、政治的環境、経済情勢などによって、おのずから原子力の比重と実用化への関心が左右されているといえます。

わが国は、エネルギー資源のない先進工業国として、原子力エネルギーは将来の繁栄にとって不可欠なものであります。その認識がわが国の原子力計画を支えているといえます。

現在においては、このように国によって原子力計画の違いがありますが、２１世紀

の世界を考えると、資源的にも技術的にも原子力の重要性は世界各国にとって共通したものであると思うのであります。その意味で、私は、わが国は世界の原子力計画のなかでの中核的な位置にあり、原子力発電の国際的な牽引車の立場にあると考える次第であります。

他方、わが国の原子力の現状を見ますと、原子力発電は全発電量の約３０％近くを占め、石油火力を超えて、第一の発電源となったのであります。少なくとも電力に関する限りは、原子力はもはや代替エネルギーではなく、主力エネルギーであります。これを「原主油従」の時代に入ったというわけであります。

また、そのパフォーマンスも極めて良好であります。現在、原子力発電所の稼働率は大幅に向上し、常時７０％を超えていることは、すでに有澤会長のごあいさつにあった通りでありますが、スクラムによる停止も、原子炉１基当り年0.１回と、極めて低い値を示しております。

すなわち、わが国の原子力発電は軽水炉を中心として技術的にも経済的にもエネルギー基幹産業としての基盤が確立されたということが出来ます。

以上を要約しますと、わが国の原子力開発は国際的には、今までの受身(passive)な役割から能動的（active）な責務を負う時代になった。また国内的には軽水炉を中心として原子力産業が国の計画から自立した産業部門（Sector）として確立したということであります。

このような条件のもとにわが国の原子力開発は第２ラウンドを迎えたといえます。

研究開発は常に原子力計画の重要な柱であります。現在も原子力研究開発において、ひきつづき、原子力が安全で安価な信頼性のあるエネルギー源としての役割を果たすための一層の努力が必要であることはいうまでもありません。

しかし、この第２ラウンドというべき状況のもとで、わが国の原子力研究開発はさらに新たな展開が求められております。

その主要な点をあげますと、先ず、第１に原子力エネルギーは今までの化石エネルギーが資源の存在に大きく左右される資源集約型エネルギーであるのに対して、技術力によって多くの可能性を開くことの出来る技術集約型エネルギーであります。従って実用化の進んだ現在、研究開発も今までの軽水炉から高速増殖炉への既存の実用化・産業化の路線から、より広範な原子力利用の可能性の追求へ向かうことが望まれます。これは新しい炉型の開発、電力以外のエネルギー利用の展開などであります。

第２は、先端科学技術の中核としての原子力開発であります。原子力は化学反応から核反応への飛躍という意味で人類にとっての画期的な技術革新であります。いうま

でもなく核融合や放射線利用という面において、原子力は今日の先端科学技術分野の開発に先導的な役割を果たしております。

しかし、さらに詳細に見ると軽水炉や燃料サイクルなどの原子力としては、一見確立されたと思われる技術分野においても、多くの先端技術の利用がますます活発に進んでおります。

すなわち、原子力研究開発において、先端科学技術としての原子力の位置付けを強く認識して、これを進めることが重要であります。

第3は、原子力研究開発における国際性の重視であります。今後の第2ラウンドにおいては、わが国の国際的な役割の確認と人類共通の課題の克服に向けての積極的な貢献を目指す必要があります。

また、世界の科学技術水準の向上への寄与のための革新的、創造的な研究開発への挑戦とその成果の国際社会への提供が今後の目標であり、課題であります。

以上の原子力研究開発の新展開に当って現在のわが国の情況は必ずしも楽観的なものではありません。原子力研究開発は先端的な大規模研究を必要とするものであり、大きな開発資金と技術的挑戦に応えるための人材と組織を必要とします。現下の低経済成長と国家財政の逼迫のもとにおいては、開発資金は必ずしも十分に保証されるものではありません。

また、革新的、創造的な研究開発は、今までの研究開発体制と人材の配分では十分な成果をあげることが出来ません。

すなわち、わが国の原子力研究開発は、その基本的戦略においても研究開発体制においても、抜本的な見直しを必要としております。

この場合の課題として重要と考えられる4つの点を申しあげます。

まず第1に、原子力技術基盤の強化・充実があげられます。従来の研究開発は早期の実用化を目指すことに重点を置いて進められてきましたが、今後は中長期的視野に立って支援技術を含めた広範な研究開発を行ない、層の厚い調和のある原子力技術体系を完成する必要があると思われます。

第2は、創造的研究開発を推進していくことです。原子力技術はさらに大きく発展する可能性を有しており、従来の導入技術消化型研究開発から新たな可能性を求めての創造的研究開発へ向かう必要があるのです。

さらに第3番目としては、研究開発基盤を維持していくことがあげられます。高度成長に支えられた研究開発基盤は曲がり角にきています。原子力開発の健全性を保ち、

さらに将来の可能性をひろげる研究開発を進めるための経済的基盤の維持発展をはかっていくことが必須であります。そのために新たな研究契約の方式の導入、重点的研究開発など、特別の配慮が必要であります。

また、原子炉熱利用など将来の原子力需要の増大を目指した研究開発の促進が望まれるわけです。

そして第4には、研究開発の効率化を進めていくことです。開発プロジェクトを適正に評価し、必要に応じ改廃をはかるメカニズムを確立し、研究開発のより効率的な推進をはかると共に、よりダイナミックな国際協力を展開する必要があります。

このようないくつかの課題があげられますが、さらに重要なことは研究開発体制の改革であります。わが国は今日まで原子力研究開発に多くの資金と人材を投入してまいりました。まさにその成果が今日の原子力産業の経済的、技術的な基盤の確立を達成したのだといえます。

今後の展開に向けて、この優れた人材と豊かな技術の蓄積を活かすことが最大の課題であります。このためには既存の体制を脱して新しい体制を作ることが不可欠であります。

この新しい体制にあっては、国や公的研究開発機関の役割の変化、産業技術における民間の主導性と経済性の強化、大学の政府機関および産業界との柔軟な協力関係が求められます。

国家的プロジェクトに関しても、古典的なパイロットプラント・実証プラント・実用プラントといった巨大プラントを何段階も経る方式から、最近のコンピュータ・ソフトウェアを導入したより柔軟・多様な方式の採用が考えられます。また従来の総花的な委託研究体制から各メーカーの特色および提案に基づく個別的委託や競争原理の導入も考えるべきであります。

また、基礎研究は、研究者の自由な発想によって画期的成果が生まれるものであります。その研究の進め方はできるだけ研究者および研究開発機関の自主的判断にゆだねることが肝要であります。このための各種の制度的見直しが必要となります。

現行予算制度は、プロジェクト優先で研究者の能力や創造性よりも研究成果の説得性が重視される傾向にあります。これは創造的研究と最もなじまないものです。プロジェクトを特定しない研究予算枠を設け、研究者のイニシアチブによる創造的研究にあてるなど予算制度の変革を考える必要があります。

安全性研究についても、単なる安全性検証研究をこえて、新しい原子力技術の可能性を開くための積極的な研究開発として、その成果を反映することにより、適正な安

全規制の確立に役立つものとする必要があります。

今後の研究開発体制の重要な基本課題としては、日本原子力研究所、動力炉・核燃料開発事業団の研究開発機関としての役割と体制の再検討があります。

日本原子力研究所に関しては、今後の情勢変化のもとで原子力研究開発に積極的な発展的役割を果たすことが期待されますが、そのためには、学界、産業界を含む国民の強い支持を得る必要があります。最も重要なことは、優秀な人材の確保と研究者の意欲を高揚することです。また、原子力研究から派生した他分野（新素材、超電導マグネット等）への研究の拡大、発展途上国の研究者の受け入れ等を考えることが重要であります。

動燃事業団は、これまでナショナル・プロジェクト推進上主要な役割を果たしてきましたが、プロジェクトの中にはすでに次の開発段階へ継承するもの（ウラン濃縮、再処理、ＭＯＸ加工、ＡＴＲなど）と、さらに研究開発を推進すべきもの（実用段階技術の高度化、ＦＢＲ、高レベル廃棄物）とがあります。その場合、動燃事業団の新しい性格付けの基礎として、民間との関係における開発目標の設定、技術移転の円滑化が重要となってきます。さらに、その新しい機能を考えるにあたっては、例えば、当初原型炉までを目標としていた新型炉開発の動燃事業団の役割の妥当性、共同研究・委託研究の可能性、動燃事業団のもつ強放射能・Ｐｕの取扱い機能等の特色、またエンジニアリング機能の充実等が問題となるでありましょう。

今後は、原子力研究開発における電力会社の役割が重要となります。電力会社は柔軟な将来展望のもとに、ユーザーとしてのニーズを明確に示し、動燃事業団等による公的機関の研究開発の成果をふまえ、産業技術としての原子力の発展の推進のために広範な民間産業の活力を結集し、経済性の高い実用化技術の確立を目指すべきであります。

わが国の原子力発電の高いパフォーマンスは、メーカーの優れた技術力に負うところが大きいのですが、電力需要の伸びの安定期に入った現在、将来に備えて、メーカーの技術力の維持、発展を積極的にはかることが重要であります。

また、特に強調されるべきことは、原子力研究開発における大学の役割であります。革新的、創造的な基礎研究の担い手としての大学の重要性は、いまさら強調するまでもないと思いますが、今後は大学が積極的に実用的研究の基礎的な問題にとり組むことが期待されます。このことは、原子力が技術集約型エネルギーとして優れた技術者、研究者によって支えられるものであることを考えますと、これらの人々にとって

魅力ある産業として生き続けるためにも極めて重要であります。

最後に、研究開発の国際協力について一言ふれてみたいと思います。

わが国の原子力開発は、その発足の時から、緊密な国際協力のもとに進められてきました。ＩＡＥＡ、ＮＥＡ等の国際機関や日米、日英、日仏、日独など、多くの二国間協定を通じて活発な国際協力が行なわれています。しかし、原子力後発国として出発したわが国の国際政策は、常に受身の姿勢が強かったと言わざるを得ません。今日、原子力発電設備において自由世界第３位となり、原子力開発計画も最も順調に進んでいる状況において、わが国としての主体的な構想にもとづく積極的な国際協力の基本政策を構築し、国際関係における主導的な役割を果たすべきであります。

発展途上国に関して申しますと、人材育成、研究協力、原子力発電の計画・管理、安全規制から原子炉建設、燃料供給、燃料再処理に至るまで、発展途上国からの協力の要請は広範な領域にわたっています。

将来の原子力のエネルギー源としての重要性を考える時、これらの発展途上国、特に近隣諸国の原子力計画に対して積極的に協力を行うことは、これらの諸国のみならず、わが国にとっても重要な意義を持つものといえます。そのためには、組織的、継続的に協力が進められなくてはなりません。特にそれぞれの国の実情に合致した研究開発協力を進めるべきであります。協力のための国際センター、途上国のための固有安全炉の開発等の具体的な協力の推進が必要です。

先進国ならびに国際機関との研究協力においては、資金面を含めて主導的、積極的な貢献を計るべきであります。

わが国にとっての原子力計画の重要性とわが国の国際経済における比重の増大を考える時、国際協力におけるわが国の積極的な貢献に対する期待が高まっています。

その意味で国際協力においては、もはや在来の受動的な立場をとることは許されず、意欲的な政策転換が必要であるといえるのです。

以上、原子力研究開発の展望と課題について、私なりの意見を述べてまいりましたが、皆様方の討議の一助となれば幸いであります。

REMARKS BY

COMMISSIONER KENNETH M. CARR

U.S. NUCLEAR REGULATORY COMMISSION

AT THE

JAPANESE ATOMIC INDUSTRIAL FORUM ANNUAL CONFERENCE

TOKYO, JAPAN

APRIL 15, 1987

U.S. REGULATORY INITIATIVES RELATED TO NUCLEAR RESEARCH AND DEVELOPMENT

IT IS INDEED AN HONOR TO PARTICIPATE IN THE 20TH JAPANESE ATOMIC INDUSTRIAL FORUM (JAIF) ANNUAL CONFERENCE. I WANT TO THANK DR. ARISAWA FOR INVITING ME TO TAKE PART IN THE SESSION DEVOTED TO NEW ASPECTS IN NUCLEAR RESEARCH AND DEVELOPMENT. THE CONFERENCE THEME, "NUCLEAR POWER FOR THE PROGRESS OF WORLD ECONOMY AND SOCIETY", IS CERTAINLY TIMELY AS IT PLACES THE FOCUS APPROPRIATELY ON THE ISSUES THAT MUST BE RESOLVED FOR THE NUCLEAR POWER INDUSTRY TO CONTINUE ITS ROLE AS AN IMPORTANT CONTRIBUTOR TO ENHANCED ENERGY SECURITY INTO THE 21ST CENTURY.

HAVING BEEN A PART OF THE DEVELOPMENT OF NUCLEAR TECHNOLOGY FOR OVER 42 YEARS DURING MY CAREER IN THE U.S. NAVY, AS WELL AS IN MY CURRENT POSITION WITH THE U.S. NUCLEAR REGULATORY COMMISSION (NRC), I BELIEVE MORE THAN EVER THAT IT IS OUR MUTUAL RESPONSIBILITY TO

SEE THAT THE PEACEFUL USE OF NUCLEAR ENERGY PROVIDES THE MAXIMUM BENEFIT FOR ALL MANKIND. WE MUST STRIVE TO SATISFY FUTURE ENERGY NEEDS THROUGH A STRATEGY THAT EMPHASIZES A BALANCE OF SAFE TECHNOLOGY AND ENERGY EFFICIENCY. CONTINUITY OF RESEARCH AND DEVELOPMENT IS ESSENTIAL AS A BASIS FOR FURTHER EVOLUTION OF THIS SAFE NUCLEAR TECHNOLOGY. SUCH RESEARCH WILL LAY THE GROUNDWORK FOR ENHANCED SAFETY IN EXISTING DESIGNS AND FOR EVEN SAFER DESIGNS IN THE FUTURE.

IN ORDER TO PROVIDE THE NECESSARY ENVIRONMENT TO EFFECTIVELY CONTINUE NUCLEAR RESEARCH AND DEVELOPMENT, AN INTERNATIONAL FOCUS ON SAFETY OF OPERATIONAL UNITS IS IMPERATIVE. TO FACILITATE THIS, NRC ENGAGES IN A BROAD PROGRAM OF INTERNATIONAL COOPERATION AND INFORMATION EXCHANGE, BOTH BILATERALLY AND THROUGH THE INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA) AND THE NUCLEAR ENERGY AGENCY OF THE ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD). IN THE BILATERAL ARENA, NRC HAS CONCLUDED FORMAL ARRANGEMENTS WITH THE REGULATORY AUTHORITIES OF 22 COUNTRIES UNDER WHICH WE REGULARLY EXCHANGE TECHNICAL INFORMATION AND COOPERATE IN GENERAL NUCLEAR SAFETY MATTERS. THESE ARRANGEMENTS PRIMARILY INVOLVE COUNTRIES WHICH ARE BUILDING OR OPERATING LIGHT WATER REACTORS SIMILAR TO THOSE IN THE U.S. WE HAVE ALSO RECENTLY RESUMED A DIALOGUE WITH THE SOVIET UNION WHICH MAY LEAD TO A GREATER UNDERSTANDING AND SHARING OF SAFETY INFORMATION.

SINCE CHERNOBYL, THE PACE OF MANY OF NRC'S INTERNATIONAL ACTIVITIES HAS ACCELERATED. NRC PARTICIPATED IN THE MAJOR EFFORT BY THE IAEA AND MANY OF ITS MEMBER STATES TO DEVELOP AND IMPLEMENT TWO NEW INTERNATIONAL CONVENTIONS, ONE REQUIRING PROMPT NOTIFICATION TO THE IAEA OF NUCLEAR ACCIDENTS WITH THE POTENTIAL FOR TRANSBOUNDARY RELEASES AND THE OTHER PROVIDING A VEHICLE FOR EMERGENCY ASSISTANCE REQUESTED BY AFFECTED COUNTRIES. NRC HAS SUPPORTED THE IAEA'S EXPANDED SAFETY PROGRAM, INCLUDING PARTICIPATION IN ITS INCIDENT REPORTING SYSTEM AND IN OPERATIONAL SAFETY REVIEW TEAM (OSART) VISITS TO SELECTED NUCLEAR POWER PLANTS. AN OSART VISIT IS ALSO PLANNED IN THE U.S. LATER THIS YEAR.

PRESENTLY, IN THE UNITED STATES, ABOUT 16 PERCENT OF THE ELECTRICITY USED IN THE NATION COMES FROM NUCLEAR ENERGY. THERE ARE 108 NUCLEAR POWER PLANTS LICENSED BY THE NUCLEAR REGULATORY COMMISSION TO OPERATE, WITH SOME 17 IN VARIOUS STATES OF CONSTRUCTION. HOWEVER, NO NEW NUCLEAR PLANTS HAVE BEEN ORDERED IN THE UNITED STATES SINCE 1978. THE CRUCIAL PROBLEM FACING THE NUCLEAR INDUSTRY IS HOW TO RESTORE AND SUSTAIN PUBLIC CONFIDENCE IN THE TECHNOLOGY. THIS CONFIDENCE CAN ONLY BE RESTORED WHEN THE PUBLIC RECOGNIZES THAT THE NUCLEAR POWER PLANTS ARE DELIVERING A BILLION KILOWATT-HOURS A DAY WHILE SUSTAINING AN EXCELLENT SAFETY RECORD. IT IS MY BELIEF THAT THOSE OF US WHO ARE RESPONSIBLE FOR REGULATING THE NUCLEAR INDUSTRY AND THOSE WHO

WORK IN THE INDUSTRY ARE VESTED WITH AN IMPORTANT TRUST. WE MUST REMEMBER THAT IN ALL OUR ENDEAVORS, SAFETY MUST TAKE PRIORITY. SAFETY MUST BE THE WATCHWORD FOR ALL OF US WITH NUCLEAR POWER RESPONSIBILITIES.

IN THIS REGARD LET ME MENTION SOME AREAS WHERE I BELIEVE ADDITIONAL ATTENTION IS NEEDED IN U.S. PLANTS TO INCREASE CONFIDENCE IN THE SAFETY OF PLANT OPERATION AND TO ACHIEVE IMPROVED RELIABILITY. RECENT EVENTS SUGGEST THAT MAINTENANCE AND HUMAN PERFORMANCE ARE AREAS WHERE ALMOST ALL U.S. PLANTS CAN IMPROVE. REVIEWS OF REACTOR TRIP AND EMERGENCY SAFEGUARD ACTUATIONS CLEARLY SHOW THAT A LARGE PERCENTAGE OF THESE ACTUATIONS ARE CAUSED BY BALANCE-OF-PLANT COMPONENTS. CERTAINLY, MORE ATTENTION BY INDUSTRY TO THE BALANCE-OF-PLANT WILL RESULT IN IMPROVED SAFETY AS WELL AS ECONOMIC AND RELIABILITY BENEFITS. ALSO, IT IS MY FIRM CONVICTION THAT A SIGNIFICANT KEY TO THE SUCCESSFUL OPERATION OF ANY NUCLEAR FACILITY IS COMPETENT MANAGEMENT FROM TOP TO BOTTOM. THERE MUST BE A COMMITMENT TO EXCELLENCE, AS WELL AS A DILIGENCE AND VIGILANCE IN THE INTEREST OF SAFETY--FOR THIS IS A TOUGH AND DEMANDING TECHNOLOGY.

PERMIT ME TO DESCRIBE SOME OF THE SAFETY INITIATIVES THAT THE COMMISSION CURRENTLY HAS UNDER WAY. NRC IS WORKING TO IMPROVE ITS "EARLY WARNING SYSTEM" IN ORDER TO RECOGNIZE TRENDS AND IDENTIFY POTENTIAL SAFETY PROBLEMS WHETHER THE SOURCE OF THE PROBLEMS

RELATES TO A REACTOR SAFETY SYSTEM OR TO A UTILITY MANAGEMENT OR ORGANIZATIONAL ISSUE. THE COMMISSION HAS APPROVED THE USE OF PERFORMANCE INDICATORS TO PROVIDE A MORE EFFECTIVE MEANS FOR TOP NRC MANAGEMENT AND THE COMMISSION TO RECOGNIZE CHANGES IN THE SAFETY PERFORMANCE OF OPERATING REACTORS. SOME SAFETY INITIATIVES OF THE NRC AND THE INDUSTRY HAVE BEEN UNDER WAY FOR A NUMBER OF YEARS. AN EXAMPLE IS NRC'S SEVERE ACCIDENT POLICY STATEMENT WHICH WAS ISSUED IN 1985 AND URGES THAT ALL NUCLEAR POWER PLANT LICENSEES ASSESS THE LIKELIHOOD OF A SEVERE ACCIDENT AND SEEK WAYS TO FURTHER REDUCE THE ALREADY LOW RISK OF A MAJOR CORE ACCIDENT. THE COMMISSION HAS ISSUED THE SAFETY GOAL POLICY STATEMENT WHICH STATES THAT THE RISK TO THE PUBLIC FROM THE OPERATION OF NUCLEAR POWER PLANTS SHOULD BE A SMALL FRACTION OF OTHER ACCIDENT AND CANCER MORTALITY RISKS FACED BY THE PUBLIC.

LIKEWISE, THE NUCLEAR INDUSTRY IN THE U.S. HAS ALSO BEEN ACTIVE IN IMPROVING REACTOR SAFETY AS DEMONSTRATED BY THE REACTOR SAFETY PROGRAMS OF THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI), INSTITUTE OF NUCLEAR POWER OPERATIONS (INPO), AND OTHER ORGANIZATIONS. MR. GRAHAM OF THE U.S. ATOMIC INDUSTRIAL FORUM DISCUSSED SOME OF THESE INITIATIVES YESTERDAY. OTHER EXAMPLES INCLUDE CURRENT EFFORTS BY THE BABCOCK AND WILCOX OWNERS' GROUP IN REVIEWING THE SAFETY OF THEIR PLANTS. ALSO, THE GENERAL ELECTRIC OWNERS' GROUP IS REEXAMINING THE SAFETY OF CONTAINMENT DESIGNS FOR BOILING WATER REACTORS.

RESEARCH ALSO HAS A LEADING ROLE IN ASSURING THE SAFETY OF THE EVOLVING NUCLEAR TECHNOLOGY. I BELIEVE THE PRIMARY ROLE OF NRC'S RESEARCH PROGRAM IS TO PROVIDE A SOUND TECHNICAL BASIS FOR DECISIONS ON THE RESOLUTION OF SAFETY ISSUES FOR THE CURRENT GENERATION OF PLANTS AND SAFETY ISSUES THAT MAY ARISE FOR FUTURE DESIGNS.

NRC HAS AN ACTIVE RESEARCH PROGRAM TO EXAMINE AREAS WHERE ADDITIONAL DATA ARE NEEDED TO CONFIRM PREVIOUS REGULATORY DECISIONS, TO SUPPORT THE RESOLUTION OF MAJOR POLICY ISSUES AND TO DEVELOP SUFFICIENT DATA AND UNDERSTANDING IN ANTICIPATION OF FUTURE LICENSING ACTIONS. SOME EXAMPLES ARE:

- EXPERIMENTAL PROGRAMS TO VALIDATE BEST-ESTIMATE COMPUTER CODES FOR PREDICTING THE BEHAVIOR OF FUEL AND COOLANT DURING REACTOR TRANSIENTS;

- THE STUDY OF SEVERE ACCIDENT BEHAVIOR, SOURCE TERMS AND THE DEVELOPMENT OF SEVERE ACCIDENT ANALYTICAL METHODOLOGY;

- THE STUDY OF THE EFFECTS OF PLANT AGING AND ISSUES ASSOCIATED WITH PLANT LIFE EXTENSION.

WE ARE CONCENTRATING OUR RESEARCH EFFORTS OVER THE NEXT FEW YEARS ON TOPICAL AREAS WHICH WE FEEL ARE ESSENTIAL TO RESOLVE THE REMAINING SAFETY ISSUES OR UNCERTAINTIES RELATED TO LIGHT WATER REACTOR (LWR) OPERATION. THESE AREAS ARE HUMAN FACTORS AND ACCIDENT MANAGEMENT, LIFE EXTENSION AND PLANT AGING, STUDIES ON CONTAINMENT INTEGRITY, SEVERE ACCIDENT RISK ANALYSIS AND UNCERTAINTY RESOLUTION, RELIABILITY ENGINEERING AND THE ANALYSIS OF THERMAL-HYDRAULIC TRANSIENTS. THE IMPORTANCE OF A SHARPLY FOCUSED RESEARCH PROGRAM AS A BASIS TO REDUCE UNCERTAINTIES RELATED TO SAFETY ISSUES CANNOT BE OVERSTATED.

BECAUSE OF THE NRC'S INTEREST EXPRESSED IN THE COMMISSION'S ADVANCED REACTOR POLICY STATEMENT IN DEVELOPING THE CAPABILITY FOR TIMELY ASSESSMENT AND RESPONSE TO INNOVATIVE AND ADVANCED DESIGNS THAT MAY BE PRESENTED TO THE NRC FOR REVIEW, WE CLOSELY FOLLOW THE DEVELOPMENTAL EFFORTS OF THE U.S. DEPARTMENT OF ENERGY (DOE) IN COOPERATION WITH INDUSTRY. THESE EFFORTS ARE DIRECTED AT IMPROVING THE DESIGN OF LWRs AND IN PROMOTING THE DEVELOPMENT OF THE GAS AND LIQUID METAL COOLED REACTOR CONCEPTS. FROM NRC'S POINT OF VIEW, BY CLOSELY FOLLOWING DOE'S REACTOR DEVELOPMENT WORK, WE CAN BEGIN TO FORMULATE REGULATIONS WHICH RECOGNIZE THE UNIQUE REQUIREMENTS AND SAFETY ISSUES ASSOCIATED WITH THESE NEW CONCEPTS. THUS, WHEN THESE NEW DESIGNS ARE FORMALLY PRESENTED TO US IN A LICENSE APPLICATION,

ALL THE REQUIRED PROCEDURES AND PROTOCOLS WILL BE IN PLACE. THIS SHOULD GREATLY FACILITATE AND ACCELERATE THE LICENSING PROCESS EVEN FOR THESE "NEW" CONCEPTS.

FROM ITS INCEPTION, THE NRC HAS PLACED GREAT IMPORTANCE ON INTERNATIONAL RESEARCH COOPERATION. WE PURSUE JOINT OR COORDINATED RESEARCH PROGRAMS BOTH TO EXPAND THE TECHNICAL BREADTH OF PROJECTS AND TO MAXIMIZE THE BENEFIT TO BE DERIVED FROM LIMITED RESOURCES. COOPERATIVE RESEARCH IMPROVES THE QUALITY OF RESEARCH BY PROVIDING SHARED INSIGHTS, TIMELY ACCESS TO A BROAD RANGE OF KNOWLEDGE AND EXPERIENCE, AND CROSS FERTILIZATION NEEDED TO RESOLVE TECHNICAL ISSUES.

NRC CURRENTLY HAS OVER 55 COOPERATIVE RESEARCH AGREEMENTS IN PLACE AND IS DISCUSSING AN ADDITIONAL 32 NEW INITIATIVES WITH TWENTY DIFFERENT COUNTRIES. THE UTILIZATION OF FOREIGN SAFETY RESEARCH EFFORTS IS BECOMING MORE AND MORE AN INTEGRAL PART OF THE NRC RESEARCH PROGRAM. A FEW OF THE EFFORTS CURRENTLY UNDERWAY ARE:

- THE INTERNATIONAL PIPING INTEGRITY RESEARCH PROGRAM (IPIRG), A COOPERATIVE PROGRAM ON PIPING EXPERIMENTS;

- THE STEAM GENERATOR GROUP PROJECT WHICH IS DEVELOPING VALIDATED MODELS FOR PREDICTING DEGRADED STEAM GENERATOR TUBE FAILURE. THE STEAM GENERATOR PROGRAM ALSO INVESTIGATES THE RELIABILITY OF NONDESTRUCTIVE EXAMINATION (NDE) FOR CHARACTERIZING TUBING FLAWS;

- AN AGREEMENT CONCLUDED WITH THE AGENCY OF NATURAL RESOURCES AND ENERGY (ANRE) OF THE JAPANESE MINISTRY FOR INTERNATIONAL TRADE AND INDUSTRY (MITI) CALLS FOR EPRI AND NRC PARTICIPATION IN SEISMIC STUDIES OF A 1/3 SCALE MODEL PRESSURIZED WATER REACTOR (PWR) COOLANT SYSTEM INTO THE INELASTIC RANGE;

- UNDER AN AGREEMENT WITH THE JAPAN ATOMIC ENERGY RESEARCH INSTITUTE (JAERI), RIG OF SAFETY ASSESSMENT-IV (ROSA-IV) PROVIDES FOR COOPERATIVE RESEARCH ON SMALL BREAK LOSS-OF-COOLANT ACCIDENTS (LOCAs) AND TRANSIENTS IN PRESSURIZED WATER REACTORS (PWRs). ROSA-IV IS THE LARGEST SCALE FACILITY IN THE WORLD FOR THE STUDY OF SMALL BREAK LOCAs AND TRANSIENTS IN PWRs;

- THE 2D/3D PROGRAM IS A THREE PARTY COOPERATIVE PROGRAM AMONG THE NRC, JAERI, AND THE GERMAN FEDERAL MINISTRY FOR RESEARCH AND TECHNOLOGY (BMFT) FOR THE STUDY OF LARGE BREAK LOCAs IN PWRs;

- SEVERE ACCIDENT RESEARCH IS CARRIED OUT THROUGH THE JOINT INTERNATIONAL SEVERE FUEL DAMAGE AND SOURCE TERM RESEARCH PROGRAM ORGANIZED BY THE NRC.

CONDUCTING AN EFFICIENT RESEARCH PROGRAM IN TIMES OF AUSTERE BUDGETS IS NOT WITHOUT PROBLEMS. THE COMMISSION IS WORKING TO IMPROVE THE FOCUS OF NRC RESEARCH AS IT RELATES TO THE REGULATORY PROGRAM AND TO ESTABLISH MORE MEANINGFUL PRIORITIES. WE HAVE RECEIVED RECOMMENDATIONS FROM THE NATIONAL ACADEMY OF SCIENCE REGARDING INITIATIVES TO IMPROVE MANAGEMENT AND REVITALIZE NUCLEAR SAFETY RESEARCH. ALTHOUGH OUR EFFORTS ARE NOT COMPLETE, I EXPECT THAT THE COMMISSION WILL TAKE A STRONGER LEADERSHIP ROLE ON THE FRONT LINE OF THE RESEARCH EFFORT. AS A COMMISSIONER, I LOOK FORWARD TO SERVING IN THAT ROLE AND MEETING OUR FOREIGN PARTNERS, SUCH AS YOURSELVES, IN THAT CAPACITY.

AS A REGULATOR, ANOTHER MAJOR CHALLENGE IS TO ENSURE THAT THE REGULATORY PROCESS DOES NOT IMPOSE UNNECESSARY BARRIERS TO THE DEVELOPMENT OF NUCLEAR ENERGY TECHNOLOGY. RECENTLY, NRC PROPOSED LEGISLATION TO THE U.S. CONGRESS INTENDED TO PROMOTE NUCLEAR SAFETY BY ENCOURAGING STANDARDIZATION OF FUTURE NUCLEAR POWER PLANTS AND TO PROVIDE AN ACCURATE, EFFICIENT, AND MORE EFFECTIVE LICENSING PROCESS. THE PROPOSED LEGISLATION WOULD PERMIT THE ISSUANCE OF A COMBINED CONSTRUCTION PERMIT AND OPERATING LICENSE AND WOULD FACILITATE NRC REVIEW OF ESSENTIALLY COMPLETE DESIGNS PRIOR TO

CONSTRUCTION. ALSO, NRC REGULATIONS CURRENTLY CONTAIN SEVERAL OPTIONS TO ACHIEVE STANDARDIZATION. THEY INCLUDE DUPLICATE PLANTS, MANUFACTURING LICENSES, DESIGN APPROVAL, AND DESIGN CERTIFICATION. ALL OF THESE OPTIONS ENCOURAGE STANDARDIZATION AND TO VARYING DEGREES ALLOW USE OF A SINGLE DESIGN REVIEW IN ASSESSING THE ACCEPTABILITY OF THAT DESIGN IN FUTURE APPLICATIONS. I BELIEVE THAT STANDARDIZATION OF DESIGNS HAS THE POTENTIAL FOR SIGNIFICANTLY ENHANCING SAFETY, RELIABILITY, AND AVAILABILITY OF NUCLEAR PLANTS.

WE IN THE UNITED STATES, LIKE YOU, ARE CONCERNED THAT NUCLEAR POWER CONTINUE ITS CONTRIBUTION TO A BALANCED AND DIVERSIFIED ENERGY SUPPLY THUS ENHANCING INTERNATIONAL ENERGY SECURITY FOR THE FUTURE. I BELIEVE THAT THE NRC CAN CONTRIBUTE TO A SAFE AND PROMISING FUTURE FOR FURTHER DEVELOPMENTS IN NUCLEAR TECHNOLOGY BY PROVIDING A STABLE REGULATORY ENVIRONMENT. BUT MORE IMPORTANT - EACH OF US MUST RECOGNIZE THAT INTERNATIONAL COOPERATION TO ENHANCE SAFETY OF THE TECHNOLOGY WILL PROVIDE A BASIS FOR BOLSTERED PUBLIC CONFIDENCE WORLDWIDE. IN OUR RESPECTIVE ROLES, WE EACH MUST RESPONSIBLY MANAGE AND REGULATE OUR OWN OPERATING UNITS. WE MUST MAKE SURE THAT EACH INDIVIDUAL WORKER INVOLVED IN THE CONSTRUCTION OR OPERATION OF THESE PLANTS REALIZES THAT HIS WORK IS A KEY TO THE FUTURE.

IN THIS REGARD, WE MUST FULLY ACKNOWLEDGE THE IMPORTANT ROLE OF RESEARCH IN ASSURING THE SAFETY OF THE EVOLVING NUCLEAR TECHNOLOGY AND MAINTAINING NUCLEAR TECHNOLOGICAL OPTIONS. WE MUST FACE THE IMPORTANT MANAGEMENT CHALLENGES THAT THIS BRINGS. ALTHOUGH EACH OF OUR COUNTRIES FACES DIFFERENT ECONOMIC, CULTURAL, AND POLITICAL CIRCUMSTANCES, WE MUST INCREASE OPPORTUNITIES FOR COOPERATION TO ESTABLISH A STABLE ENVIRONMENT TO FOSTER THE RESEARCH AND DEVELOPMENT OF NUCLEAR TECHNOLOGY FOR PEACEFUL ENDEAVORS. WE AT THE U.S. NUCLEAR REGULATORY COMMISSION LOOK FORWARD TO WORKING WITH YOU TOWARDS THESE GOALS.

"Methods of Promotion of Nuclear R&D in the Federal Republic of Germany and International Cooperation"

Dr. Günter Lehr, Federal Ministry for Research and Technology, Federal Republic of Germany

In the Federal Republic of Germany, promotion of nuclear research and development is oriented to the goals of energy policy. Before speaking on the promotion methods applied and on international cooperation in this field, I should therefore like to comment on the energy policy pursued in the Federal Republic of Germany.

I. The energy policy pursued by the Federal Republic of Germany

In autumn 1986, the Federal Government presented its new Energy Report, containing its assessment of the energy supply situation in the Federal Republic of Germany.

The findings of the report are as follows:

> The energy supply of the Federal Republic of Germany is generally stable, economical and compatible with the environment. Dependency on oil imports has been further reduced, German pit coal continues to be used and environmental pollution as a result of power generation has been considerably diminished.
>
> In this respect, a major role is played by the German nuclear power stations currently in operation. They are safe and there is therefore no reason to close them down.

A decision to the contrary - in other words a decision on the part of the Federal Republic of Germany to dispense with the peaceful uses of nuclear energy - would involve risks which, to some extent, can either not be properly assessed or only with great difficulty. This would entail serious consequences, in particular, for

- the Federal Republic of Germany as a country with important and complex industries (competition, industrial structure, workplaces)
- our environment (emissions released by the combustion of fossil sources of energy) and
- future generations, since deposits of fossil energy raw materials are exhaustible.

II. Future energy research in the Federal Republic of Germany

Research and development projects in the field of energy are intended to contribute to the attainment of energy policy goals. In the past, the German government's research promotion has done a great deal through its support of the application of new technologies to make the generation of energy more economical and therefore also more efficient and - where fossil sources of energy are concerned - more compatible with the environment.

In my country, government-supported energy research activities cover more than 30 years' development of nuclear energy and almost 15 years' promotion of non-nuclear energy technologies.

Energy research policy must be oriented to long-term goals. At the same time, it must start out on the basis of the existing situation and also take into account different future developments.

In the first 6 months of 1986, coal accounted for 28.1 % of primary energy consumption in the Federal Republic of Germany, mineral oil for 43.5 %, gas for 15.7 %, and nuclear energy for 9.9 %, while renewable energies accounted for a share of approx. 2.8 %.

This shows that the fossil sources of energy, with 87.3 %, continue to form the backbone of the Federal Republic of Germany's supply of primary energy. But nuclear energy is catching up: it now accounts for 35 % of the power generated in my country. I shall refer later to its further development and to the relevant priorities in research and technology.

In my highly-industrialized and densely-populated country, the major share accounted for by fossil sources of energy in primary energy consumption raises the urgent question of the resulting environmental pollution. It is true that, in past years, major successes have been achieved with the introduction of low-pollution firing and flue gas treatment systems, so that the control of sulphur and dust emissions is at present largely successful. In time, it will become possible to reduce nitrogen oxide emissions further, but this cannot be achieved before advanced technological developments have been perfected. The worldwide impact of the release of CO_2 - which is inevitable when fossil fuels are used in firing systems - must also be borne in mind.

According to optimistic estimates, renewable energy technologies may be able to increase their share of the primary energy generated in the Federal Republic of Germany up to the year 2000 from the present percentage of approx. 3 % to approx. 7 %. They are not, however, to be regarded as a substitute for nuclear energy but primarily as a fuel saver, since the use of fossil fuels will be reduced. Moreover, wind and solar energy sources are not always available.

During the past decade, the increased application of technologies aiming at energy conservation - in other words, energy-saving technologies - has been extremely successful and has helped us to ride out the consequences of the two oil crises during the 70s without suffering serious losses.

Consequently, the following goals emerge in the non-nuclear sector for a long-term energy research policy:

1. Although most experts agree that there will not be any major opportunities for the use of renewable energies before the 21st century, the Federal Research Minister will continue to give special promotion to the development of this technology. This is why promotion focuses on activities in the fields of photovoltaics and wind energy, on the utilization of biomass and geothermal energy as well as various energy storage technologies.

2. In the field of fossil sources of energy, apart from several mining engineering projects aiming to reduce the costs of coal production, activities are concentrated first and foremost on power plant engineering and combustion technologies, whose goals have now virtually become a subsector of environmental technology. In addition, there are projects for the use of unconventional oils and projects for coal conversion. In this respect, our coal gasification and coal liquefaction projects are extremely successful. However, the costs of coal conversion products - which, in comparison with today's low oil and gas prices, are still relatively high - currently prevent the large-scale introduction on the market of these products.

III. Nuclear energy development in the Federal Republic

The methods applied to promote nuclear research and development have to be considered in connection with the above energy policy and energy research goals. In order to accord proper importance to the peaceful uses of nuclear energy, it must constantly be emphasized that, after all, nuclear energy is the sole genuinely new large-scale energy source which has been discovered during the present century. In the Federal Republic of Germany, activities in this field commenced after my country regained sovereignty and in the wake of the First Geneva Conference on Nuclear Energy in 1955. From the very outset, nuclear energy development in the Federal Republic of Germany was planned as a cooperative action by government, the science community and industry.

This coherent interaction between government, the science community and industry is, by the way, characteristic of the development of nuclear energy in practically all highly-industrialized countries, although the individual countries have chosen different ways of organizing this cooperation. In my opinion, such cooperation is the sole method which promises success with regard to the development of new large-scale technologies - e.g. also with regard to space technology.

It is important for the success of this strategy - at least in view of the social, economic and political general conditions prevailing in the Federal Republic of Germany - that the respective roles of the three partners (government, the science community and industry) are not rigidly established from the very outset for the entire duration of a development programme.

The first requirement made of the government is that it establish reliable general conditions even if these will have to be modified later on in the light of new knowledge. First, clear legal principles must be elaborated for these general conditions to be established by the government. In the Federal Republic of Germany, such legal principles were first and foremost created by the Atomic Energy Act passed in 1959. This Act established two basic mandates for the government, namely

1. The promotion of research, development and the use of nuclear energy for peaceful purposes and
2. the protection of life, health and property from the hazards of nuclear energy.

Establishing such general conditions also meant providing an appropriate basic infrastructure for the work of the science community. In the Federal Republic of Germany, this was first achieved with the development of existing institutions, that is, the relevant institutes at the universities and those maintained by the Max Planck Society, and then - for the first time in this form, even though based on foreign models - by setting up national research centres maintained and financed by the government.

Owing to post-war conditions and the statutory prohibition of research imposed by the Occupying Powers, the Federal Republic of Germany lagged considerably behind other Western industrialized countries in the field of nuclear research and technology. First, universities, the Max Planck Society and national research centres endeavoured to develop research in the nuclear sector, including the construction and operation of research reactors.

More or less concurrently, German industry endeavoured first of all to produce reactor lines of its own but then directed its attention to the construction of light-water reactors on the basis of foreign licences. This helped industry to catch up fairly quickly with the level of reactor technology and, on this basis, to introduce successfully its own reactor lines on the market.

The fact that German nuclear power stations are unusually efficient and safe can be already deduced from the annual 'hit lists', in which reactor performances are listed in an international comparison. Against this background the demand voiced by certain groups in the Federal Republic of Germany that all German nuclear power stations be closed down can hardly be backed up by sound reasons. The Federal Government's Energy Report, which I mentioned at the beginning of my speech, therefore comes to the conclusion that

- in view of the worldwide demographic development (it is estimated that the world population will have doubled by the year 2025),
- in view of the anticipated world primary energy consumption (up to the year 2020, consumption is expected to double and up to the year 2060 it may triple),
- in view of limited fossil energy reserves,
- in view of the anticipated price trend with regard to sources of primary energy and, in particular,
- in view of the increasing environmental pollution as a result of the use of fossil sources of energy

it would be an unjustifiable action if the Federal Republic of Germany were to dispense with the peaceful uses of nuclear energy.

In his government declaration of March 18, 1987 - that is only a few weeks ago - the Federal Chancellor once again explicitly advocated the peaceful uses of nuclear energy. These uses, he said, would be justified, because German safety provisions met the most stringent requirements.

Following these more general remarks on nuclear energy, I shall now speak on the promotion of individual areas of nuclear engineering.

1. Reactor safety research

Due also to the renewed controversies concerning the use of nuclear energy in our country which have been triggered off by the events of Chernobyl, we are continuing to focus our research and development efforts increasingly on the subject of reactor safety research, the priority areas being:

- accident management
- man-machine interface and
- vented containment.

As far as accident management is concerned, the central goals of our research projects are accident prevention, accident limitation and post-accident management.

Projects on the subject of man-machine interface are intended first and foremost to prevent events from taking a turn similar to that characteristic of the accident in Chernobyl.

Projects on the subject of vented containment concern the controlled depressurization of the containment via filters, whose further development and improvement is being systematically promoted.

2. Advanced reactors

The category 'advanced reactor lines' is understood to comprise the development of the sodium-cooled fast breeder reactor and that of the helium-cooled high-temperature reactor.

The methods applied in the Federal Republic of Germany for the promotion of a nuclear technology are demonstrated particularly well by the activities undertaken to develop these two reactor lines.

The first step was the construction of experimental reactors in national research centres with a final output of several tens of megawatts: the AVR at the Jülich Nuclear Research Centre for the high-temperature reactor line and the KNK at the Nuclear Research Centre Karlsruhe for the fast breeder

line. The latter is comparable with the JOYO reactor in Japan. It can be seen from this that, during this first stage development and testing were the task of a national research centre. It is true that the centre cooperated closely with universities and Max Planck institutes on the one hand and with the reactor-builders and their subcontractors on the other hand. But the centre - and therefore in the final instance, the government - retained responsibility for management and funding. Both experimental reactors have been operating successfully for several decades and are still in operation.

On the basis of experience gained with these experimental reactors, prototype reactors with an output of several hundred megawatts were then tackled: the THTR 300 in Schmehausen for the high-temperature reactor line and the SNR 300 in Kalkar for the fast breeder line. Responsibility for development and construction was thus transferred from the government to industry, namely to reactor construction firms for setting up the reactors and to power supply companies as contract-awarding parties and builder-owners in the construction phase and as operators later on. At first, government responsibility for funding the reactors was almost 100 % and today - following considerable cost increases and delays in the construction schedule - chief responsibility for their financing still lies with the government.

The operating costs of both the prototype reactors THTR 300 and SNR 300 are met from electricity sales revenue. In order to guard against specific risks involved in the operation of prototype reactors such as temporary low availability, longer shutdown periods or even premature decommissioning - steps have been taken to provide funds under a risk-sharing contract concluded between the respective operator and the government.

In the meantime the THTR 300 has long reached full power and is now in trial operation. It will shortly be handed over by the manufacturer to the operator. This means that the Federal Republic of Germany has achieved a leading position worldwide as regards this reactor line, which, for several reasons, is extremely interesting.

To all intents and purposes, the SNR 300 is also ready to go into operation and the licence for nuclear commissioning is awaited. There have been delays in the licensing procedure, which, in accordance with the legal situation in the Federal Republic of Germany, has to be implemented by the Government of Land North-Rhine Westphalia on behalf of the Federal Government. The said delays have been caused by differences of opinion on the part of the Federal and Länder governments.

Owing to its loop concept and its size, the SNR 300 largely corresponds to the MONJU reactor currently under construction in Japan.

The Federal German Government considers its direct promotion task fulfilled with the completion of these prototype reactors, THTR 300 and SNR 300. It is now industry's task to decide how and with what output it intends to introduce the two reactor lines on the market.

As regards the high-temperature reactor line, a 500 MW version, the HTR 500, is being discussed. Its power generation costs are to be no higher than those of the modern light-water reactors, which are twice as big. In addition, smaller versions are to be offered in the 100 MW range, for the generation both of power (electricity) and of process heat.

As regards the fast breeder, planning activities are envisaged for an SNR 2 - a breeder in the 1,000 MW class - which is to be constructed in Germany within the framework of international participation.

The transfer from the government to industry of the decision concerning the realization of such follow-up projects - and therefore also their management and funding - does not, however, mean that the government is longer interested in the future of these reactor lines. The government will continue to promote research projects on related problems,

particularly with regard to the safety aspects involved, though to a far lesser extent, and still drawing on the human resources available in the respective national research centres.

I hope that, with this example, I have been able to explain clearly to you the methods applied in the promotion of nuclear research and engineering in the Federal Republic of Germany. As a nuclear technology reaches maturity, responsibility for management and funding is transferred from government to industry.

3. Enrichment

The same promotion method is applied in the case of enrichment. R&D for centrifuge enrichment and the production of enriched uranium have been transferred completely to industry within the framework of direct international cooperation. Government promotion is no longer provided. Only laser enrichment, as an option for the future, is still being promoted by the government to the amount of approx. DM 10 million per year.

4. Reprocessing and recycling

Following the execution of important preliminary work in this field, particularly at the Nuclear Research Centre Karlsruhe, and the construction of a prototype plant, the continued promotion of reprocessing and recycling activities is a task for industry. The Wackersdorf reprocessing plant is also an industrial project. The government still promotes research and development concerning safety, safeguards, radiation protection and protection of the biosphere against radiation. Promotion funds amount to approx. DM 35 million per year.

5. Disposal and final storage

In accordance with the Atomic Energy Act, the government is directly responsible for disposal and final storage. The costs involved, as well as the costs incurred by relevant

as well as the costs incurred by relevant research and development activities, are borne by the users - that is, by the power supply companies. Promotion funds amount to approx. DM 150 million per year.

Development activities concerning direct final storage are also the responsibility of industry. Government funds are provided only for safety and monitoring.

6. Fusion

Fusion research in the Federal Republic of Germany is fully integrated in European cooperation. This also applies particularly to the joint European JET project and to the preparation of the NET follow-up project.

Fusion research is a subject which is extremely well suited to international division of effort and cooperation owing to its long-term character and the tasks and amount of funds involved. We would very much like to expand the basis of work even further and hope that the four major centres of fusion research - namely Japan, the Soviet Union, the USA and Europe - will soon join forces to cooperate on joint activities.

IV. International cooperation

With reference to the example of nuclear fusion, I should now like to add a few comments on international cooperation. In the sector of energy research, and particularly in the field of nuclear research and development, international cooperation has always been considered extremely important. Irrespective of current events, there are several important reasons for practising international cooperation in this field:

- Exchange of information, cooperation and division of effort in the field of energy research bring about a more efficient use of available knowledge, capacities and funds. This is of particular importance in the case of major projects involving considerable time, outlay and effort.

- The large-scale generation and use of energy often has transboundary repercussions on the environment. This calls for close cooperation - particularly in the densely-populated area of Central Europe - on the monitoring of emissions and in connection with short- and long-term measures designed to prevent, or reduce, damage. This need for international cooperation has become more pressing as a result of the events in Chernobyl. Today, the general public demands the further development of transboundary cooperation.

- Uniform measuring techniques and standards can be developed only on the basis of international cooperation. Such techniques and standards are crucial to facilitating a comparison of the designs of safety-related components and of the economic efficiency of reactors. Such techniques and standards also permit optimization by the combination of domestic and foreign components. This is particularly important for cooperation with developing countries.

- Cooperation with developing countries with the aim of improving and securing their energy supply should constitute a primary aim of international cooperation. This is also in the industrialized countries' interest, because several of the current uses of energy in developing countries - e.g. burning wood - will, in the long term, have adverse effects on nature and the climate on a global scale.

1. Cooperation in international organizations with extensive tasks and large memberships

It was precisely the joint development and use of nuclear energy that, during the past few decades, formed an integral part - or even prompted the establishment - of international organizations. It is clear that, given different national goals and often different levels of technological development, common interests were frequently oriented to only relatively general goals.

For the Federal Republic of Germany, cooperation in the following programmes and agreements in the nuclear energy sector is of special importance:

- One of the three keystones of the European Community was the joint promotion of the peaceful uses of nuclear energy by EURATOM. At the present time, nuclear energy research activities are concentrating on two priority topics, namely

  ° the research and development activities on nuclear fusion already mentioned, which are clearly long-term in nature, and,

  ° in the now classic sector of fission energy, R&D work concerning reactor safety problems, including fissile material safeguards, and the disposal of radioactive wastes.

- A further important example of international cooperation is the work undertaken by the OECD. Major activities in the field of nuclear energy are concentrated at the Nuclear Energy Agency (NEA). For the Federal Republic of Germany, participation in the activities of NEA are important, especially with regard to reactor safety research and to nuclear fuel cycle problems.

- Cooperation within the International Atomic Energy Agency (IAEA) has gained increasing importance - particularly in the eyes of the public - in the months following the Chernobyl disaster. Within the wide range of its activities, growing interest is focused particularly on reactor safety questions, on the safeguarding of nuclear material and on the uses of nuclear energy in the specific conditions prevailing in developing countries.

2. Cooperation between several countries in defined sectors of nuclear energy

In addition to joint activities within these large international organizations, cooperation is practised at the bilateral or multilateral level, which is frequently concerned with the implementation of joint large-scale projects.

- One good example in the sector of reactor safety is the big science project 2D3D/UPTF jointly devised by Japan, the USA and the Federal Republic of Germany.

- Several European countries - and, to some extent, also some non-European countries - are cooperating in the joint fast breeder development and on specific nuclear fuel cycle problems, including plutonium recycling.

- It is a particular indication of the economic maturity which has been achieved in the uses of nuclear energy that joint transboundary activities are being agreed and carried out with success not only between governments but also to a rapidly increasing extent between industrial firms.

I could quote many more examples of this.

It is a pleasure for me to take this opportunity here, in our host country, Japan, to express the view that, in my opinion, the opportunities for Japan and the Federal Republic of Germany to practise cooperation precisely in the field of the peaceful uses of nuclear energy have by no means been exhausted. The long-standing close contacts established between both sides at all levels of government, industry and the scientific community constitute a sound basis for continuing this cooperation and all are capable of further development.

Ladies and gentlemen,

the world has become even smaller, even after Chernobyl, and precisely because of Chernobyl. Let us draw the logical conclusion from this bitter experience and endeavour to build up more confidence by engaging in even closer international cooperation in the peaceful uses of nuclear energy.

原子力研究開発の新しい展開

動力炉・核燃料開発事業団
副理事長　石渡鷹雄

1．はじめに

日本における原子力研究開発は，昭和30年12月に制定された原子力基本法により，進められている。この法律は，原子力の研究，開発及び利用を推進することにより，①将来におけるエネルギー資源を確保し，②学術の進歩と産業の振興を図り，もって人類社会の福祉と国民生活の向上に資するものとしている。この考え方に従って，過去30年以上に亘って，国は，約３兆円の資金をその研究開発に計画的に投入して来たのである。

この巨大な研究開発プロジェクトは，エネルギー資源の確保という点で概ね成功しつつあるといえる。しかし学術の進歩と産業の振興に寄与するという点では，まだ課題が残されていると思われる。即ち，軽水炉発電体系は，確立されつつあるが，一方，これまで進められてきた新型動力炉開発，燃料サイクルの分野での研究開発は産業界での実用化へ向けての展開がようやく始まったところであるからである。さらに，チェリノブイル事故後のより一層の安全性の向上およびエネルギー源間のコスト面の競争などを背景に，より一層の経済性向上も求められてきているという実態もある。

また，より広範な研究開発の展開として，独創的な原子力技術の開発など，今後政府における，新しい視点に立った原子力研究開発政策の展開が必要である。

2．ウラン利用体系における研究開発

我が国の炉型戦略としては，「軽水炉からＦＢＲへ」をその基本としているが，今日の天然ウラン需要の緩和状況に加え，軽水炉技術の定着状況及び今後のより一層の高度化の見通しを勘案すると，軽水炉主流時代は，従来考えられていた以上に続くものと考えられている。

このため，軽水炉技術の高度化や技術革新を目指した技術開発を推進すると共に，軽水炉によるウラン利用体系を支えるウラン燃料加工，ウラン濃縮，軽水炉再処理および高レベル廃棄物の処理・処分等の核燃料サイクルの確立を図ることの重要性が一層増大してきている。特に，遠心分離法ウラン濃縮，軽水炉再処理等のプロジェクトは，実用化移行段階にあり，ウラン利用体系の開発は，今後民間によって主体的かつ積極的に行われると考える。

従来，これらの技術開発を担当してきた動燃においては，原燃産業㈱および原燃サービス㈱の両事業体における事業化を支援及び補完することを目的に，技術移転・技術協力を重要業務として積極的に進めている。

3．プルトニウム利用体系における研究開発

(1) プルトニウム利用の意義

天然ウランを海外に依存している我が国においては，欧米各国のインセンティブ以上に，ＦＢＲを中核としたプルトニウム利用体系の確立を目標として，政策展開を図ることが必要である。再処理等の高度な技術を用いて回収されるプルトニウム及びウランは，技術が作り出すエネルギー資源であると同時に，原子力利用体系の経済性の向上等の可能性を秘めているといえる。即ち，プルトニウムの利用を推進することにより，天然ウラン及び濃縮ウランに対する需要を抑え，価格の安定への寄与が期待できるからである。

以上の観点から，軽水炉によるウラン利用に優るプルトニウム利用体系の確立を目指し，着実に研究開発を行うことが期待されるところであり，国の研究開発機関の果たすべき役割は大きい。

その際，核不拡散への国際的責務を強く認識し，保障措置，輸送技術等を含め，トータルシステムを構築していく努力を積み重ねることが重要である。

(2) ＦＢＲの実用化までのプルトニウム利用推進

ＦＢＲの実用化の時期は2020年～2030年頃と考えられているが，

これまでの助走期間あるいは中間段階として，軽水炉およびＡＴＲでのプルトニウム利用を進め，段階的にプルトニウム利用体系を確立していくことは合理的な選択であると考える。

このようにＦＢＲの実用化に先立ちプルトニウムを利用することによって，再処理技術，ＭＯＸ燃料加工技術等のプルトニウム利用に係る広範な技術体系の高度化及び経済性の向上が図られ，ＦＢＲ技術の高度化と相まって，ＦＢＲが軽水炉に比し経済的に競合し得るようになることが期待できるのである。

(3) ＦＢＲ実用化を目指した研究開発

ＦＢＲの開発を進めるに当たっては，軽水炉によるウラン利用体系に優るＦＢＲによるプルトニウム利用体系を積極的に開発していく姿勢が必要であり，そのための開発政策が進められなければならない。

また，ＦＢＲは技術的に多様な広がりを持っており，開発を進めるに当たっては，プラント及び燃料サイクルを一体的なものとしてとらえ，プラントシステム，燃料・材料等に係る革新的な技術のブレークスルーを図ることも重要である。燃料開発については，経済性・信頼性向上のため，高燃焼度燃料，新型燃料等の開発を総合的に進める必要がある。一例をＦＢＲ再処理の開発について述べると，全サイクルコストの低減を図る観点に立って，技術革新を目指した実証試験を進め，この成果をもとに「パイロットプラント」の設計・建設に進んで行くことを計画している。

4．原子力研究開発の新たな展開

前述の基本法に，学術の進歩への貢献が義務づけられている。

従来の原子力研究開発は，エネルギーの安定確保を目指して，実用化．早期達成を目的とした研究開発に重点を置いて推進されてきた。今後は，安全性の一層の向上，経済性の向上等原子力利用に課せられたニーズの多様化・高度化に柔軟に対応していくとともに，独創的な原子力技術を開発することが重要となる。

一方，原子力技術は，種々の先端技術から構成される総合的技術体系であり，独創的な原子力技術の開発への努力は，日本の科学技術政策の中核の一つとしての役割を果たすことになろう。

5．人類社会への貢献（国際協力の重要性）

日本の技術開発の進展に伴い国際協力における領域も広がり，初期の頃の技術導入型から，イコールパートナーとしての協力活動が求められてきている。

そのためには，原子力の研究開発の分野において共同研究，研究者の相互交流，施設共同利用等の研究開発レベルでの積極的な国際協力の積み重ねが，これまで以上に重要になっていると考えている。

また，最近の欧米の原子力関係プロジェクト推進の低迷傾向をふまえ，我が国は国内はもちろん，国際協力を通じて研究開発活動を一層推進し，革新技術，新概念等を創出していくことにより，国際社会に貢献していくことは，我が国の責務と考える。

原子力研究開発の新しい展開

中部電力株式会社
常務取締役　山崎　巍

はじめに

我が国における原子力発電は１９８５年度に全発電電力量に対する割合が、石油火力を抜いて第一位の電源シェアを占め、１９８６年度には２８％を越えるに至った。

一方、永年の懸案であった原子燃料サイクルについても青森県下北で、事業化が進行中である。

しかし、原子力発電の開発利用を更に高め、社会経済に寄与してゆくためには、今後とも、所要の研究開発の推進とその効率的実施が必要であり、この機会を使わせていただいて、若干のコメントを申し上げたい。

	設備構成比［％］			発電電力量構成比［％］		
年　度	６１	６６	７１	６１	６６	７１
原子力	１７	１９	２４	２８	３２	３８
水　力	２２	２１	２０	１４	１３	１３
石　炭	７	８	９	１０	１０	１１
LNG, LPG, その他	２２	２５	２４	２５	２６	２３
石　油	３２	２７	２３	２３	１９	１５

注：１．昭和６２年度電力長期計画（６１年度は推定実績）
２．９電力，電発，その他受電分（ＭＩＴＩ発表の数値には電力会社以外への卸分も入っているため，原子力比率は約１％低くなる）
３．速報では，原子力比率は約２９％となっている。

原子力ビジョンの主要データ

		1985	2010	2030
原子力発電設備	(万kW)	2,452	8,700	13,700
同比率	(%)	16	32	40
基　数	(基)	32	86	112
原子力発電電力量	(億kWh)	1,590	5,500	9,000
同比率	(%)	26	49	58
原子力産業売上高	(兆円)	1.6	4.2	6.7
原子力施設従事者数	(万人)	5	13	17
原子力の一次エネルギー供給に占める比率	(%)	9	20	27

注：１．数値は低位予測の場合
高位予測では　２０１０年　７７００万ｋＷ　４８００億ｋＷｈ
２０３０年　１０７００万ｋＷ　７０００億ｋＷｈ
２．原子力発電所の設置基数（含リプレース分）
１９８６～２０１０年平均　２．３基／年
２０１１～２０３０年平均　３．２基／年

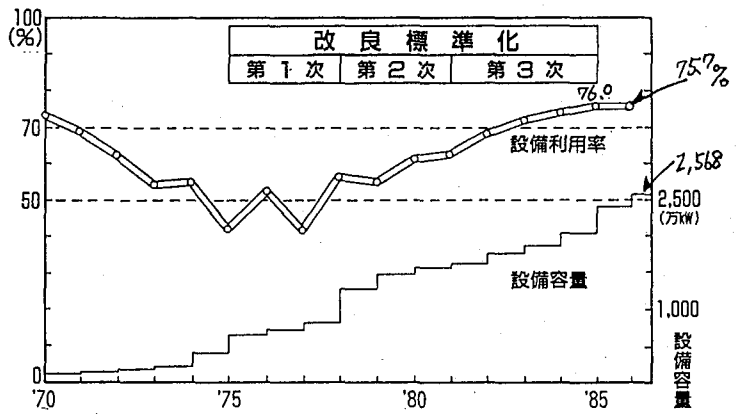
（出典）２１世紀の原子力を考える（通産省編）

1．　これまでの研究開発と今後の研究開発の方向性

我が国における事業用原子力発電は軽水炉を米国から導入した初期の段階において、配管の応力腐食割れ、蒸気発生器のチューブの漏洩等のトラブルを経験し、自主技術による対応の必要性を痛感した。これを契機に官民一体となって第１次、第２次および第３次改良標準化を進めた結果、信頼性の向上、被曝量の低減等めざましい性能の向上がはかられた。

これから先、我が国が取り組まねばならない研究開発分野は「軽水炉高度化と原子燃料サイクル」および「ＦＢＲの実用化」であると認識している。

原子力発電設備利用率及び設備容量の推移



①第１次改良標準化（昭和50年度～昭和52年度）
②第２次改良標準化（昭和53年度～昭和55年度）
③第３次改良標準化（昭和56年度～昭和60年度）

（出典）原子力ポケットブック

（第１次及び第２次改良標準化計画の成果の概要）

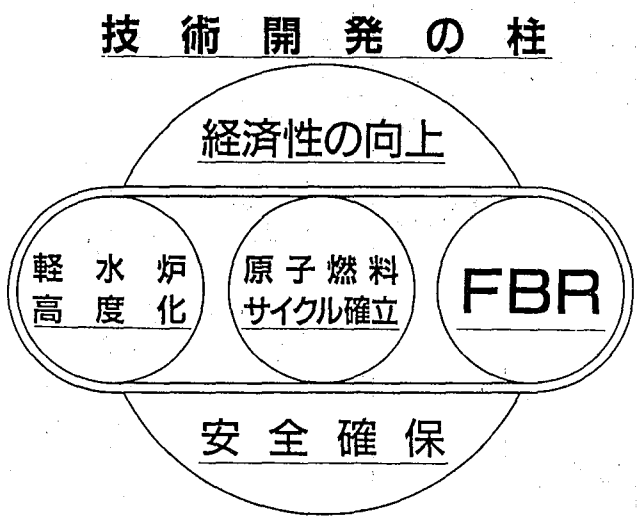
		従来のプラント (80,110万kW級)	第１次改良標準化プラント (80,110万kW級)	第２次改良標準化プラント (80,110万kW級)
信頼性及び稼動率	時間稼動率	プラントにより	約75%	約80%
	設備利用率	かなり異なる	約70%	約75%
定期検査日数		90～100日 (補修工事がない場合)	約85日 (同左)	約70日 (同左)
従業員の作業放射線量		(100%とする) 〔約500 人・レム/年・炉〕	約75% 〔約350 人・レム/年・炉〕	約50% 〔約250 人・レム/年・炉〕

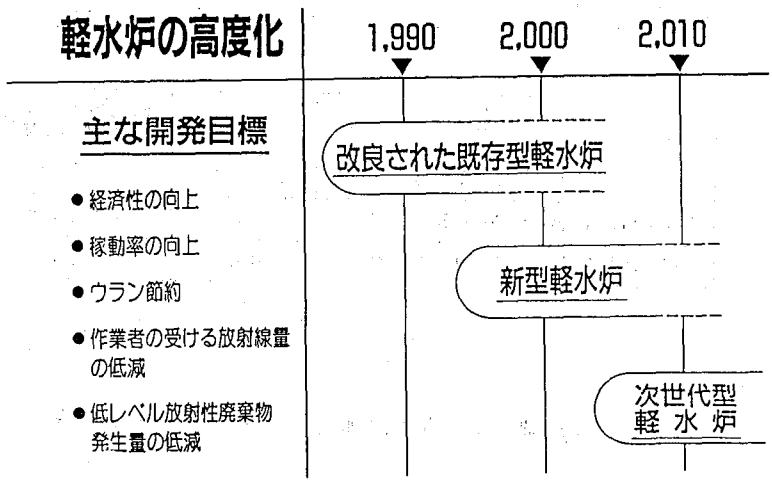
2．　電気事業者としての今後の研究開発の考え方

2－(1)　軽水炉高度化と原子燃料サイクルの確立に向けての研究開発

ＦＢＲの実用化時期がやや遅れ、軽水炉時代の長期化が予想される現在、軽水炉の安全性、信頼性を高めつつ、より一層の経済性向上をめざした軽水炉の高度化と原子燃料サイクルの確立に取り組むことが、我々の考えている技術開発分野の１つの柱である。

すなわち、安全確保を最優先としつつ、経済性向上をはかるため、軽水炉技術の高度化、具体的には稼動率の一層の向上、建設費のコストダウン、保修・運転の効率化、高燃焼度化等の燃料効率化の向上に取り組むと共に、フロントエンド・バックエンドを含む原子燃料サイクル全体の経済性の向上を図ることにより、トータルシステムとしての原子力発電を最適化し発電のコストミニマムをはかるべく、技術開発を進める考えである。



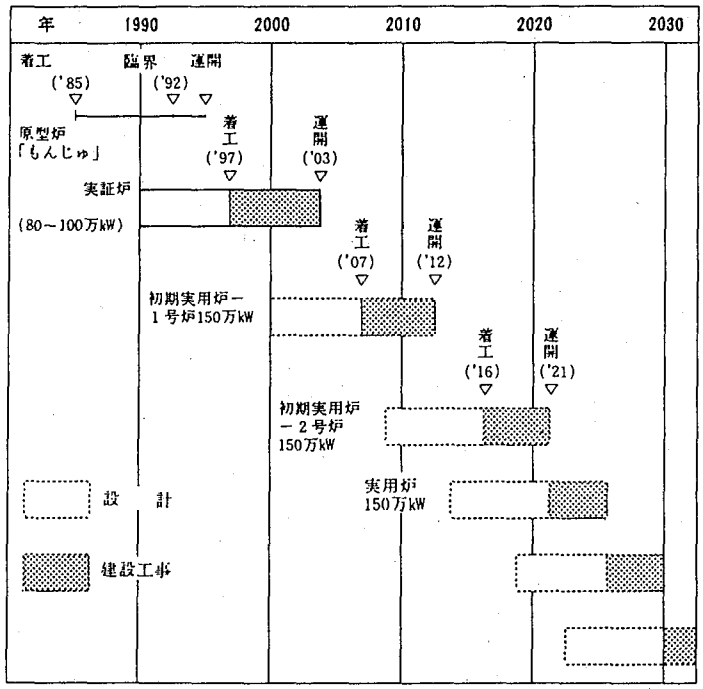


２－(2)　ＦＢＲ実用化に向けての研究開発

２１世紀を展望した資源の有効利用とエネルギーのより長期な安定を目指すために、私ども電気事業者として「軽水炉からＦＢＲへ」を原子力開発の基本路線と考えており、ＦＢＲは我が国にとって将来の原子力発電の主流とすべきものであると考えている。

電力として、その２１世紀ビジョンにおいて２０３０年頃をＦＢＲ実用化のターゲットとして、それまでに技術的、経済的問題解決の見通しを立てる計画としている。そのためには、現在建設中の原型炉「もんじゅ」に引き続き、２～３基の実証炉開発を経て、段階的に軽水炉とほぼ同程度の発電原価を目指すための研究開発を、国際協力も考慮しつつ、積極的に推進する考えである。

図３-４　FBR開発見通し



	出　力　規　模	運開時期	建設費の目標(軽水炉に対する倍率)
実　証　炉	80～100万KWクラス	2003年頃	1.5倍程度
初期実用炉１号炉	130～150万KWクラス	2010年代前半	1.2倍程度
初期実用炉２号炉	130～150万KWクラス	2020年代前半	1.1倍程度

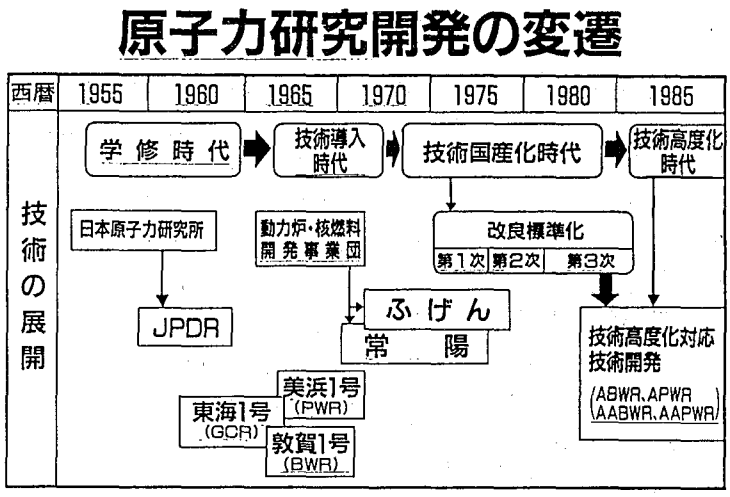
（出典）２１世紀の原子力を考える（通産省編）

３．研究開発体制

３－(1)　研究開発の変遷

我が国の原子力研究開発は、１９５０年代後半に始まる。当初は、国は日本原子力研究所を中心に基礎研究を、民間は発電プラントの導入研究を進めてきたが、１９６７年に国の機関として動力炉・核燃料開発事業団が設立され、ＡＴＲ原型炉「ふげん」やＦＢＲ実験炉「常陽」等の自主技術による大型プロジェクトの実証開発が進められるようになった。

一方、軽水炉は初期の段階において、前述のように数々のトラブルに遭遇し、自主技術による信頼性向上が痛感されたため、１９７０年代後半には、軽水炉分野で官民一体となって改良標準化計画が進められるとともに、民間における共通課題を効率的に解決する目的で「電力共通研究」というシステムも確立された。



	型　式	出　力	運転開始
ＪＰＤＲ	－	１２.５ＭＷ	１９６３　初送電
東海１号	ＧＣＲ	１６６　ＭＷ	１９６６　運転開始
敦賀１号	ＢＷＲ	３５７　ＭＷ	１９７０　運転開始
美浜１号	ＰＷＲ	３４０　ＭＷ	１９７０　運転開始
常陽	ＦＢＲ	１００　ＭＷ	１９７７　臨界
ふげん	ＡＴＲ	１６５　ＭＷ	１９７９　運転開始

３－(2)　新しい時代に対応する研究開発体制

これまで、原子力の基礎的および、実証移行段階までの研究開発を中心にかなりの部分が、国ならびにその関係機関で行われてきたが、近年、プロジェクトの実用段階への移行と、原子燃料サイクルのように事業化段階に達したものもあって、技術開発分野における民間の役割は益々増大しつつある。このため、レーザー濃縮技術研究組合や、技術研究組合原子力用次世代機器開発研究所および、原子燃料サイクル事業のようなプロジェクト毎の民間組織が設立される方向にある。

今後、多様化する研究開発を効率的に推進するためには、官民の役割分担を明確にすると共に、その成果の実用化のために国から民間への技術移転を円滑に行うことが重要である。民間は、特に、信頼性の向上、コストダウンおよび、運転保守の合理化等、実用化に向けての研究開発に重点を置いて推進する考えである。

また、リスクが大きく、多額の資金と期間を要するような技術については、国際協力も含めて、推進するといった方策も必要であると考えている。

技術開発計画に関する基本的な考え方

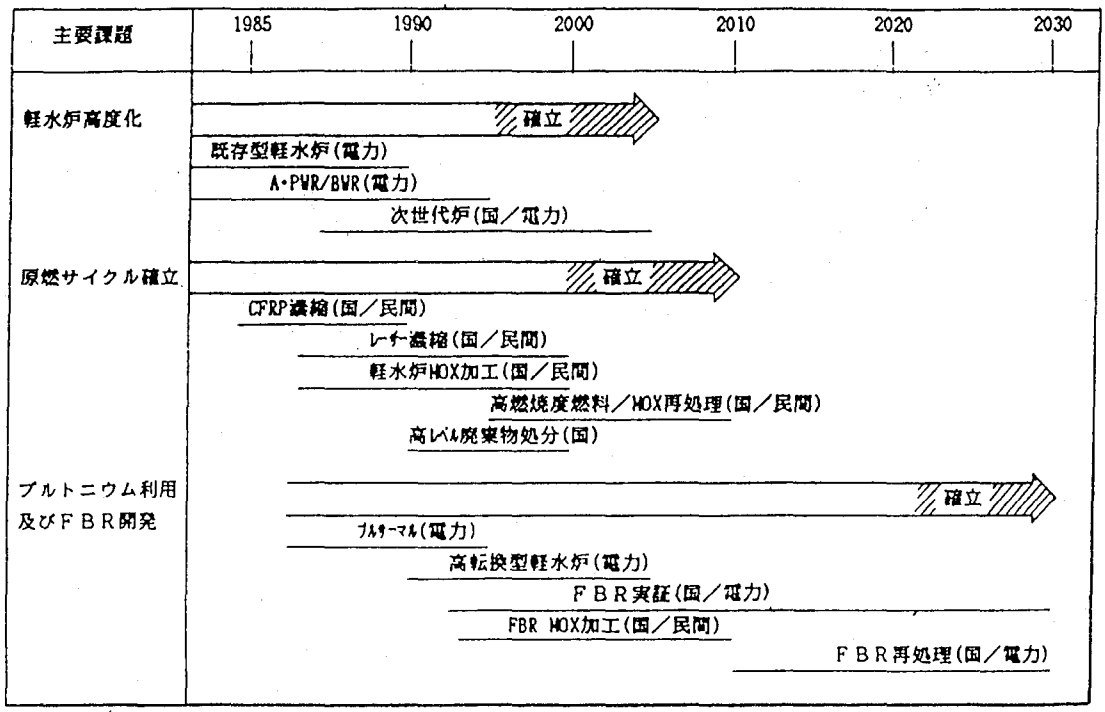


図５－３　技術開発課題

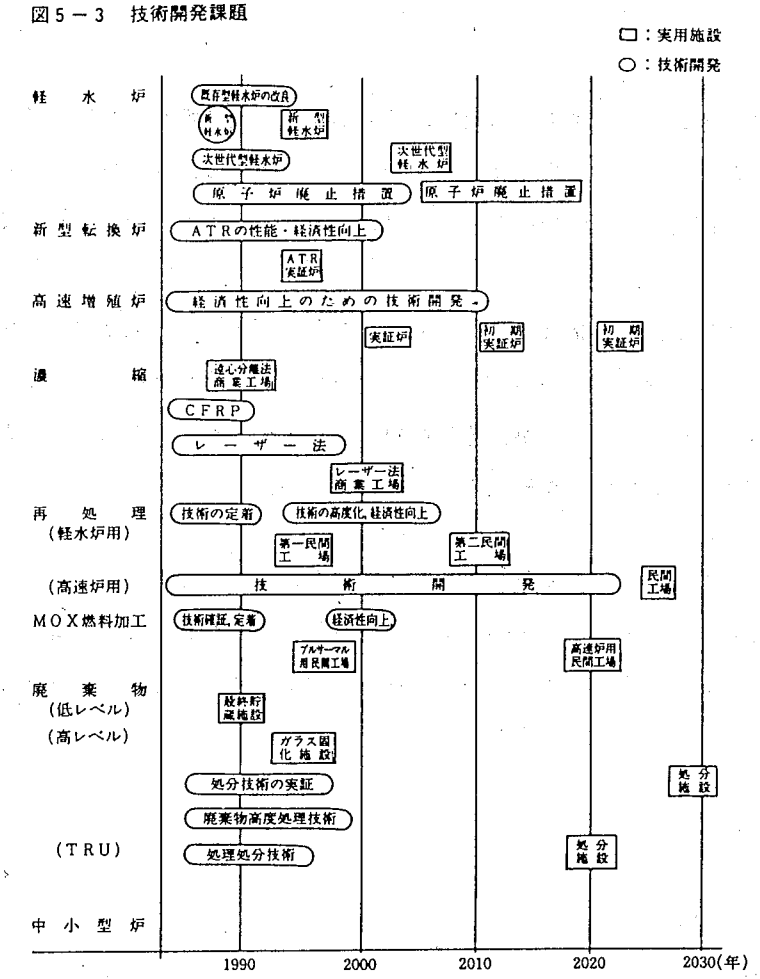
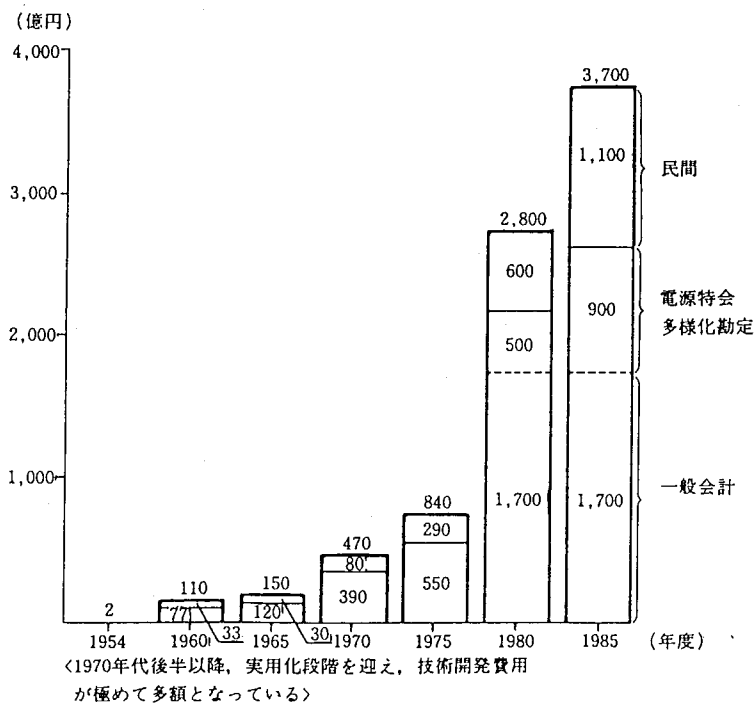


図５－１　原子力技術開発資金の推移



（注）　民間の技術開発資金は，原子力産業実態調査報告(原産会議)による。

（出典）２１世紀の原子力を考える（通産省編）

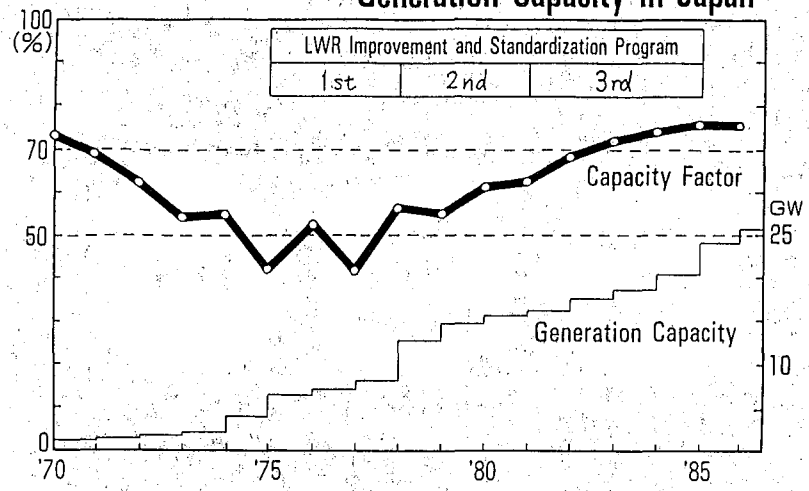
むすび

以上、電気事業者として考えている研究開発のおおきな方向性を述べた訳であるが、軽水炉の安定運転が定着し、原子燃料サイクルの確立とＦＢＲの開発を目指す今日、原子力利用は更に高度な段階に歩を進めるひとつのターニングポイントに差しかかっていると思われる。

原子力の研究開発は、実用化までに長期間を必要とし所要資金も大きいことから、適時に国と民間の研究開発計画の総合調整やテーマの選別・重点化を行いつつ、これら成果を最も効率的に実用化していくことが、今後の原子力産業の成否に重要な係りをもつという強い認識にたって、今後の新たな展開を考えていきたい。

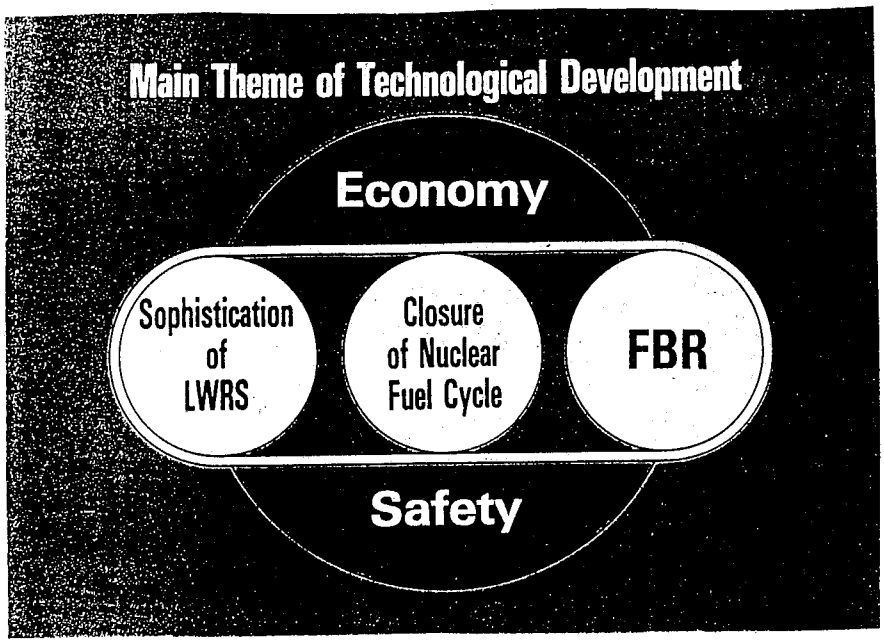
原子力は，言うまでもなく，人間の知恵が人類にもたらした唯一のエネルギーであります。私共は，このエネルギーを人類のためにより一層役立たせるために，研究開発を進めることは十分価値あるものであると認識し，努力してまいりたいと思っております。

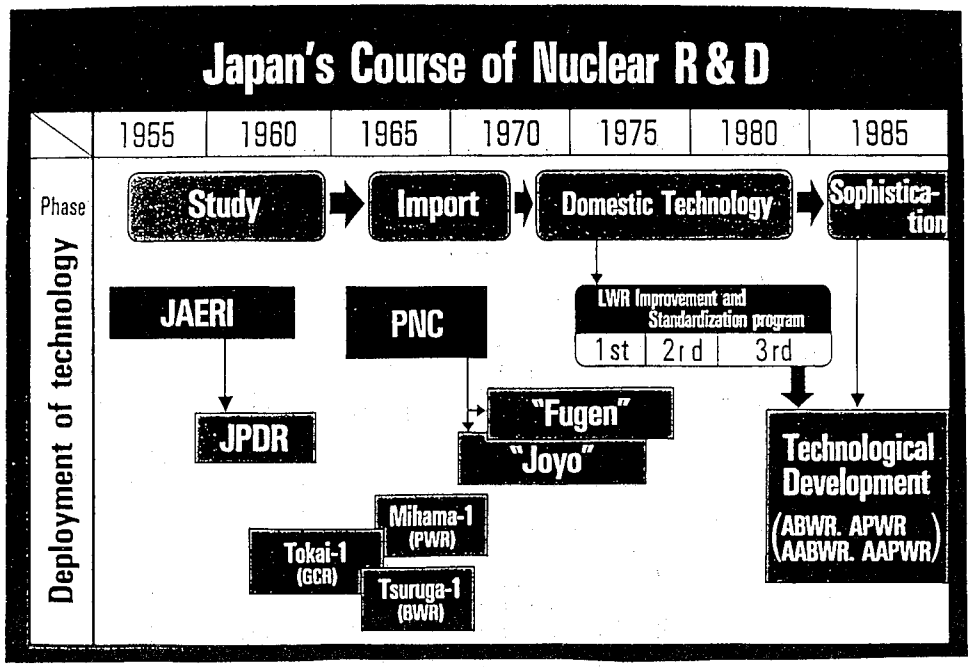
Trends of Nuclear Capacity Factor and Generation Capacity in Japan



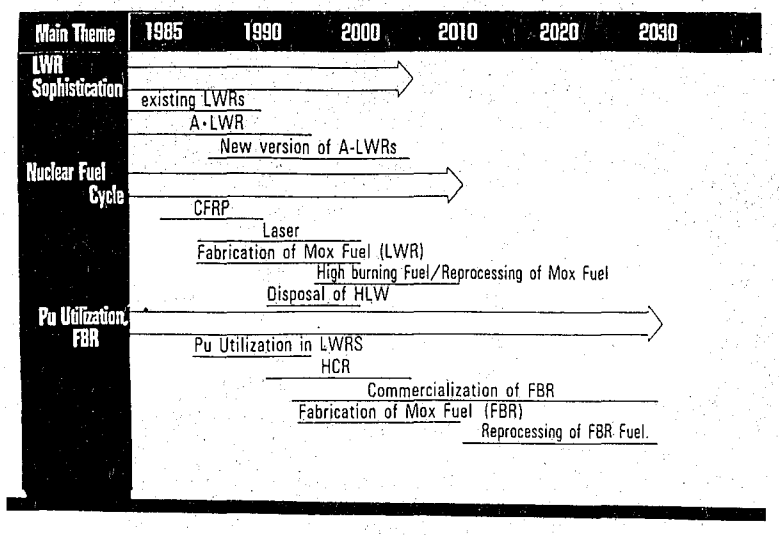
Target of the second improvement / standardization program

		Non-improved plant	The first program plant	The second program plant
Reliability and capacity factor	Availability factor	Fair difference depending on the type of plant	about 75%	about 80%
	Capacity factor	(ditto)	about 70%	about 75%
No. of days for periodic inspection		90 to 100 days for normal repair work	about 85 days for normal repair work	about 70 days for normal repair work
Exposure of employee		(Take as 100%) (about 500 man-rem/reactor-year)	about 75% (about 350 man-rem/reactor-year)	about 50% (about 250 man-rem/reactor-year)


Main Theme of Technological Development
Economy
Sophistication of LWRS
Closure of Nuclear Fuel Cycle
FBR
Safety

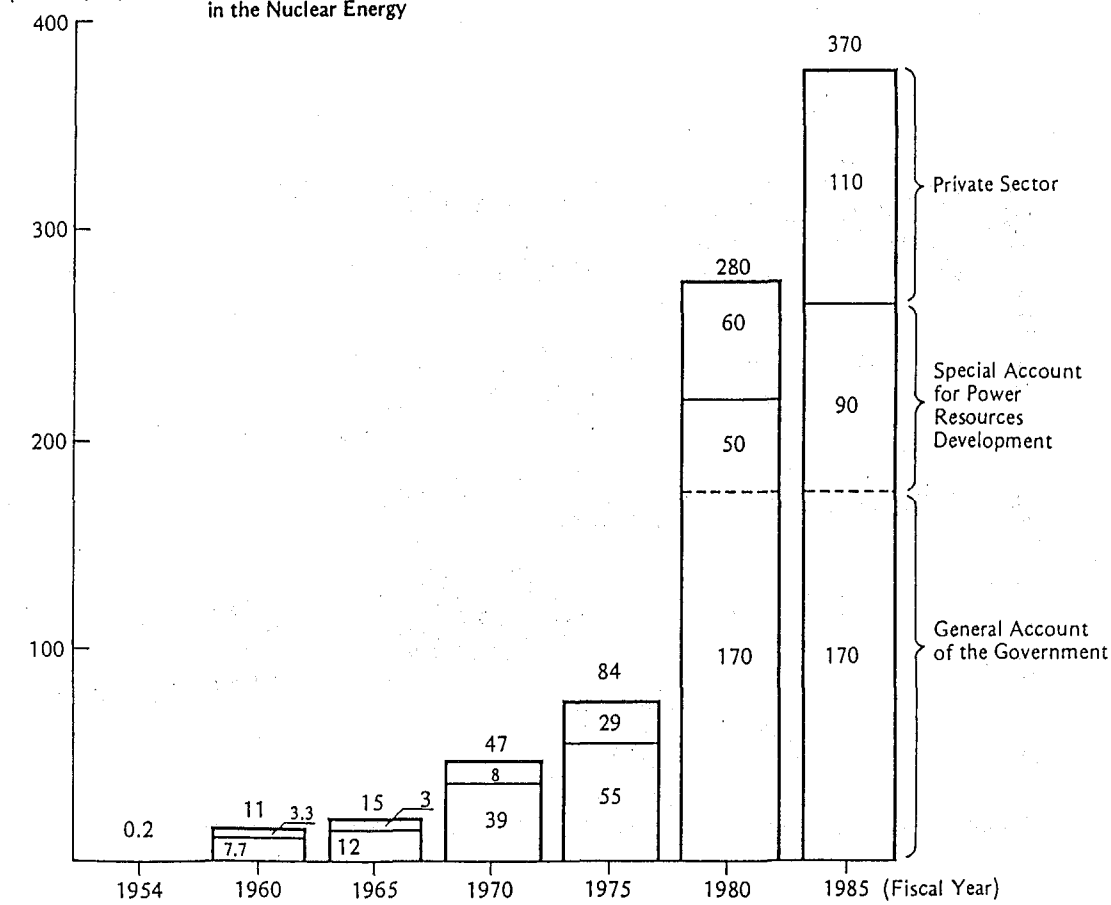

Japan's Course of Nuclear R & D
1955
1960
1965
1970
1975
1980
1985
Phase
Deployment of technology
Study
Import
Domestic Technology
Sophistica-tion
JAERI
PNC
LWR Improvement and Standardization program
1st
2rd
3rd
JPDR
"Fugen"
"Joyo"
Technological Development
(ABWR. APWR AABWR. AAPWR)
Mihama-1 (PWR)
Tokai-1 (GCR)
Tsuruga-1 (BWR)

BASIC GUIDELINES FOR NUCLEAR R&D PROGRAM



(Billion yen)

Evolution of Financial Resource for Technological Development in the Nuclear Energy



< Investments for technolgoical development have spiraled upwards since the latter half of the 1970s, when nuclear energy entered the stage of commercial utilization. >

Note: Data referring to technological development investments in the private sector is provided by the survey of JAIF.

第２０回　原産　年次大会　セッション２：「原子力研究開発の新しい展開」

コメンテーターとしての発表（メーカの立場からコメント）

（社）日本電機工業会　原子力政策委員会委員長
株式会社　東　芝　副社長
青井　舒一

わが国が原子力の開発に着手してより３０年、また原子力発電が本格的に開始されてから、すでに２０年を経て、この間我々メーカとしましても貴重な経験、実績が蓄積されてまいりました。

軽水炉技術につきましては、昭和４０年代初頭、米国の原子力メーカより、軽水炉技術の導入をはかり、爾来、その消化吸収、国産化技術の確立、自主技術による技術改良を鋭意進め、今日では原子力発電技術は成熟の域に達しつつあるものと考えております。最近の原子力発電プラントの信頼性、稼働率、被曝線量、廃棄物量等の運転実績が如実にその成果を物語っていると思います。

これらの成果は国および電力会社の強力な御指導と研究開発に対する理解と多額の援助によるところが極めて大きいのでありますが、メーカ自身も、莫大な研究開発投資ときめ細かい改良努力を積み上げてきた成果であると自負しております。日本原子力産業会議の昭和６０年度原子力実態報告によれば、鉱工業分野では昭和３１年以来の累積で、実に７０００億円の研究開発費を投資して来ています。昭和６０年度についてみると、８５０億円を投資しています。これは、総売上げ高の５．５５％に達し、一般産業の研究開発投資率１．９９％にくらべ非常に高く、原子力研究開発の特徴を示しています。

今後我々は、原主油従時代の中核としての軽水炉への期待に応えるため、引続き、一層の技術改良の推進と経済性向上をめざし、技術の高度化に、注力して行く所存であります。

軽水炉技術高度化につきましては、官民協力して数年来鋭意努力してきているところでありますが、その成果の一例として、１３５万KWの改良型軽水炉ＡＢＷＲについて紹介させていただきます。

ＡＢＷＲは、わが国での技術改良の成果をベースとして世界各国の実証された秀れた技術およびわが国の先端技術を採用し、理想的軽水炉をめざしたもので、安全性・運転性の向上は勿論のこと、キロワット当りの建設費についても、在来のものに較べて約２０％の低減を達成しています。

この図は、ＡＢＷＲプラントの原子炉構造を示します。。

ＡＢＷＲの代表的な特色は、インターナルポンプとコンクリート製格納容器であります。インターナルポンプは、ご覧のように、原子炉圧力容器に内蔵され、これによって、システムはより一層単純化され、安全性が一層向上しています。インターナルポンプの採用で原子炉系システムがコンパクトとなり格納容器自体も小形化できました。また原子炉の重心が低くなり耐震性が向上しました。

原子炉建屋は１３５万ＫＷと大容量ながら従来の１１０万ＫＷのＢＷＲにくらべ、実に約２５％もコンパクト化され、経済性の向上を実現しました。また、５２インチ・タービン翼をつかった大容量・高性能原子力タービン・発電機の開発を完了し、３５％以上という高効率タービンサイクルを実現しています。

以上述べましたように、今日まで、わが国の原子力発電が堅実に発展してきました理由としては、

第１に　原子力が日本の代替エネルギーの中核として位置付けられていること

第２に　電力会社が原子力を推進するという強い意志を持ち続けられ、また原子力という高度な技術を使いこなすために必要な優れた人材と優れた技術力を保有されていること。

第３に　日本のプラントメーカーは電力会社のニーズを満すことを自らの使命と考えており、また原子炉系だけではなく所謂バランス　オブ　プラントのシステム、機器を製造し、プラント全体のエンジニアリングも行なうという幅の広いスコープをカバーしているので、電力会社のニーズに総合的に対応出来る利点があること。

でありまして、この中のどれが欠けても今のようにうまくはいかなかったろうと思われます。

次に、今後の原子力研究開発の大きい課題として、原子燃料サイクルの確立とＦＢＲ開発につき御説明します。

最初に昭和４０年代より研究開発を進めて参りましたウラン濃縮の現状を紹介します。昭和５９年、動燃事業団の原型プラント年産200T-SWUの建設が決定し、更に電力会社の商用プラント計画も見通しがついてきました。これに対応して、我々は５９年１２月に東芝、日立、三菱重工の重電３社でウラン濃縮機器（株）即ち、ＵＥＭを設立いたしました。

これはＵＥＭが仙台に建設した新工場の写真であります。これまで３社が各々独立に生産してきました遠心機をＵＥＭで集中生産することによって、最大限の量産効果を産み出すことがＵＥＭ設立の目的であります。

待望久しかった商用プラントも、下北半島の第１濃縮プラント年産1500T-SWU のうち、第１期工事年産600T-SWUを日本原燃産業（株）が建設準備中であり、我々メーカはこの詳細設計に協力させて頂いております。将来計画としては、複合材料回転胴遠心機、原子法、および分子法レーザ濃縮を並行開発し、６５年にチェックアンドレビューを行なって、その先の路線を決定することが合意されております。新しい濃縮技術の開発は広範囲に努力を要する仕事ですが、我々の持てる技術を駆使して積極的に取り組んで参りたいと考えております。

次に使用済燃料の再処理でありますが、ウラン資源の少ない我が国にとりまして、再処理を行なってプルトニウムの利用を計ることは、エネルギー・セキュリティの確保の面から非常に重要であり、わが国の原子力開発利用長期計画の柱となっております。それゆえ私共メーカもこれに全面的に協力していく考えであります。

電力会社が下北半島に建設を予定しています再処理工場の主工程施設につきましては、ソフトは実績のあるフランスなどから技術導入されますが、ハードはわが国の製造技術を基に、我々としての、必要な研究開発を推進し、信頼性の高い機器を国産化したいと思っています。

プルトニウムを軽水炉にリサイクルするプルトニウムサーマル研究は、すでに昨年２体のＭＯＸ燃料が日本原子力発電（株）敦賀発電所に装荷され、少数体実証試験が始まりました。

電力会社の計画では、１９９０年代の始めにＢＷＲ／ＰＷＲ各一基にＭＯＸ燃料を装荷し、９０年代後半には、それぞれ６基程度になる予定です。この時のＭＯＸ加工量は年間１００トンに相当しますが、遅くとも１９９０年代の早い時期に具体的な燃料加工体制を確立するよう検討を進めております。

ＦＢＲにつきましては、軽水炉につづく新型炉の本命として開発に注力しております。実験炉「常陽」と原型炉「もんじゅ」の２つの炉の建設が国のプロジェクトとして推進されてきました。メーカはこれに参画、協力すると共に自前のナトリウム試験研究設備の設置、人材の育成につとめ、すでに２０年以上にわたり、研究開発への投資、技術蓄積を行なって参りました。

現在我々にとって最も大きなＦＢＲのイベントは原型炉「もんじゅ」の建設であります。これはサイトの現況を示す写真です。近々、格納容器の全体漏洩率試験が開始される予定です。１９９２年度臨界に向けて、動燃事業団をはじめ、現地工事施工管理を請け負っておられます日本原子力発電（株）に協力し、着実にプラントの建設を進めております。

今後につきましては、経済性向上に向けての開発が何より重要な点であると認識しております。昨年8月「もんじゅ」以降のＦＢＲ開発のすすめ方について、電力会社の検討結果が示されましたことは、私共にとりまして大変心強いことであります。

この線に沿い、ＦＢＲ実証炉は、日本原子力発電を中心に、建設費の低減をめざしたプラントの合理化努力が行なわれています。メーカは、これに積極的に参画し、諸基準の見直し、プラントのコンパクト化、系統システムの簡素化、新技術の適用などによる経済性向上研究に注力しています。

これら原子燃料サイクルおよびＦＢＲ開発の特徴は、技術が高度なこと、完成までに長期を必要とすることなどから、超長期の先行投資を必要とするものであります。その上マーケットが限られています。すなわち、メーカの立場としましては、今後長期にわたって技術力保持、人材育成などの研究開発能力を計画的に維持し、発展させていく必要があります。このため、国および電力会社による谷間のない研究開発の実施と絶えざる御支援が、特に必要と考えています。この研究開発を資金面、人材面、技術面において、効率よく推進していくためには、国際協力も有効と考えます。

以上、新しい原子力研究開発について、メーカの取り組みを紹介しました。わが国に於ては今後とも原子力発電が長期にわたり中枢電源として位置付けられると思います。また、２１世紀に向けての原子力政策は、ＦＢＲを中核としたプルトニウム利用体系の確立を基軸として展開して行くものと考えます。我々メーカは、今まで同様これらの目標に鋭意取り組み、原子力平和利用の一層の成功に注力する考えであります。

以　上

NEW ASPECTS IN NUCLEAR RESEARCH AND DEVELOPMENT

MANUFACTURERS' VIEW POINTS

J. Aoi

Chairman
Committee on Atomic Energy Policy
The Japan Electrical Manufacturers' Association

Senior Executive Vice President
Toshiba Corporation

Already it is about thirty years since Japan initiated research and development on nuclear power, and about twenty years since the first commercial nuclear power plant came into operation. Since LWR technology was introduced to Japan in mid 1960's, we have endeavored to establish our own domestic technology, and to improve it further. Today, our LWR technology is reaching its maturity, which has been well demonstrated by recent good operational records of LWR plants on reliability, availability, radiation exposure dose level, and radioactive wastes.

This success in LWR power generation owes very much to the government and Japanese electric utilities' strong leadership and good support on research and development activities. At the same time, Japanese manufacturers are taking a pride in themselves to that the success is also a result of their constant efforts to carry out actual tasks for the activities by investing money and putting resources of their own.

According to 1985 JAIF annual report on the nuclear business situation, total 700 billion yen has been invested to research and development in nuclear field by the mining and manufacturing sector since 1956. In the fiscal year of 1985, it reaches to 85 billion yen, which is about 5.55% of the total sales amount. This percentage is very high compared to 1.99% in the case of ordinary industries. This clearly shows one of features in the nuclear research and development.

Entering into the "Nuclear First, Oil Second" era of Japan and to meet with the expectation as a principal power source of Japanese energy, we are making efforts towards further sophistication of LWR technology jointly with the government and utilities for several years, which is going to be materialized as advanced LWRs, that is, ABWR and APWR. Here, as an example, 1350MWe ABWR will be introduced briefly as follows.

ABWR is designed to integrate excellent proven technologies in the world and advanced technologies in Japan, utilizing the various results of technological improvements in Japan.

ABWR is aiming at an ideal LWR providing higher reliability and operability as well as lower construction cost which is expected to be reduced by 20% compared to the existing BWR.

This slide shows the structure of ABWR.
Major features of ABWR are in reactor internal pump system and reinforced concrete containment vessel. Reactor internal pumps are installed within the reactor pressure vessel as shown in the slide. The adoption of this system realizes simplification of

reactor system which results in attaining higher safety and reliability. The containment vessel itself can be made compact. Moreover, aseismatic feature is also improved by means of lowering gravity center of the reactor.

The reactor building of 1350MWe class ABWR is also made compact by about 25% compared to the existing 1100MWe class BWR which contributes for improving economy. The large and highly efficient nuclear turbine and generator with 52 inches last backet blade has already been developed and turbine cycle with a high efficiency of over 35% is to be realized in ABWR plant.

As mentioned above, the reasons why the nuclear power development has been successfully proceeded in Japan are:

The first is the national policy or concensus to position nuclear power generation as a leading alternative energy source.

The second is the utilities' strong leadership to promote nuclear power development and their possession of excellent human resources and technical capabilities to fully utilize high technology of the nuclear power.

And the third is the manufacturers' determination to satisfy the utilities' needs, and their capability to supply full scope of nuclear power facility including overall plant engineering and BOP systems and components, as well as those of NSSS.

Each of above factors seems to be indispensable key to the success of nuclear power development in Japan.

Now, some other areas of our activities are explained as follows.

Closing the nuclear fuel cycle and developing FBR are two major tasks of Japanese nuclear power research and development for years to come.

First let me introduce the present status of uranium enrichment which we have been developing since 1965. In 1984, Power Reactor and Nuclear Fuel Development Corporation (PNC) decided to construct the prototype plant of 200 tons SWU per year, and also construction of commercial plants of electric power utilities was put in good foresight. In response to this situation, we set up, in December 1984, a joint company named Uranium Enrichment Machinery, Ltd. (UEM) among Toshiba Corp, Hitachi Ltd. and Mitsubishi Heavy Industory, Ltd.

This slide shows the picture of the new factory built by UEM in Sendai. Before establishing UEM, the gaseous-centrifuge machines had been manufactured independently at the factories of the above three companies. Therefore the primary purpose of UEM is to concentrate the production to this new factory, thereby maximizing mass-production effect.

The first commercial enrichment plant of 1500 tons SWU per year, 600 tons SWU per year as the first step, is being prepared by Japan Nuclear Fuel Industries Co., Ltd. in Shimokita Peninsula. We are cooperating in detailed design of the plant. For future project, the gaseous-centrifuge machines using composite material drum, atomic laser vapor isotope separation, and molecular laser isotope separation will be developed in parallel.

Check-and-review for these projects will be expected in 1990 to decide on further plan. Development of this new technology in uranium enrichment requires extensive efforts, and we plan to commit ourselves to the projects to the best of our technology.

To establish the technology for reprocessing and plutonium utilization is the main objective of Japanese nuclear power development program, in order to insure the nation's energy security on a long term basis. To support such national policy, Japanese manufacturers are positively participating in reprocessing plant supply and associated development works.

Software technologies on the main process facilities of the reprocessing plant constructed by the utilities in Shimokita Peninsula, will be introduced from France etc. but we intend to supply highly reliable hardware based on necessary research and development.

Regarding plutonium recycle to LWR, two mixed oxide fuel assemblies were already loaded into Tsuruga power plant of Japan Atomic Power Company (JAPC) last year for verifying their performances.

It is planned that the full core loading of mixed fuel assemblies will be attained to one BWR and one PWR respectively in the beginning of 1990's, and increased up to about six plants each in late 1990's. At that time, mixed oxide fuel fabrication demand will reach to about 100 tonnes a year, and to satisfy this demand, it is planned to establish mixed oxide fuel fabrication system in early 1990's.

FBR is regarded as the most promising successor of LWR, which best serves the future energy needs in Japan.

The experimental FBR, JOYO, and the prototype FBR, Monju have been developed as national projects. Japanese manufacturers have been positively participating in these projects, and also endeavored, over twenty years, to develop their own technical capabilities for supporting these projects while operating their own sodium facilities. The largest activity on FBR at present is the construction of the prototype reactor Monju. This slide shows the current status of Monju construction site. Containment leak test will start soon. Towards attaining its criticality in the fiscal year 1992, we will do our best to make steady progress in the construction work cooperating with PNC and JAPC which is managing the site construction work.

Towards commercialization of FBR after Monju, we recognize that economical improvement is the most important task. We are encouraged very much with our utilities' direction on FBR development after Monju which was presented last August.

Along this direction, extensive research and development efforts on Demonstration FBR centering JAPC are being carried out. Manufacturers are actitively participating in this effort, and, in order to reduce the plant construction cost as much as possible, working for improving design criteria, reducing the plant volume and commodities, simplifying systems and applying new technology.

In the nuclear research and development from now, it is necessary for manufacturers to maintain technical expertise and qualified human resources for a long time and to improve technology, in spite of limited business opportunities. For this purpose, it is indispensable for us to obtain research and development work and supports from the government and utilities continuously. In executing this long term research and development, international cooperation is also considered to be effective in funding, human resources, and technical aspects.

Nuclear power generation will continue to play a key role as the principal electrical power source in Japan in the future, and the government nuclear policy will be deployed to establish plutonium utilization system centering FBR towards the next century. We will continue to work towards these objectives to achieve further success in peaceful uses of nuclear power.

原子力研究開発の新しい展開
<コメント>

東京大学工学部
教授　田畑米穂

1. はじめに

原子力研究開発における基礎研究、基盤研究の重要性と問題点について述べる。先ず研究開発分野と現状について概観し、研究開発の新しい展開、研究の推進方針、今後の方向についてコメントし、最後に国立研究所のあり方について私見を述べたいと存じます。

2. 研究開発分野と現状

原子力研究開発の分野は大きく

1) エネルギー利用

2) 非エネルギー利用

の二つに大別でき、エネルギー利用は、

1) 電力

2) 非電力

に分けられます。従来の最も重要で中心的な研究開発課題として電力利用がとりあげられ、集中的に研究開発が進められ、“核燃料サイクルの確立”など重要ないくつかの問題を残しながらも、一応成熟期を迎えつつあることは、皆様のよく御存じのところであります。残りの一つ、非電力分野、すなわち、推進、核熱利用などについては、工学的基礎の体系的な研究、開発が充分に行われているとはいえないと思われます。

他のもう一つの残りの非エネルギー分野は、ＲＩ・放射線利用であります。ＲＩ・放射線は、我々の身近の農業・工業・医療など、日常的な生活に密着したところで極めて幅広く利用されており、国民生活の向上に大きく貢献しています。しばしば原子力利用の中で、エネルギー利用とともに、車の両輪といわれます。

近年、放射線の新たな利用、すなわち物質・材料、情報・電子、ライフサイエンス等の先端科学技術の急速な進展および放射線利用分野における加速器技術の進歩などが相まって、先端科学技術の放射線利用への応用と、放射線利用技術の

先端科学技術への応用が相互に進みつつあり、今後の一層の進展が期待されています。

ＲＩ・放射線利用は、車の両輪といっても、偏った小さい規模であります。この分野の十分な研究開発が望まれるところであります。

調和のとれた原子力開発として、従来の電力利用の研究・開発に加えて、この残された二つの分野の研究開発に次第に力を注いでいくべきものと考えております。

幸い、非電力エネルギー開発としては、高温ガス研究、試験炉のプロジェクトが動き始め、放射線利用として、イオンビームの高度利用プロジェクトがスタートしています。

これからの重要研究課題として、昨日の開会セッションで三ツ林科学技術庁長官も核融合と放射線の高度利用について言及されましたが、重要な将来技術と新しい原子力の重点分野として考えるべきものと思います。

3. 原子力研究開発の新しい展開

原子力委員会長期計画専門部会の第３部会では、原子力開発利用長期計画を

- 創造的基礎研究
- 先導的研究開発
- 原子力利用分野の拡大

の観点より、原子力の新しい課題として、“原子力に課せられたニーズの多様化・高度化に弾力的に対応できる原子力技術体系の確立”を目指すべきとし、創造的原子力技術を作り出す努力をする必要があることを指摘しています。

原子力技術はいうまでもなく、広範な学問領域に基礎をおいており、極限状態にかかわる諸技術、先端技術より構成される総合技術体系であり、原子力技術の高度化は科学技術全般の発展に寄与します。従って、原子力技術は科学技術の中核的領域の一つと位置付けることが出来ると思われます。

4. 研究開発推進

多様化・高度化する原子力のニーズに弾力的に応えていくためには、既存の技術の改良のみならず、創造的な原子力技術をつくり出す必要があります。このためには、従来行われてきている研究開発体制の転換をはかることが必要と思います。原子力の研究開発は、原研、動燃、国研、大学、民間企業等の原子力関連研

究機関によってそれぞれの役割分担のもとに進められてきており、蓄積された技術ポテンシャルを最大限活用し、それぞれの研究機関の特徴を生かすことが必要であります。大学は基礎研究、国研は目的基礎や関連したプロジェクト、民間は実用化が大まかな役割分担であろうことは、しばしば指摘されているところであります。

5. 今後の研究開発の方向

今後の研究開発の方向として、次の3点があげられます。

1) 基礎研究の重視と強化 → 科学技術の急速な進歩の中で、原子力の研究開発が常に新しい技術の芽（シーズ）を生み出し、または新しいコンセプトを作り出し、活力を維持・向上させることが必要。

2) 幅広い“技術基盤”の強化と確立 → 新しい技術への飛躍や創造的技術を生みだすのに必要な基盤を確立することが求められています。
基盤技術は、現行プロジェクトの推進と飛躍化や、将来のプロジェクトの基盤形成、すなわち、よくいわれる“目的基礎研究”であり、原子力技術全般の高度化・革新に寄与すると思われます。

3) 核融合、高温工学、高速増殖炉、核燃料サイクル、放射線高度利用等の進行中または将来のプロジェクトの推進 → これらは本来の目的達成のために重要であるのみならず、科学技術全般の先端科学技術の発展にとっても非常に重要であると思われます。

換言致しますと、1) → 未知の領域の研究　2) → 中長期的ニーズに対応した原子力技術の高度化に役立つ基盤技術の開発　3) → 先導的プロジェクトの推進であります。

6. 原子力研究開発における国立研究所の対応および役割について、偏った立場になるかも知れませんが、若干私見を加えて述べさせて戴きます。

1) 進行中のプロジェクトの整理、再編が漸次行われるべきものと考えられます。民間へのスムースな移行と、ふさわしい規模と内容への転換が要請されているものと思います。

2) 技術移転の円滑化と、原子力研究機関と産業界との協力であります。この点に関連して、まず英、仏、独の現状について簡単に説明させて戴きます。
各国の歴史、企業の規模、ポテンシャルを反映し、国ごとに異なった形態

をとっていますが、いずれも原子力分野において研究技術ポテンシャルを蓄積し、それを幅広い分野に活用しようとしています。イギリス原子力公社（ＵＫＡＥＡ）では、原子力開発の進展と技術力の蓄積に伴い、非原子力（Non-nuclear）分野における研究をも実施するとともに、Business Center や Club などの組織により民間への技術協力を行っています。フランス原子力庁（ＣＥＡ）では、原子力分野での蓄積を利用し得る分野について、産業界との共同研究を含め、エレクトロニクス、バイオテクノロジー、ロボティクス、新素材等の分野で工業化のための応用研究を進めている（valoriza-tion）。西独では、国家プロジェクトは、当初から産官の協議のもとで産業界との協力によって実施し、その成果を共有することによって円滑な相互の技術移転を図っています。

我が国においても、いろいろな形で技術移転や両者間の協力が実施されていますが、さらに工夫・改善の余地が残されていると思われます。

3) 基盤研究の強化・推進

これは中・長期の先導的プロジェクトを確立するに必要であることは、すでに申し述べたところであります。プロジェクトを特定しない横断的な研究開発を強化することによって、将来への新しい展開に備える必要があるものと思われます。

4) 基礎研究の充実

中・長期的に安定した研究環境の整備が是非必要と思われます。さきにも触れましたように短期的には応用に結びつかない基礎研究も先端技術を生みだす力として、重視すべきものと考えられます。

特に、大学との協力関係の強化が強く望まれるところであります。

幸い、大学による原子力研究所共同利用は、長期に亘って成果を挙げて来ており、近年になってさらに“原研・大学間の共同プロジェクト”のプログラムがスタートし、幅広い両者間の協力関係が築かれつつあります。最初に Down Stream がスタートし、次に放射線高度利用が予定されており、さらに引続いて、高温工学関係へと進むものと期待しています。

5) 人材の確保と養成

人材の確保は、推進力の中心的課題であり、当然極めて重要であることはいうまでもありません。

6) 資金の獲得

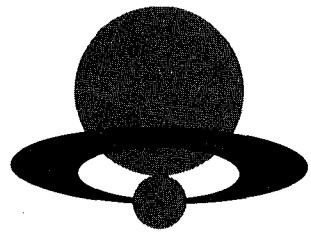
長期的に基礎・基盤研究を維持することが、必須と考えますが、このためには、安定的な資金の獲得が必要であります。

全体の予算枠の中で、一定の比率を決めて、予め獲得するなど、一つの方策かと思われます。ちなみに英国においては、目的基礎研究（underlying Research）に限定して約１０％、フランスＣＥＡでは、大幅に基礎研究をとり入れた枠として約３０％を獲得しています。

7) 研究体制の見直し

異なる組織間で横断的な協力体制をつくりあげることが基礎・基盤研究を効果的に推進するために必須であり、このことについては、今迄も繰返しいわれて参りました。特に最近では、大型施設を必要とする研究・開発が多く、Flexible な組織や体制づくりが、欠かせない重要なことになって参りました。今回の原子力委員会の原子力開発利用長期計画の見直しを契機に是非この点は実現して戴きたく、この機会に強く要望致したいと存じます。

午　餐　会



通商産業政務次官所感

中　川　秀　直

特別講演　　森林 — その価値と文化

京都大学名誉教授

四手井　綱　英

第二十回（社）日本原子力産業会議年次大会午餐会

通商産業政務次官所感

通商産業政務次官　中川秀直

昭和六十二年四月十五日（水）一二・二〇～一四・一五
於 ホテルオークラ本館一階 平安の間

政務次官所感

一、（あいさつ）

通商産業政務次官の中川秀直でございます。

本日は、第二十回原産年次大会午餐会にお招きにあずかり誠にありがとうございます。

原子力の開発利用に長年係わってこられた皆様と、親しくお話しできる機会を得ましたことは、私にとって大きな喜びでございます。また、第二十回年次大会がこのように盛大に開かれることになりましたことにつき、心からお祝い申し上げるとともに、本大会の準備に御尽力された有澤廣巳会長、山下勇大会準備委員長を始め、関係の方々に敬意を表する次第です。

二、（安全確保対策）

さて、昨年四月に発生したソ連チェルノブイル原子力発電所の事故は、我が国のみならず世界の原子力開発に大きな影響を及ぼしました。私も電源開発の責任者として、原子力開発利用の推進に当たっては安全の確保が大前提であることを改めて認識いたしました。

通商産業省といたしましても、今後、二十一世紀に向かって、国民の十分な理解と信頼の下に原子力開発利用を推進するため、昨年八月、原子力発電安全確保対策のより一層の充実を内容とする「セイフティ２１」計画を決定いたしました。そして、「安全確保なくして原子力利用なし」との

認識の下に、官民挙げて、従来からの安全確保対策を着実に実施するとともに、安全性を更に向上させる努力を継続すること及びこのための所要の体制を整備することといたしました。

また、これらの諸方策を円滑に実施するため、円城寺先生を座長とし、通商産業省、学識経験者、関係業界等から構成する「セイフティ21推進委員会」を設置し、三月十九日に第一回目の委員会を開催いたしました。更に、毎年五月を「原子力発電安全月間」とし、国民的運動を推進することといたしております。

一方、チェルノブイル事故は、原子力の国際性を認識させるものでもありました。このため、原子力事故に対する国際的な通報・援助に関する二条約が昨年のＩＡＥＡ総会で採択され、我が国も本年三月、二条約に署名いたしました。

三、（原子力推進の必要性）

さて、最近のエネルギー情勢をみますと、国際的な石油需給は緩和基調にあるとともに、一昨年来の原油価格の低下以降石油価格の推移は不透明な状況であり、現在、石油、石炭、原子力等のエネルギー間の競合が厳しくなっております。

しかし、このような状況下においても、昨年十二月に通商産業省が行った各電源の耐用年発電原価試算におきましても、原子力の経済性については、他電源に比べて依然優位性を維持する結果が得られております。とは

いえ、昨今の円高、原油安をうけ、電源間のコスト格差は縮まってきております。今後の電源開発におきましては、経済性及び供給安定性に優れた原子力発電を積極的に推進することには変わりはございませんが、原子力につきましても、今後とも一層のコストダウンを目指していくことが必要でありましょう。

四、（今後の課題）

原子力発電は、安定的な電力供給の担い手としての地位を確立した訳ですが、今後とも原子力発電を着実に推進していくためには、幾つかの課題があります。

「①核燃料サイクル事業化の推進」

まず第一には、自主的な核燃料サイクルの確立が挙げられます。特に、昨日の有澤会長の御所信の中にもありましたように、使用済燃料の再処理は核燃料サイクルの要であり、この事業化は極めて重要であります。

現在計画が進められている、商業用再処理工場建設に必要な、仏国からの再処理技術導入につきまして、本年一月に仮調印が行われました。その後の交渉も順調に進みまして、本日、いわゆる外為法に基づく役務契約の届出を受理し、順調にいけば、今月末にも契約の本調印が行われる見込みでございます。通商産業省といたしましても、本事業の重要性に鑑み、再処理技術が真に我が国に国内技術として定着するよう、事業者が行う実規模確証試験に対する補助等の財政的支援を積極的に行っていく所存でござ

います。

第二の課題といたしましては、軽水炉の高度化が挙げられます。

「②軽水炉技術の高度化」

軽水炉は、今後とも長期にわたり原子力発電の主流として貢献することが期待されており、より一層の信頼性、経済性の向上を進める必要があります。

通商産業省といたしましては、これらの施策の具体的実施を図るため、「軽水炉高度化推進委員会」を設置し、四月二十七日に第一回委員会を開催することといたしております。今後は、本委員会での検討を踏まえつつ、既存型及び改良型軽水炉のより一層の信頼性、経済性の向上を目指した技術開発を行うとともに、二十一世紀の軽水炉の技術開発等を進めていくこととしております。

第三の課題としては、プルトニウム利用の推進が挙げられます。

「③プルトニウム利用の推進」

資源の乏しい我が国においては、ナショナルセキュリティ及び資源節約の観点から、使用済燃料を再処理して得られるプルトニウムを有効に利用することが必要です。このため、軽水炉によるプルトニウム利用の推進、新型転換炉及び高速増殖炉の開発の推進を図ることが重要であります。

軽水炉によるプルトニウム利用につきましては、現在、その本格利用に向けて実証計画を段階的に進めているところでございます。

また、新型炉についても、実用化に向けて、これまでの技術開発成果を基に、実証炉計画が推進されているところであります。

国といたしましても、それらの計画が円滑に推進されるよう支援を行うとともに、必要な技術開発等を進めているところでございます。

五、（原子力ビジョン）

このように、我が国の原子力開発利用は、電力供給における原子力発電の定着、核燃料サイクル事業化の具体的進展等、過去三十年の努力の結果、一つの節目を迎え、新たな段階に入りつつあるといえましょう。

これからの原子力に課せられた課題は、経済性の推進、民間事業化の推進に伴う一層の民間活力の活用、国際化の推進等であります。

かかる観点から、昨年七月、総合エネルギー調査会原子力部会において、二千三十年までを対象とした「原子力ビジョン」と題する報告書が取りまとめられ、二十一世紀の原子力のあり方が示されました。

二千三十年には、原子力発電規模は一億七百万kW～一億三千七百万kWと、全発電設備容量の約四割を占め、発電電力量においては、原子力の割合が、約六割になると見込まれていおります。このように積極的な見通しは、国際的にも大変注目されているところでございます。

六、（おわりに）

以上、我が国の原子力開発の現状、政策及び課題を簡単に申し上げた訳

ですが、これらの展望に沿って、与えられた課題を着実に克服していくことが、原子力の円滑な発展のための鍵であります。

このような課題を解決していくためには、国際的な理解と協力の下に、関係する者全員の英知の結集が不可欠でございます。このため、本日御列席の皆様方を始めとする国内外の関係者の方々の御協力をお願いする次第でございます。

今回は、第二十回目の年次大会でございます。来年の大会にも、また、新たな成果を皆様に御披露できますよう、皆様の御協力の下、着実に原子力開発を進めてまいりたいと存じます。

最後に、年次大会をこのように盛大に開催されました日本原子力産業会議の方々の御苦労を多とするとともに、皆様の御発展を心からお祈り申し上げまして、私の挨拶とさせていただきます。

〔午餐会特別講演〕

森林－その価値と文化（要旨）

京都大学名誉教授
四手井　綱英

日本列島は北東から南西に長くのび，亜寒帯から温帯を経て亜熱帯にわたる広い気候帯を含むうえに，列島の中央部を列島沿いに縦断して2000mを越える山脈が連なり，太平洋と日本海の両気候を形成しているので，すこぶる多様な気候が分布することになる。また，植生の発達に有力な気候要因となる降水量は全列島にわたりきわめて豊かで，年降水量は1800mm～2000mm，時にはそれ以上になる。内陸の一部にはやや乾燥する地域もあるが，年降水量1000mmを下る所はなく，森林の発達をさまたげられるほどの寡雨地帯は認められない。それ故，古代の日本列島は，あます所なく森林植生でおおわれていたであろう。

日本列島の主要部分は温帯に属するが，これは生態学的に2大別される。すなわち，北部の冬の温度の低い地帯は，ブナ，ナラ類を主とする落葉広葉樹林になり，南部の冬の温度の比較的高い地帯は，シイ，カシ，クスノキ類などからなる常緑広葉樹林になる。

古来日本人の大部分はこの二つの森林帯で生活してきたと言ってよい。現在でも日本人の住居地域は標高1000m以下であって，亜寒帯地帯に住む人はきわめて少ない。

この両帯はいずれも密な森林におおわれているから，日本人は森林とともに生計を立ててきたといってよい。そのため人々の森林観は時代の推移とともに変遷して現在にいたっている。

まず，日本人の原始信仰は多神信仰であって，森林，巨岩，水流，滝

などの自然に神を認め，それを祭り，現在でも神教として，宮の森を大切に守ってきている。豊かな自然は，一方では豪雨，洪水，山崩れのような自然災害を多発したから，日本の信仰は神を恐れ，自然にさからわない思想が生れ，神の宿る山や森は人の立入りをこばむ神の場として大切に守ってきた。この自然観は今でも残り，近代文明の発達した現代でも，平野部や山麓地帯に多くの原生状態またはそれに近い宮の森を残している。

また，直接人の生活と連なる森林としては，原始時代の狩猟・採取にたよっていた時代には，森林は多量の樹の実（ブナ，ナラ，トチ，クリの実）のような貯蔵可能な食糧を得る場所であり，けものを狩る場所でもあり，そこから流れる河川は豊富な魚を獲る場所でもあった。これらの自然の動植物から得られる食糧は，落葉樹林地帯の方が豊かであったので，縄文時代にはむしろ，北東部の日本の方が人口密度が高かったといわれる。次いで原始的な農法である「焼畑」が始まるが，温帯林での焼畑は，土壌に含まれる養分が熱帯に比べ極めて豊かであったので，一定の間隔をおいて繰り返し耕作することが可能であった。この場合森林は農耕へ豊かな養分を供給するものとして，森の神があがめられたであろう。

次いで中国大陸南部からイネが導入され，稲作は南西日本から次第に東北へ進み，現在では稲作は日本全土の主要穀物になり，高い人口を保つことに役立っている。稲作の普及とともに，平野部の森林は，宮の森を除く他はかんがいの発達とともにほとんど水田として開発されてしまった。水田を維持してゆくためには多量の肥料が必要となるが，その主なものは，平野部に近接する里山から採取された。里山はその結果次第にやせ山に変わり，急速にやせ地に強いマツ林が拡大した。現在平野部から眺められる里山（近郊林）は，時に南西日本ではほとんどアカマツ林に変わってしまっているが，こうして，長年マツ林と親しんできた日本人にとっては，マツは自然美を現わす秀れたものとして受けとめられ

るようになり，日本庭園にも多く採り入れられるようになった。京都の自然美は東山，西山のアカマツ林がなくては語れないと言われている。稲作文化の発達とともにこうした里山の大きな変化があったのである。こうしたことは他国ではあまり認められない。

他方，木材生産を通じての森林には，二つの方向がある。その一つは燃料としての木材生産で，わが国では，第二次大戦後の燃料革命が起こるまでは，家庭燃料の主力は薪炭であり，人口の増加とともに薪炭の消費量は増大した。薪炭生産林は低林と言われる根株からの萌芽と天然に再生産されるもので，低林による薪炭生産は里山ばかりでなく，かなりの奥地林までを二次林化した。特に初期は，製鉄用燃料に用いられた木炭が，その便利さから専ら家庭燃料として生産されるようになってから，奥地林は広く低林化，二次林化したし，山里の主な生業になった。木炭の生産量は第二次世界大戦後極大値に達したが，その後経済復興とともに急激に減少し，電気，石油等に代ってしまい，日本の森林の過半を占める二次林は現在，ほとんど無価値なものになった。

建築，家具，農具用材としての木材は，日本が木の文化国といわれるように古代から住居建築の他，社寺建築用材，築城用材として多量に消費されたが，家具農具用材等は硬木の広葉樹が用いられたが，建築用材は主として軟材の針葉樹が用いられてきた。

これは温帯性針葉樹の良材が広く広葉樹林中に混生していたからであろう。特に良材として認められるものは，藩政時代に人工造林木になったスギ，ヒノキであろう。

こうした用材は古い時代には天然材から採取されていたが，中世以降人工造林が始まり用材の供給に役立った。本格的な人工造林は今から約300 年以前からである。

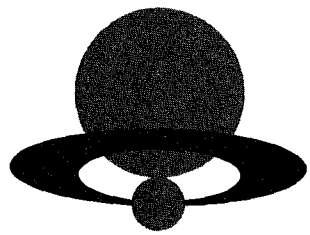
今次大戦中および戦後，木材の需要が激増したため，人工造林は急速に進展し，現在では日本の森林面積の40数％が人工造林地化したが，現在では外材のインパクトで造林意欲は甚だしく低下した反面，高度経済

成長期に多発した公害に起因して，広く国民の間に自然保護思想が生れるとともにレクリエーションのための森林が要求されるようになり，木材生産を森林の造成の主目的にした森林観は衰微しはじめている。

最近ヨーロッパと日本の人々の自然感について，私達の調査した結果，最も大きな違いは，日本人は外部から森林美を眺めるのが好きで，あえて林内へ入ろうとはしない。これは森林にもつ古来からの恐怖心が大きく働いているものと考えられる。それに反しヨーロッパ人は森林を内部から見るのを好み，林内の散策をレクリエーションなどの第一にあげている。

セッション3

アジア地域における原子力開発と国際協力



＜基調講演＞

これからの国際協力の課題

原子力委員会委員

藤　波　恒　雄

＜パネル討論＞

国際原子力機関（ＩＡＥＡ）事務局長
Ｈ．ブリックス

インド原子力委員会前委員長
Ｒ．ラマンナ

中国原子力工業省次官
李　　定　凡

韓国科学技術院教授・監査役
林　　瑢　圭

インドネシア技術評価応用庁（ＢＰＰＴ）エネルギー転換・省エネルギー技術部長
Ｌ．Ｍ．パンガベアン

国際協力事業団副総裁
牟田口　道　夫

(財)日本エネルギー経済研究所理事長
生　田　豊　朗

関西電力(株)常務取締役
大　石　　博

「これからの国際協力の課題」

原子力委員会委員

藤波　恒雄

1. 本日このセッションの初めに、「これからの国際協力の課題」についてお話しする機会を得ましたことを幸に存じます。

2. 近年、エネルギー情勢の急速な緩和やチェルノブイル原子力発電所事故の発生などで、原子力開発利用推進の気運が世界的に停滞していくのではないかという懸念がありますが、長期的には世界のエネルギー需給は逼迫するとの考え方が一般的であります。この中にあって、原子力は有力な石油代替エネルギーとしてその安定供給に貢献しうるとともに、科学技術全般の総合的な向上への寄与が大きいことから、社会・経済の発展の基盤的存在であるとも考えられます。このような観点から、我が国はもとより、世界的にも原子力平和利用が着実に推進されることが期待されるところであります。

3. 他面、原子力について大事なことは、国際的に核不拡散および安全性が十分に確保された形で、その研究開発利用の推進が行われることが必要不可欠なことであります。また原子力の研究開発は多くの人材と極めて巨額の資金を必要としています。このような原子力のもつ特有の性格からして、原子力の平和利用は、本来、国際的に協調し会い、相互理解の下に進めてこそ可能であり効果的であると思います。

4. 原子力委員会におきましては、新しい「原子力開発利用長期計画」を策定するため、現在、専門部会を設けて審議を進めていますが、国際協力問題も重要事項の一つとして、その今後のあり方について検討がなされております。本日はこの審議、検討の中で出されている意見や提言をもとに、このセッションに関係のある部分を中心に私の私見をお話ししたいと思います。

5. 先ず国際協力全体を通ずる基本的認識、考え方についてですが、

我が国は今日、世界のＧＮＰの約一割を占めるとともに、世界有数の技術レベルに達するまで発展したことから、今後主要先進国の一員として世界経済の活性化、エネルギー問題等人類共通課題の克服及び世界の科学技術水準の向上への貢献など、我が国の一層の国際化に対する内外の要請が高まっていること、

我が国原子力技術の高い安全性、信頼性が国際的に評価されつつあるなど、原子力をとりまく内外の諸情勢とその中での我が国の立場を踏まえて、

今後の国際対応は、従来のどちらかといえば先進国へのキャッチアップ型、あるいは受動的といわれる姿勢を転換して、次のような観点、すなわち、

① エネルギー需給事情の改善等世界共通の課題の解決

② 各国の人的、財政的資源の効率的活用

③ 原子力国際環境の整備

等に資するとの観点に立って、他の国や国際機関に積極的に働きかけていくなど―勿論核不拡散との両立を前提にですが―今後はより主体性をもった能動的な国際対応を進めていくことが重要であるとの考え方が出されております。

我が国の原子力基本法の第１条に、原子力利用は平和の目的に限ることが明記されていると同時に、「進んで国際協力に資する」ことが唱われておりますが、この基本法の精神にも沿うものと思います。

6. さて、アジアの国々との協力についてですが、我が国と地理的、経済的に密接な関係にあるこの地域の国々においても、原子力平和利用の努力が着々と進められており、基礎研究の段階から放射線・ＲＩ利用、更には原子力発電の実用化に至るまで、国によって差異はありますが、近年、その活動は次第に高まりをみせております。我が国は、それらの国々とは従来からＲＣＡ、ＪＩＣＡ、ＩＡＥＡによる研修生の受入れや専門家の派遣等色々な形で協力関係をもっていますが、今後一層の拡大充実が望まれております。

7. また、相互依存関係の深い近隣諸国の原子力開発が、技術基盤や経済性の向上の面だけでなく、安全性の確保や核不拡散体制の面でも、健全な姿で発展することが極めて重要であります。

我が国は、これまで先進諸国からの導入技術の習得と、自らの研究開発の努力とが相まって、

原子力技術基盤の向上、軽水炉発電技術の確立等で相当の実績をもつところまで来ました。これからは地域内の原子力先進国としての国際的責務を十分認識して、蓄積された知見、経験を生かして、地域諸国の原子力開発利用の円滑な進展に寄与すべきであると考えております。

8. 協力を進めるに当っての考え方としては、

先ず相手国の国情を勘案しつつ、協力ニーズの把握に努めるとともに、その国の開発レベルに応じた協力をすることに心掛ける必要があります。すなわち、放射線・ＲＩ利用から原子力発電の実用段階まで、それぞれの段階に応じた協力が行われるべきであります。

また、相手国の研究基盤、技術基盤の整備に寄与することを重点におき、その国の原子力開発利用計画の、出来るだけ初期段階から協力関係をもつことが望ましいと考えます。

原子力開発レベルが比較的高い国については、今後の協力関係の一層の拡大、充実を図る観点から、原子力協力協定等協力の枠組を整備することが重要である。その際は、核不拡散にも十分配慮することは勿論、また、国力相応の役割分担が図られることが重要であると考えられます。

9. 次に協力分野によっては、二国間協力の形だけでなく、地域協力の形態、すなわち、我が国を含めた地域ぐるみの協力関係をもつことも、地域の保有する人的・財政的資源を効率的、効果的に活用する等の観点から、有効であると考えております。従来は、ＩＡＥＡのＲＣＡ協定の下で放射線・ＲＩ利用の分野でしか協力が行われていませんが、今後は研究炉利用、原子力安全、緊急時対応といった面での地域協力も有益ではないかと考えております。

10. 以上、基本的な考え方について私なりの考えもまじえまして述べました。このような考え方に基づいて、今後の協力推進の具体的方策や課題についても色々と議論、検討が行われておりますが、そのいくつかを取り上げてみます。

11. 先ず人材交流についてでありますが、

協力関係の永続的な発展に不可欠な相互信頼関係を築いていくのには、その基礎となる人的つながりの形成が大事であり、また人材育成は研究基盤・技術基盤の整備のもとをなすものでありますので、従来から、人材交流の重要性が強く認識されておるところであります。

従来、科学技術庁の原子力関係要人招へい制度、ＪＩＣＡの技術協力を通じて、あるいは日本原子力産業会議により、また最近は海外電力調査会などによっても、原子力関係要人の交流、調査ミッションの派遣、受入れ、シンポジウム、セミナー、ワークショップの開催など行われてきております。

しかしながら、今後は、これらに加え、政府レベルあるいは原子力委員レベルでの国際会議の開催等も行い、ニーズの把握、協力の枠組作りに努めるべきであるとの意見やまた、開発途上国に原子力アドバイザーとして十分な経験を有する人材を長期派遣することなどが出来るように、いわゆる「ニュークリア・シルバーボランティア制度」を設立することも提案されております。

12. 近年、我が国とアジア諸国との間で研究交流が活発化しつつあることは誠に喜ばしいことであります。

特に一昨年より科学技術庁が中心となって、通産省とも連携しつつ実施している原子力研究交流制度は高く評価されます。本年度はアジア諸国から50余名の研究者を、３ケ月から６ケ月にわたり我が国に招へいすると聞いておりますが、今後ともこのような制度は一層充実させていくべきであります。

13. このような研究者交流を通じて、我が国とアジア諸国の研究機関相互の協力関係も、今後ますます緊密化するものと期待されます。現在、原研ではインドネシア及びマレーシアとの間で新たな研究協力のための実施取決めの話が進んでいると聞いておりますが、これらの動きもそのあらわれではないかと思っております。

14. 次に各分野毎の協力についてですが、

先ず、放射線・ＲＩ利用については、アジア諸国において医療、農業、工業等広範に応用されており、産業及び国民生活の基盤の形成にとって極めて重要であると考えております。従いまして、今後とも引き続きアジア原子力協力協定―すなわちＲＣＡ―等を活用するとともに、二国間協力を更に充実させ研修生の受入れ、専門家の派遣、共同研究等の実施によりその技術レベルの向上及び実生活・産業振興への反映に積極的に貢献していくべきであります。

研究炉利用分野については、中性子を利用した各種の基礎研究のレベル向上のみならず、将

来の原子力利用の発展に備えて、設計、運転等の経験の蓄積の面で重要であるので、今後研究の効率的な実施及び研究施設の有効利用への助言・指導、共同研究等を行っていくのがよいと考えます。

原子力発電分野の協力については、国のみならず、電気事業者やメーカーを中心とする民間に負うところも大きい点に留意しながら進めなければなりませんが、原子力発電を検討中の段階から、計画、建設、運転の段階に至るまで国によって事情はかなり異りますので、それぞれの段階に応じて、

- 原子力発電に関するフィージビリティ・スタディの実施
- 原子力発電に関する一般情報・経験の提供
- 安全設計の考え方、運転管理、品質管理等総合的に技術を把握できる指導者的人材の育成
- 安全規制、建設管理、運転管理等に必要な情報の提供
- 運転要員、検査・保守要員の育成
- 原子力機器の標準化・規格化
- 緊急時対応、放射性廃棄物処理処分に関する基盤整備

等の面で協力を進めていくことが重要であるとされています。

また我が国の原子力産業は、プラントの信頼性、安全性の高さなどその優れた技術力を生かして産業としての国際展開を図ることが期待されますが、その際、適切な協力の枠組の下で我が国のみの努力の他に他国とのジョイントベンチャー、共同受注等を積極的に行っていくことが望まれております。また、いわゆる「ＢＯＴ方式」など新たな協力方式の可能性について検討を行うことも考えられましょう。

更に、長期的には、ＲＩの提供や核燃料分野における役務の提供も検討していく必要が出てくると思います。

今後、このような協力の一層円滑な推進のためには、我が国とアジア諸国との間で原子力協力協定等政府レベルでの協力の枠組が設定されることが重要であると思います。

15. 以上は二国間協力を前提に述べてきましたが、先程も申しましたように、協力分野によっては地域ぐるみの協力の方が有効であるものもあります。

例えば、昨年のチェルノブイル事故以降、原子力安全確保、緊急時対応といったテーマは地域共通の重要な関心となっており、地域協力を推進していくことが必要と考えます。また、地

域の特性に合った、且つ斬新な原子炉システムの共同研究、例えば共同設計等について検討を行ってみてはどうかとの提案もあります。例えば、中小型炉、固有安全炉、メンテナンスフリー炉とかいったイメージのものであります。

更に放射線・ＲＩ、研究炉利用等におけるＲ＆Ｄや訓練のための地域センターを設立・育成することも有効ではないかと考えられます。例えば一昨年我が国からＩＡＥＡを通じてマレーシアに子宮癌の治療装置（ラルストロン）が供与されておりますが、その後、その装置は地域の訓練センターの中核として利用されていると聞いております。また、インドネシアでは現在、30ＭＷの研究炉を中核とする大研究所を建設しており、将来は海外の研究者を多数招へいし、アジアの研究センターとなろうという構想をもっていると聞いております。我が国も原研が専門家を派遣するなどこのプロジェクトに協力している他、ＪＩＣＡも中性子回折装置を供与することとしておると承知しております。

今後、各国のニーズ、特徴に合致した機能を有するこのような地域センターが地域内に複数設置され、互いに相補的に機能すれば、アジア地域の原子力技術の向上に大いに貢献するのではないかと思います。

16. 以上のような国際協力、国際対応を円滑に進めていくためには、適切な国内環境の整備が不可欠であります。

先ず第一に、国レベルの企画・調整機能の強化ですが、国として国際対応のための戦略的方針を策定し、ダイナミックな国際情勢に対応して、これを効果的に調整・実施していくメカニズムが必要であり、このため原子力委員会を中心に官民連携して所要の機能の強化・充実を図っていかなければならないと思います。すなわち、関係省庁やその所管の機関がそれぞれ個々別々に対応するのではなく、ひとつの統一的な政策の流れの中で対応していかなくてはならない時期にきていると考えられます。例えば協力ニーズの把握から協力分野・方法、協力実施機関の選択、協力実施上の核不拡散や安全確保上の種々の問題の統一的処理等、そのような必要性はますます高まってきていると考えます。

第二に、協力の窓口の体系的整備については、情報収集・提供、各種協力の斡旋等を行う窓口が官民毎、主要分野毎に体系的に整備されることが必要であります。当面民間においては、日本原子力産業会議、海外電力調査会等が窓口機能を果たすことが期待されます。

第三に、国際協力事業団（ＪＩＣＡ）の活用についてですが、ＪＩＣＡは従来から、研修生

の受入れ、専門家の派遣といった人材交流及び機材供与等で大きな役割を果たしていますが、今後とも多様な協力ニーズに対応して、技術協力分野におけるより弾力的、積極的活用が期待されます。

最近では、原子力安全問題への関心の高まりを反映して、科学技術庁と呼応してさっそく原子力安全規制行政セミナーを開催することにしていると聞いており、私としてはこれを高く評価する次第であります。

第四に、研究機関等の国際化についてですが、とりわけ、原研、動燃の果たす役割は重要であり、先ずはこれらの機関において国際化が進められる必要があります。そのためには、国際協力活動を各機関の事業計画の中に明確に位置付け、所要の環境整備及び弾力的な組織運営を図る必要があり、それにより、特に今後アジア地域諸国からの要請に対応し、国際的な研究交流がより積極的に行えるような機能・体制の充実が図られることが期待されます。

また、民間においては、電気事業者、発電設備技術検査協会、原子力工学試験センター、原子力安全技術センター等の機関が協力活動の実施機関としての所要の機能が強化されることが期待されます。

最後は国際人の育成・確保についてでありますが、我が国はその生い立ちから、なかなか国際人が育ちにくい社会風土にあるのではないかといわれていますが、今後我が国が真に国際化していくためには、人自身が、またその人の考え方が国際化することが必要であります。そのような意味で、研究者はもちろんのこと、それら研究者を支えている周りの人達も含めて、国際活動がより円滑に出来るような国際人育成制度が確立されることが強く期待されます。

17. 以上、これからの国際協力問題について色々と申し述べましたが、これらの考え方や提案に基づいて、国際協力を積極的に進めるには、その実施計画の枠組作りに格段の努力を要する面が多いと思います。

原子力開発利用の国際協力問題は、外交政策や産業政策に関係深い問題でもあり、関係官庁間の呼吸が合い歩調が揃わなければ事は運ばず、また、国と民間との連携・協力がなければ実効はあがらないと考えます。

大方の御理解と積極的な御協力をお願いして結びといたしたいと思います。

JAPAN ATOMIC INDUSTRIAL FORUM

15 April 1987

Panel on "International Nuclear Co-operation in Asia"

Introductory Statement

Hans Blix
Director General
International Atomic Energy Agency

In talking about nuclear co-operation in Asia, I think one has to start with the observation that Asia comprises some of the fastest developing countries in the world. It is not surprising that advanced nuclear techniques are being used in this development and form important parts of it. Examples that come to mind in the field of agriculture are mutation breeding of rice and food preservation through irradiation; in the field of industry examples are non-destructive testing and polymerization; in medicine there are examples both in diagnostics and in cancer treatment. Electricity generation through nuclear power has been introduced in several Asian countries and some others are actively considering it as an alternative to burning oil, gas or coal to produce electricity. Some of the nuclear power programmes have now reached such a size that they are essential for the country's development. In this situation it is natural that a closer international co-operation is sought through trade and the exchange of experience.

The IAEA expressly supports and promotes regional co-operation. In the Asian region, the Agency acted on a visionary proposal for a regional co-operation agreement first made in the late 1960s by the former Chairman of the Indian AEC, Dr. Raja Ramanna. The programme took some years in materializing, but in 1972, the Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology, or RCA, was launched for a first five year period. The agreement has served the participants well, and it has been renewed three times -- the third time being only a few weeks ago. It now has fourteen members from within the Asian and Pacific Region.

In my experience, RCA is unique among co-operative agreements within the UN system. In 1986, the operating budget was $1.9 million, but of this, 70% came from sources outside the IAEA. Australia and Japan were donors, but so were two developing countries from the region, namely, India and the Republic of Korea. This shows the spirit of and the importance attached to this regional agreement. In addition, UNDP contributed $3 million over a five-year period to a Regional Industrial Project, with the objective of supporting the application of nuclear techniques in four subject areas:

-- Tracer technology in industry;
-- Non-destructive testing;
-- Radiation processsing; and
-- Nuclear control systems.

Japan, too, contributes to this project, as well as to a project on Medical and Biological Applications. Within this, I would note in particular a project to improve instrument maintenance, which in my experience meets a strongly felt need.

Besides other projects in the subjects of food and agriculture and basic nuclear science, a new activity has been introduced as of this year, namely, workshops concerned with Energy and Nuclear Power Planning. This has been done as most of the countries in the region use the Agency's methodologies for energy demand forecasting and electricity system planning (MAED and WASP respectively) and they would stand to benefit from a closer exchange of experience.

RCA has been successful, I believe, because it responded to a real need. Scientists in the region got to know each other and could get help with their problems through a telephone call or a visit. It is also notable that there is a strong interest from the industries, which propose projects and participate very actively. Certainly, the existence of donor countries and technology suppliers within the region has also played a very essential role.

The RCA has served as a model for the Latin American Regional Co-operative Agreement which was launched recently and I hope that it will become possible to start another project of this type for Africa in the future. Needless to say, each regional agreement will have to have its specific characteristics, and they will not be exact copies of each other.

RCA is only one example of what may be achieved through regional co-operation in Asia. I have described it because it has considerable volume and is administered within the auspices of the IAEA. There are other forms of regional co-operation which could be developed to the benefit all participants. One is certainly a direct exchange of experience between operators of nuclear power plants. They could discuss the methods and procedures which they use to improve performance. They could tell each other about the incidents of safety significance which they have experienced, what their root causes were, and how they coped with them. Another object of co-operation could be a similar exchange between operator training centres in the region, ultimately perhaps aiming at establishing common qualification standards for operating crews. This would not have to mean that a shift supervisor should have the same qualifications in all countries concerned. That may not be realistic, considering the different educational backgrounds, the different organization and career schemes and the different cultures. In the IAEA, the approach has rather been to try to define the qualifications which you need to have available in the operating crew, whatever the functional titles are. I believe this could be a useful area of regional co-operation and the Agency would gladly support it.

It is also at the regional level that one might best break the seemingly inherent isolation of utilities to which I referred yesterday and promote a direct exchange of information between plant owners. The Agency would be prepared to assist in any efforts in that direction, as they would probably contribute to achieving the standards of excellence in performance and safety to which we aspire and which will be needed to regain a general public confidence in nuclear power.

There have been some examples of nuclear projects owned jointly by utilities in two countries. France at present shares ownership of plants with both Spain and Belgium. The Superphenix fast breeder is another example of an international venture. Within the United States, many projects were joint between the utilities in different states. They were not always successful. Power plants have been built in Canada with the express objective to deliver part of the output to the USA.

One joint project already exists in the Asian region in the Daya Bay or Guandong plant which is now being constructed as a joint venture between China and Hong Kong. There are, of course, many other locations in the region where such joint projects would be possible. They could give essential benefits to the participating countries through the integrated electric grids they presuppose but -- more importantly -- through the shared resources they would use.

In summary -- the experience of regional nuclear co-operation in the Asian region has been very positive. There seems to be a real possibility of usefully expanding it into new areas, notably nuclear power operations. The IAEA would be prepared to assist in such efforts.

中国の原子力平和利用における国際協力

中国原子力工業省
次官　李 定 凡

議長ならびにご出席の皆様：

昨年われわれは日本原子力産業会議創立３０周年をお祝いいたしましたが、今年はまた日本原子力産業会議の第２０回年次大会を迎えることになり、中国原子力工業省代表団がお招きにあずかり、本年次大会出席のため日本を訪問することができましたことは大変嬉しく存じます。私は謹んでわれわれ一同を代表して、本大会が成功をおさめますようお祈りするとともに、ご出席の皆様に心からご挨拶申し上げます。

日本原子力産業会議は原子力分野における国際協力を重視され、この方面において多くの大きな成果をあげられた事業をなされております。私はこの機会に皆様に対し中国の原子力国際協力に関する基本的な方針と活動状況についてご紹介したいと思います。

中国の原子力産業は既に３０余年の歴史があり、原子力について比較的整った科学、技術、産業体系が出来上がっています。対外開放政策を実行する中で、積極的に原子力平和利用についての国際協力を広範に展開しております。われわれの基本方針は、第一に、自力更生を貫徹させるという原則の基礎のもとに、外国の先進的な技術と経験を努力して学び、わが国において原子力技術の利用を促進する。

第二に、主権を尊重し、平等互恵の原則の基礎の上に、国際協力を積極的に展開する。各国とともに、原子力分野の世界的な科学技術交流の促進、繁栄のために貢献する。

第三に、核拡散を主張しない、奨励しない、実行しないという原則と立場を堅持する。原子力の資材および機器を導入する場合、平和目的に使用することを堅く守ること、そして原子力の資材および機器を輸出する場合、国際原子力機関の保障措置を受入れることを要求することであります。

上述の基本方針にもとづき、原子力工業省は中国の原子力事業の当該機関として、多様な方法を採用して各国の関係機関と広範な交流と協力を行っております。最近の５年間で、原子力工業省関係で外国を訪問し、視察、国際学術会議に出席あるいは短

期的な研修を行なったものは、全部で１００余の代表団・チームに達し、延べ人数は１２００余人になります。また３０余の国家と地域から来た代表団あるいは専門家は合計４００組、延べ２０００余人になります。これらの活動は中国と外国との間の科学技術の交流を促進するのみならず、関係者間の相互理解と友好を増進させることになります。中国はまた相前後してイタリア、フランス、西ドイツ、日本、イギリス、アメリカ等１３の国家の政府部門あるいは民間機関と原子力平和利用についての二国間協力協定あるいは議定書を締結し、これらの国家との科学技術交流と貿易を推進いたしました。

上述の活動について、われわれは以下のいくつかの方面の協力において良い効果をあげてきたと思っています。

一つは、ウラン資源の探鉱開発について、１９８３年以来、われわれと日本の動燃事業団はわが国の雲南省騰沖地区において共同でウラン資源の探査事業を行い、初歩的な成果を得ております。今年より双方はさらに詳細な共同探査の協力について検討することになっております。

二つ目は原子力発電所の建設について、中国を主とし、海外の協力を求め、そして技術と貿易を結合させるという方式をとるのが比較的有効であります。中国が現在建設中の浙江省秦山原子力発電所は、中国の自己設計により、外国の専門家の援助と協力を得て、原子力発電所の設備部分は中国自身で製造し、一部分だけ外国から導入したものであります。そのほか現在建設中の広東大亜湾原子力発電所は、中国と外国の合弁方式を採用し、外国からプラントを導入し、中国の技術者が工程管理、土木建設、据付および試運転等の作業に従事しております。現在検討中の秦山の第二期工事は、二基の電気出力６００MWの加圧水型原子力発電所として共同設計を行い、中国を主体とし、技術と貿易を結合させる方式を採用し、わが国の技術者がさらに良く原子力発電の技術を掌握できるようにしております。原子力発電所の建設にあたって、中国としては、安全第一、品質第一の方針を堅持しており、かつ原子力発電の安全性についての国際協力は必要不可欠のものと思っております。

三つ目は、特定のテーマについて学術交流を行うことであります。たとえば核燃料サイクルシステムでは、特に高、中、低レベル放射性廃棄物の処理・処分について、長年来われわれは世界の多くの国家、たとえば日本、フランス、西ドイツ等の研究機関および電気事業者と多くの接触を行い、多くの活動を行いました。われわれは関係のある国家とさらに協力し合い、放射性廃棄物の処理・処分についての技術開発を推進したいと願っております。

中国は１９８４年に正式に国際原子力機関に加盟し、積極的に国際間の原子力技術の平和利用交流に参加して、国際協力のために貢献しております。この三年間、中国はのべ２００人に近い者が国際原子力機関が行う各種のトレーニングコースと各種の特別会議に参加しており、その内容は原子力計画、放射線防護から各分野におけるアイソトープ放射線利用に及んでおります。中国はまた自己の原子力施設を利用して国際原子力機関のために多くの原子力技術トレーニングコースを設け、発展途上国、とくにアジア太平洋地域の国々のために１００余名の人々を訓練しました。中国の研究、設計、教育等４０余の部門は、国際原子力機関と約５０余項目にわたる研究取り決めを締結し、その内容は、ウラン鉱の地質、核燃料、原子力発電、放射性廃棄物処分、放射線防護、アイソトープ利用等の分野における研究開発と実用にまで及んであります。中国の多くの原子力専門家は招請されて国際原子力機関の色々な特定のテーマについての諮問委員会あるいは専門家会議に出席し、各国の専門家とともに、原子力の国際協力のために方策を提案しております。

中国政府は、それぞれの国家はすべて原子力の平和利用についての活動を展開し、かつ積極的にこの分野における国際協力に参加する権利を有するものと認めます。先進国と発展途上国との間の原子力協力はさらに拡大すべきであります。われわれはこの分野において、世界各国の関係者、特にアジア地域の関係者と、この目標実現のためにさらに緊密な協力を行い、友好の花が原子力分野において永遠に咲き誇るよう願っております。

最後に、議長ならびにご出席の皆様のご健康をお祈り申し上げるとともに、年次大会のご成功を重ねてお祝い申し上げます。

有難うございました。

THE INTERNATIONAL COOPERATION IN THE PEACEFUL USES OF NUCLEAR ENERGY IN CHINA

By Li Dingfan, Vice Minister
Ministry of Nuclear Industry, China

Mr. Chairman, Ladies and Gentlemen:

Last year, we celebrated the 30th anniversary of the foundation of the Japan Atomic Industrial Forum, while this year we are greeting its 20th Annual Conference. We in the Delegation of the Ministry of Nuclear Industry are most pleased to be invited to participate in this session and make a visit to Japan. May I now, on behalf of my colleagues, extend our cordial greetings to our friends present today and wish the Conference a success.

Attaching great importance to the international cooperation in the field of nuclear energy, the Japan Atomic Industrial Forum has done a great deal of fruitful work. Now, I would like to take this opportunity to present to our friends an overview on our basic policies and activities concerning the international cooperation in the peaceful uses of nuclear energy in China.

The nuclear industry in China has evolved over 30 years during which a fairly complete system of nuclear science, technology and industry has been established. In the course of carrying out its open-door policy to the outside world, China has actively conducted a wide-ranging international cooperation in the peaceful utilization of nuclear energy, for which our basic policies are: Firstly, we, while adhering to the principle of independence and self-reliance, endeavour to learn the advanced technologies and experiences from foreign countries so as to promote the applications of technologies of nuclear energy in China. Secondly, we advocate the vigorous international cooperation based on the principles of respect for state sovereignty, equality and mutual benefit, dedicating ourselves

to the prosperity and advancement of the world-wide scientific and technical exchange in the field of nuclear energy. Thirdly, we maintain the principal stand of neither favouring, encouraging nor engaging in nuclear proliferation. Guided by this policy, China will, in importing its nuclear materials and equipment, make sure that they are used for peaceful purposes. In the same view, when exporting nuclear materials and equipment, China will request the recipient countries to accept the safeguards of the International Atomic Energy Agency.

In line with this fundamental policy, the Ministry of Nuclear Industry, as the competent authorities for China's nuclear undertakings, has taked various measures to conduct with its counterparts the wide-ranging exchanges and cooperation. Over the past five years, the Ministry of Nuclear Industry for its own has sent over 1000 individuals represented in more than 100 delegations or teams to participate in visitations, study tours, international scientific meetings or in short-term on-the-job trainings, while at the same time, we have received delegations or experts totalling over 2000 individuals in 400 groups from more than 30 countries and regions. These interactions have not only stimulated the scientific and technical exchanges between China and foreign countries, but also improved tha mutual understanding and friendship among the partners. In addition, China has successively signed the bilateral agreements of cooperation or protocols on peaceful utilization of nuclear energy with either governmental organizations or non-governmental agencies in 13 countries such as Italy, France, the Federal Republic of Germany, Japan, the United Kingdom and the United States, which has given impetus to the scientific and technical exchanges and trade transactions with these countries.

In this context, marked results have been scored in the following areas of cooperation: First, on exploration and development of uranium resources, initial results have been observed in the joint survey of uranium resources in Yunnan Tengchong region with the Power Reactor and Nuclear Fuel

Development Corporation since 1983. Beginning from this year, both sides will further approach the cooperation on joint detailed exploration and survey. Second, on nuclear power construction, we deem it quite effective to adopt the policy of seeking foreign cooperation while emphasizing self-reliance and combining technical exchanges with foreign trade. Basing on these Zhejiang Qinshan Nuclear Power Plant which is now under construction was designed on our own, while inviting foreign experts to help make consultancy and its equipment manufactured in China and introduced from abroad each in part. While the Guangdong Daya Bay Nuclear Power Plant is accorded in the way of joint venture by importing the complete set of equipment from foreign countries and with the Chinese technicians participating in the project management, civil construction, installation, commissioning and operation, etc. Jointly designed, the Qinshan second-phase project, that is, two units of 600MW pressurized water nuclear power plant, which is under study, will be implemented by emphasizing self-reliance and combining technical exchanges with foreign trade so as to enable our engineers and technicians to well master the technologies of nuclear power. In the process of nuclear power construction, China persists in the policy of giving priority to safety and quality. We consider it imperative to conduct the international cooperation on safety of nuclear power. Third, the academic exchanges have centered on topical subjects. Over the past years, we have engaged in generous contacts and carried out many activities with the research institutions and utilities in countries such as Japan, France and the Federal Republic of Germany, etc. on nuclear fuel cycle system, and on high, medium and low level radioactive wastes treatment and disposal in particular. In this connection, we are prepared to further our cooperation with the countries concerned in order to promote the development of technologies for radioactive wastes treatment and disposal.

Since its formal admission to the International Atomic Energy Agency in 1984, China has taken an active part in international cooperation on exchanges of peaceful uses of nuclear technologies, thereby contributing to that purpose. Over

the past three years, China has sent nearly 200 individuals to participate in training courses and specialized meetings sponsored by the Agency which deals with the programmes of nuclear energy, radiation protection and the applications of radiation techniques of isotopes in various fields. By using its own nuclear installations, China has hosted a quite number of international training courses on nuclear technologies and trained over 100 participants for the developing countries, specially for those in the Asian and Pacific regions. Over 40 institutions of research, design and education in China have signed about 50 research contracts with the IAEA which relate to the research and development as well as the practical utilization in various areas of uranium geology, nuclear fuel, nuclear power, nuclear wastes disposal, radiation protection and isotopes. A quite number of the Chinese nuclear experts have been invited to participate in the advisory or expert groups on different subjects set up by the International Atomic Energy Agency, joining other experts from various countries in offering ways and means for the international cooperation in peaceful uses of nuclear energy.

The Chinese Government holds the view that every nation has the right to engage in activities of peaceful uses of nuclear energy and take an active part in the international cooperation. And the cooperation in nuclear energy between the developed and the developing countries should be further expanded. For realizing this goal, we are ready to cooperate more closely with our conterparts in various countries of the world, specially with those in the Asia. Let the flower of friendship bloom forever in the field of nuclear energy.

Mr. chairman, Fellor Delegates, Friends:

Finally, I wish you all good health and once again the Conference a success.

Thank you!

中国和平利用核能的国际合作

中国核工业部副部长　李定凡

一九八七年四月十五日

主席先生、各位女士、各位先生：

去年我们庆祝了日本原子力产业会议成立三十周年，今年又迎来了原子力产业会议第二十届年会，中国核工业部代表团应邀出席这届年会并访问日本，感到十分高兴。我谨代表我的同事们，预祝会议取得成功，并向在座的各位朋友致以亲切的问候！

日本原子力产业会议重视核能领域的国际合作，在这方面进行了许多卓有成效的工作。我愿就这个机会向各位朋友介绍，中国关于核能国际合作的基本方针和活动情况。

中国核工业的发展，已有三十多年的历史，已建立了比较完整的核科技工业体系。在实行对外开放政策中，积极广泛地开展了和平利用核能的国际合作，我们的基本方针是：第一，在贯彻自力更生的原则基础上，努力学习外国的先进技术和经验，促进核能技术在我国的应用。第二，

在尊重主权、平等互利的原则基础上，积极开展国际合作。与各国一道为繁荣促进国际核能科技交流做出贡献。第三，坚持不主张、不鼓励、也不搞核扩散的原则立场。在引进核材料和核设备时，将确保用于和平目的。在出口核材料和核设备时，将要求接受国际原子能机构的安全保障。

本着上述基本方针，核工业部作为中国核事业的归口部门，采取多种形式与各国同行进行了广泛的交流与合作。近五年来，核工业部系统出国访问、参观考察、出席国际学术会议或短期工作进修的共一百多个代表团、组，一千多人次，并先后接待了来自三十多个国家和地区的代表团或学者共四百批，两千多人次。这些活动不仅促进了中外科学技术的交流，而且增进了同行之间的相互了解和友谊。中国还先后与意大利、法国、联邦德国、日本、英国、美国等十三个国家的政府部门或民间机构签订了和平利用核能的双边合作协定或议定书，推动了与这些国家的科技交流和贸易往来。

上述活动，我们认为在以下几个方面的合作取得了较好的效果。一是在铀矿资源勘探开发方面，自1983年以来，我们与日本动燃事业团在我国云南腾冲地区联合调查铀矿资源的工作，已取得了初步成果。从今年起，双方还进

一步探讨详细勘探联合调查的合作。

二是在核电建设方面，采取以中为主、中外结合、技贸结合的方式较为有效。中国正在建造的浙江秦山核电站，就是由中国自己设计，邀请外国专家帮助咨询，核电站的设备部分由中国自己制造，部分从国外引进。另一座正在建造的广东大亚湾核电站，是采取中外合资的方式，从国外引进成套设备，中国的工程技术人员参加项目管理、土建、安装和运行调试等工作。正在研究中的秦山二期工程，即两座功率为600MW的压水堆核电站，将采取联合设计，以中为主，技贸结合的方式，使我国的工程技术人员更好地掌握核电技术。在核电建设中，中国坚持安全第一、质量第一的方针，并且认为在核电安全方面的国际合作也是必不可少的。

三是围绕专题进行学术交流。如在核燃料循环系统，特别是在高、中、低放射性废物的处理处置方面，多年来，我们与世界上许多国家，如日本、法国、联邦德国等的科研和生产部门进行了大量接触，举行了许多活动，我们愿与有关国家进一步开展合作，以促进放射性废物处理处置技术的发展。

中国于1984年正式加入国际原子能机构，积极参加国际核技术活动，为国际核技术合作做出了贡献。三年来，

中国有近二百人次参加国际原子能机构举办的各类专业培训班和各类学术会议，其内容涉及核能计划、辐射防护、同位素辐射技术在各方面的应用。中国还利用自己的核设施，为国际原子能机构举办了多期国际核技术培训班，为发展中国家，特别是亚洲太平洋地区的国家培训了一百多名学员。中国的研究、设计、教育等40多个部门，与国际原子能机构签订了约五十多项研究合同，其内容涉及铀矿地质、核燃料、核动力、核废物处理、辐射防护、同位素应用等领域的研究开发和实际应用。中国的不少核专家应邀出席国际原子能机构不同专题的顾问组会或专家组会，与各国专家一道，为核能的国际合作献计献策。

中国政府认为，每个国家都有权开展和平利用核能的活动，并积极参加这一领域的国际合作。发达国家与发展中国家之间的核能合作应该进一步扩大。我们愿在这一领域，与世界各国的同行，特别是亚洲地区的同行，为实现这一目标开展更加紧密的合作，让友谊之花永远盛开在核能领域之中。

最后，祝主席先生、各位代表、各位朋友身体健康！再次祝贺年会成功！

谢谢各位！

International Nuclear Cooperation in Asia

Presented at
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Prepared by
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Mr. Chairman and Distinguished Guests,

It is a great honor for me to have this opportunity to participate as a panelist in the 20th JAIF Conference and to address International Nuclear Cooperation in Asia.

Before going into the subject in detail, I wish to note that I will try to focus on matters concerning the international cooperation in nuclear energy rather than in other nuclear applications pertaining to food and agriculture, medicine, and hydrology. I belive that Korea's interests are much more involved in the former.

Necessity of Nuclear Cooperation

If I may, I wish to begin with a brief description of the characteristics of the nuclear energy and the necessity of international cooperation in implementing nuclear power programs.

As you are all aware, nuclear power project traditionally involve huge financial investment, highly sophisticated technology, and long lead times. Nations with desire to introduce nuclear power plants must possess the necessary infrastructure, the manpower for all the stages from planning to construction, the skills for operation and management of nuclear power plants, and the merit of economy in scale that would allow the mobilization of financial resources.

In view of all these complicated requirements, it seems very difficult, If not impossible, for a country to implement its nuclear power program without the cooperation and assistance from others. This is particularly true for developing countries. The problems associated with the nuclear power programs in developing countries can only be solved with the cooperation and assistance from advanced countries in terms of technology, manpower training and financial resources.

Status of Nuclear Power in the Asia and Pacific Region

In the Asia and Pacific Region, five countries - Japan, Taiwan, India, Pakistan, and Korea - have commercial nuclear power stations in

operation, while two of them, China and the Philippines, have plants under construction.

The total installed nuclear power capacity of the Region in 1986 was about 35 GW(e), representing 12 per cent of the world installed capacity, According to the IAEA, 19GW(e) will be added by 1990, but the total installed capacity is expected to remain on the level of about 11 per cent of the world capacity. Several other countries in the region are likely to consider the nuclear power as an energy option in the 1990's.

This could lead to a total installed capacity in the region somewhere between 80 to 125 GW(e) by the year 2000, which would represent about 15 per cent of the estimated world capacity at that time. In reality, most countries in the region are barely in a position to initiate their own nuclear programs by introducing research reactors and/or RI application facilities from advanced countries.

Korean Experience with Nuclear Power Program

Please allow me to turn for a moment to Korea's experience with her nuclear power program. Heavily dependent on imported energy sources in the wake of the rapid industrialization, Korea has paid attention in the past 20 years to the development of nuclear energy to meet its increasing energy demands. This dependency forced Korea, a country lacking energy resources, to rapidly promote the use of nuclear energy as it looked economically more attactive and less vulnerable than petroleum to a cutoff in supply.

At the present, Korea has six operating nuclear power units with 4,800 Megawatts of installed capacity, about 26% of our total electrical generation, and three additional nuclear power units each sized at 950 Megawatts under construction. When all these nine plants are in operation by the end of the 1980's, the total unclear capacity will be 7,650 Mw(e), which amounts to 35% of the nation's total electrical capacity. Meanwhile, two more units will be added to this list during the 1990's. In the long term, the unclear power program in Korea will keep expanding to meet the increasing energy demands.

For the first three nuclear power units, composed of 2 PWRs and 1 CANDU, contracts were awarded on a turn-key basis which reflects the low level of our manpower and technology accumulation. Aided by experiences with the first three turn-key projects, Korea switched to what we call a component approach for the construction of the units #5 through #10. Local engineers and manufacturers began to extensively participate in these projects under the owner's responsibility. For the units #11 & 12, the construction will be implemented with a Korean nuclear firm as the prime contractor for design and manufacture of NSSS components as well as the rest of the plant, and the foreign firms will serve only as subcontractors.

International cooperation contributed significantly to the successful conclusion of these projects. Korea, like any other developing countries, suffered initially from the lack of experience in nuclear energy, the shortage of trained manpower and research facilities, and the vulnerable infrastructure. In an effort to overcome these difficulties, she instituted international nuclear cooperation programs with the IAEA and advanced nations, including the United States, Canada, France, Germany and Japan.

The cooperation with the IAEA has had a special emphasis on manpower training. More than two thousand Korean scientists and engineers have received overseas training including technical assistance through the IAEA's Technical Assistance Program ever since Korea joined the international body in 1957. The program also played a critical role in forming and implementing the nuclear development plans.

Nuclear cooperation with advanced countries has been conducted mainly under bilateral agreements, which number seven so far. Annual meetings of the Joint Standing Committee on Nuclear Energy are held with the U.S.A since 1977. France since 1982 and Canada since 1983 under these agreements.

These channels have actively used not just for manpower training but also for joint studies, nuclear information exchange and consultant services.

No bilateral agreement with Japan has been established, but the annual Science and Technology Ministerial Meeting has played the role of a cooperation bridge between two countries since 1968.

Appropriate Areas, ways and Means of Nuclear Cooperation in Asia

The ideal nuclear cooperation should be based on mutual interests and trust among the countries involved as is true with any general trade.

However, countries in the Asia and Pacific Region are diverse in their sizes, populations, resources and the stages of development. Some are highly industrialized and some semi-industralized while others are mainly agriculture oriented. Some of us have already benefited greatly from the peaceful applications of nuclear energy. Other are just about to assess the potential of nuclear energy in their future energy needs. Some countries may never show great interests in the use of nuclear energy for power generation because of their small size or abundance of coventional energy resources.

Even among the seven nuclear countries of the Asia and Pacific Region, there exist huge gaps in technological capability, manpower and industrial structure. Therefore the interests in the international cooperation on nuclear power projects vary from country to country.

Given the diverse stages of nuclear development and differing interests in the regional nuclear cooperation, it is not an easy task to select appropriate areas for cooperation and develop the mechanisms for their implementation that will satisfy all nations. Under the constraints, however, I would like to express my opinion on the possible areas for nuclear cooperation in the Region and propose a couple of ideas as to the ways and means for the promotion of nuclear cooperation.

Taking a look at the recent international nuclear arena, I realize that many conflicting political issues are associated with the nuclear cooperation. For example, I can list the transfer of advanced technology, the assurance of nuclear supply, the early notification and mutual assistance among neighboring countries in case of a nuclear accident, the spent fuel management and the back-end fuel cycle among others.

These issues are important to the countries where the nuclear programs are essential, particularly to those seeking the self-reliance in nuclear technology.

In particular, the UN General Assembly of 1977 passed a resolution, which says all states have the right, in accordance with the principle of soverign equality, to develop their own programs for the peaceful uses of unclear technology in conformity with their priorities, interests and needs, and that, without discrimination, they should have access to and be free to acquire technology, equipment and materials for the peaceful uses of nuclear energy. Keeping this in mind, we must search for the ways and means for the transfer of advanced technology from the developed to the developing countries under the full safe guards of the IAEA without jeopardizing either the principles of the UN resolution or the non-proliferation treaty.

The chernobyl accident last year brought to our attention the importance of nuclear cooperation in the nuclear safety area.
It is my firm belief that the nuclear safety should be considered a prerequisite for the promotion of nuclear power as it is essential in the protection of the population and the preservation of the environment.
The nuclear safety issue cannot be confined to single nation as the undesirable effects of a nuclear accident are likely to spread across national boundaries.

I hope that the nuclear safety will be given top priority in the nuclear cooperation in the Asia and Pacific Region, which comprises many countries with large populations. Looking at Japan and Korea, where the populations of both the people and the nuclear facilities are dense, we recognize that a problem in one country's nuclear safety should be treated with equal importance by the other.

As the desirable areas for cooperation, I would also like to suggest the long-term storage and disposal of the radioactive waste, including spent fuels, the radiological protection, and the operation and maintanence of nuclear facilities. International cooperation in these areas will be relatively easier as they are of common concern among the countries with operating nuclear facilities.

In view of the high population density in the region, we must have deep concerns over the environmental protection and monitoring for radiological protection, we must develop cooperation programs concerning the selection of sites for radwaste disposal, and the formulation of technical criteria and standards applicable to highly populated countries.

Finally, I would like to propose some ideas for the enhancement of nuclear cooperation in the Asia and pacific Region.

At present, the Regional cooperation Agreement for Research, Development and Training in Nuclear Power and Science and Technology, Known as RCA, is the only unique official vehicle for nuclear cooperation in the Region.

With the establishment of the RCA, under the auspices of the IAEA, the nuclear cooperation in the Region gained the most critical momentum as evidenced by the accelerating exchange of experts and information in the region. The RCA has particularly contributed to the radio-isotope untilization of its technology to the Member States through seminars, joint studies, demonstrations and regional training courses, which were focussed on radioisotope applications.

Our regional common need of nuclear energy uses is greater in the industrial area than in the radio-isotopes, I hope that the RCA cooperation programs will be extended to cover the nuclear power issues of the RCA member states.

The cooperation projects in the field of nuclear power can be embodied with the RCA meetings or other Governmental working-group meetings.

It is perhaps appropriate to mention that it will be of great value to set up an Asian Nuclear Data Bank and a Regional Training Center which can be jointly sponsored by the IAEA, other UN organizations and Member states, as the promotion of peaceful uses of nuclear energy and successful implementation of nuclear power programs are heavily dependent on the extent of accessibility to nuclear information and skilled manpower.

The Data Bank can be built up by expanding and supplementing the existing data bases in the IAEA and Member States. The Regional Training Center can be set up and run without much financial burden by making good use of the existing training centers in Member States.

An alternative to the Regional Training Center will be opening all training centers of the RCA Member States to one another. In Korea, we have two

institutions for nuclear manpower training: one at the Korea Electric power Corporation and the other at the Korea Advanced Energy Research Institute.

I wish to add one more suggestion for the international cooperation on nuclear safety. To prevent a nuclear accident and minimize its harmful consequences, we must find an appropriate institutional tool for regional cooperation such as mutual assistance, exchange of information and technologies on nuclear safety and joint research for emergency measures.

In this respect, I would like to remind you of my proposal presented at the 15th JAIF Annual Conference in 1982 for the establishment of a Nuclear Emergency Response Center to effectively handle the problems associated with nuclear safety and accidents.

Conclusion

Among the countries of the Asia and Pacific Region, Japan already enjoys the full benefits of nuclear energy in contrast with other countries, including Korea. Japan has extensive and valuable experiences, high technologies and high-quality manpower in the area of nuclear energy.

In principle we all accept that the international cooperation must proceed on the basis of trust and confidence for mutual benefits of the countries involved. In reality, however, we find it very difficult to identify the appropriate areas for nuclear cooperation among the countries of the Region because of our differences in nuclear programs.

Since the nuclear technologies can flow only from have-nations to have-nots, I can say with firm conviction that the nuclear cooperation in the Region will have to be centered around Japan.

In this regard, I wish to point out that Japan must share her benefits with her neighbors to some extent, and play a leading role as a giver in the promotion of nuclear cooperation. I find it encouraging to hear that Japan has recently formulated nuclear cooperation programs with developing countries. Apart from her international responsibility as a leading nuclear power country, these will also strengthen her ties of amity with developing countries in the Region.

I wish to to offer my sincere hope and confidence that our endeavor here and fallow-up actions will make it possible in the near future for all of us to explore and establish an effective cooperation tool on a long-term basis, a frame that can be shared by all countries of the Asia and Pacific Region.

Thank you.

SOME ISSUES RELATED TO THE DEVELOPMENT OF NUCLEAR POWER PLANT IN INDONESIA

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ABSTRACT

Indonesia being a member of ASEAN belongs to the group of developing country. If Indonesia decides to embark on the establishment of Nuclear Power Plant the country will have no choice but to discuss the following issues: safe operation of the plant and management of the nuclear waste.

Safe operation of the power plant is important not only from the point of view of hazards to human being, or economic loss, or even death, but equally important it is also from the psychological point of view in that not to loose the society's confidence in the overall nuclear power plant programme in the future.

The issue of safe operation involves both a safely designed system as well as skilled personnels to execute a well designed operation procedure.

The issue of nuclear safety is getting more and more attention lately for various reasons; some due to a deep concern about the quality of the inherent safety of the nuclear power plant to be built, others may just use their emotion to ask questions like "what ifs".

The issue of nuclear waste is as fundamental as the plant safety. Common people make very little difference between an atomic bomb and waste from a nuclear power plant.

Another issue is the issue of transfer of technology which need to be tied up with the overall industrialization process, meaning that embarking on nuclear power programme needs to contribute to local industrial activities, at least for some parts or components which can be manufactured locally.

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Introduction

Indonesia like many other developing countries is just beginning to build up its industrial capabilities, especially true in the field of manufacturing.

With this in mind, a nuclear power plant programme has got to be pursued in a manner suitable to the local capabilities in that optimization of the resources available which include not only manufacturing capability but manpower as well - engineers and technicians - to build,operate and maintain a nuclear power plant.

Currently Indonesia possesses approximately 500 engineers/scientist involved in nuclear activities, but experience in the nuclear power generation is none. The state owned utility has no experience either in the operation of a nuclear power plant.

Embarking on a nuclear power generation, like any other activity, should be an integral part of the whole national concept of industrialization process. Its related activities should increase activity in the field of energy industry.

Here Indonesia needs to make a proper choice, as to whether to emphasize the construction of the plant or the operation and maintenance of the plant. Taking the things which have been mentioned above, the writer thinks,that in its effort to transfer the know-how and the technology of nuclear power plant, it is to Indonesia's benefit to emphasize on the operation and maintenance of the plant once the plant is built in Indonesia.

Safety is one of the major issues that needs to be won. Common people in Indonesia have started to air their concern about the safety of a nuclear power plant for various reasons, some are honest inquiries while others are of the kind of "hand waving" arguments. In either case for a nuclear power programme to be launched succesfully, people need to be assured of the level of safety imbedded in the technology of commercially available nuclear power plant.

Operation

Once the plant is built and the supplier left the country then the Indonesians have to be able to keep the plant running properly and safely. In addition they too have to be able to administer proper maintenance.

This requires on the part of Indonesians skill and first hand experience, both of which require a long lead time. This means Indonesia now should start finding cooperation with country like Japan or others, in which to train their engineers, operators as well as technicians in real life so that when the first nuclear power plant is built in Indonesia, there will be people who can take over the job of operation and maintenance of the plant, at least for most part of it.

This calls for a need for Indonesia to place some of their future operators working in a nuclear power plant abroad for several

years so that when the first power plant is established the job of operation can be given over to the Indonesians as soon as the supplier leaves the country.
The same thing to the maintenance crew, technicians as well need to be placed abroad working while training, in a power plant and participate in the repair as well as maintenance of the plant. This again will require several years.

Safety

Good operation and maintenance procedure as well as their practices will certainly assure safety to the plant. But this is not enough. Well designed and well manufactured parts or components according to prescribed procedures are fundamental to the establishment of high reliability and high level of safety in the operation and maintenance of a power plant.

The owner and operator of a power plant should know the history of each component or equipment that goes into the system which might be used from time to time during the life time of the plant as well as for future use in the following plants.

This assurance of high level of safety, in addition to the good operation and maintenance practice, calls for a training in the field of Quality Assurance Programme, hence a cooperation in this field is again a well sought thing on the Indonesian side. We are looking for a possibility of training in a country where a nuclear power plant is being built, for Quality Assurance Programme should not be taught on a theoretical basis only.

Nuclear Waste Management

Beside safety, the nuclear waste is the next thing that people always question in regards to the establishment of a nuclear power plant. A true picture of the situation needs to be given both to the goverment as well as to the public.People's awareness of the possibility of contamination is certainly important and should be appreciated. It is then the job of the promotor of the utilization of nuclear energy to keep them at ease with accurate information on the possibility of hazards from nuclear waste from a power plant.

A concrete way to solve this problem is not yet at hand. Here again then is an area of possible cooperation in that disseminating objective information to the public in the hope that the potential danger is not exaggerated, and "trust" among the people on the existing technology based on the experiences of nuclear nations can be established.

The other side of the issue is the management of the waste itself. Here I think it is not enough for a country who embarks on the running of a nuclear power plant just to have a facility of top quality but also the experience in the management itself. Here comes again another possible area of cooperation in that Indonesians be placed at some waste management system abroad.

Parts

When establishing the first nuclear power plant there is one thing that needs to be mentioned in the interest of the integrated effort to increase the industrial activities, and that is the local participation. Vendors are kindly urged to look into the possibilities for some parts or components to be manufactured in the country.

Although the industrial development is still in its early stage, there are a few manufacturing companies available in the country to be asked to jointly fabricate parts or components locally.

To mention some are : P.T. PAL of Surabaya, P.T. Barata and several others.

Summary

In brief I would like to summarize the important points or areas of possible cooperation between Indonesia and Asian Nuclear Nation , they are :

a. Nuclear Power Plant Safety, including practical training in Quality Assurance Programme as well as in Licensing Exercises.
b. Training in Operation and Maintenance of a Nuclear Power Plant.
c. Training in Waste Management.
d. Local production of some parts or components for a nuclear power plant.

（セッション３：アジア地域における原子力開発と国際協力）

国際協力事業団の事業活動を通じて見たアジア地域における原子力開発利用

牟田口　道夫

（国際協力事業団　副総裁）

１．国際協力事業団の事業概要

（１）　本日は、原産年次大会のパネル・ディスカッションに参加させていただく機会を与えられましたことは、私の最も光栄、かつ、喜びとするところであります。本日、ご参加の方々は、それぞれ、権威ある御専門の方々ばかりでありますが、私は、現在、皆様方とは異なる職種にありますため、皆様方とは、やや異なった角度から意見を申しあげて、ご参考に供したいと考えます。その前に、現在、私が属しております『国際協力事業団』という組織につきまして、あまり耳なれない方々が多いかと存じますので、

第一に、『国際協力事業団』なるものについて、その概略をご説明させていただき、

第二に、この国際協力事業団と原子力の国際協力との関連について、

申し上げさせていただきたいと考えます。

（２）『国際協力事業団』というのは、英語では、『ジェイ・アイ・シイ・エイ』－－『ジャイカ』－－と略称されています。１９７４年８月に設立されたもので、日本政府の全額出資による特殊法人でありまして、開発途上国政府の要請を受け、日本の政府ベースの技術協力を一元的に実施する機関であります。

つまり、国際協力事業団というのは、

第一に、政府ベースの国際協力の機関でありますが、その政策を担当する機関ではなく、事業の実施を担当する実施機関であるということと、

第二に、技術協力を主たる事業とし、資金協力を主たる事業とするものではない

ということであります。

ところで、国際協力事業団が、このような技術協力を行います際の方法といたしましては、次のようないろいろな方法によっております。

第一の方法は、開発途上国から研修員を受入れて、日本あるいは、第三国で研修を行う方法であります。

第二に、日本から、技術の専門家を開発途上国に派遣する方法も行っております。

第三の方法は、技術協力に必要な機材を開発途上国に供与する方法であります。

第四の方法としては、これらの三つの方法を有機的に組合わせた『プロジェクト方式技術協力』という方式があります。

第五の方法は、『開発調査』という方式で、開発計画のためのマスター・プランをつくるためや特定プロジェクトのフィージビリティ調査を行うためのものであります。

これらの技術協力を実施します時は、全額、ＪＩＣＡの負担によって行うことを原則とします。また、その協力の実施は、これらに関連した技術をもつ日本の公的機関や民間機関などの御協力を得てこれを実施する方法をとっています。

なお、さらに、その他の協力として、事業団は、

－青年海外協力隊員の派遣とか、

－無償資金協力の実施に関連する業務や、また、

－大規模な自然災害に対する国際緊急援助活動、

など広範にわたる協力事業をも行っております。

（３）御高承のとおり、日本は、国際社会の相互依存関係が深まる中で、日本の国際的地位にふさわしい責任と役割を積極的に果たすため、年々、開発途上国に対する経済協力の拡充を図っております。１９８５年のＯＤＡの実績　－－　ＯＤＡというのは政府ベースの開発援助とお考えいただければよいのですが、このＯＤＡの実績を、支出の純額ベースでみますと、９，０５７億円（３８億ドル）で、アメリカ、フランスに次いで世界第三位の地位を占めております。国際協力事業団におきましても、その業務は、質・量ともに飛躍的に拡大して来ておりまして、昭和６１年度の予算では、９５７億円（６億ドル）、対前年比が８％の増加となっております。協力の対象となっております国の数は、１２６ヶ国に及びまして、地域別の構成比では、アジア地域が最も多く、約半数を占めております。また、協力する技術の分野は非常に広い範囲に及んでおりまして、

－農業、林業、水産業は勿論、

－鉱業（マイニング）、製造工業のほか、

－運輸、通信

－医療保健

などにまたがっております。また、特に、最近の傾向といたしましては、開発途上国からの協力要請が多様化し高度化して参っておりますのが、大きな特色であります。例えば、

－経営・品質の管理、生産性向上、貿易振興　などのソフト面を重視した要請や

－マテリアル・サイエンス、コンピューター・サイエンス、バイオテクノロジー　などの高度技術分野に対する要請も急激に増加しております。

また、協力の要請は、各国政府からなされて参りますほか、ＩＡＥＡなどの国際機関からもなされておりまして、事業団といたしましては、これらにも積極的に対応することといたしております。

２．原子力関連分野の事業活動

（１）それでは、次に、国際協力事業団では、これまでに、原子力に関連する分野では、どういう事業活動をしてまいりましたか、ということにつきまして、その概略を申し上げたいと存じます。

冒頭に申し上げました事業団の事業活動の分類にしたがって、申し上げますと、

－先ず、第一の分類の『研修員の受入れ』があります。開発途上国の技術者や研究者が日本におきまして、原子力関連分野の研修や関係研究機関などの視察を行っております。

－また、第二の分類の『専門家の派遣』では、日本から開発途上国へ専門家を派遣して共同研究や研究指導を行っております。

これらの研修員の受入れや専門家の派遣は、これまでのところ、アイソトープや放射線の開発利用を中心といたしております、しかし、昭和６１年度からは、これに加え、原子力発電にかかわる研修員の受入れが新に開始され、また、特に原子力の安全法規について新しくコースが設けられ、合計７つのコースの研修を実施し、５９名の開発途上国の人々がそれぞれのコースで研修を受けております。

また、専門家派遣の分野では、原子力発電所の安全審査制度や原子炉運転監視システムなど、原子力発電に関する協力案件も増加して来ております。昭和６１年度は原子力関連で４名の専門家を派遣しております。

これらの研修員の受入れと専門家の派遣を地域別にみますと、アジア地域が圧倒的に多く、約７割前後を占め、ブラジル、コロンビアなどの中南米諸国がこれについでおります。

（２）次に、分類の第三番目の『機材の供与』でありますが、これまでの実績といたしましては、中性子回析装置や放射線防護室などの関連資機材の供与が行われております。

（３）分類の第四番目の『プロジェクト方式の技術協力』では、保健医療分野でのアイソトープ・放射線利用による治療や診断などの医学・生物学利用に関するものが中心となっております。

また、第五番目の分類の『開発調査』につきましては、資源開発基礎調査として、インドネシアとモロッコでのウラン資源探査の実績が過去に２件ありますが、最近は、実施案件がありません。

３．原子力関連分野の協力に関する当面の課題

国際協力事業団の事業活動のなかで、原子力に関連する分野の協力実績は、ここ数年、増加の傾向にありますが、現在のところ、その全体に占める割合は、かなり低い状態にあります。研修員の受入れと専門家の派遣を例にとって見ますと、両者ともに、総数の１％前後にすぎません。

このため、事業団は、原子力の分野について、必ずしも、重点を置いていないのではないか、という見方をされますが、これにつきましては、次のような点を御説明あるいはお願い申し上げて、私の話のしめくくりとさせて頂きます。

第一に、相手国政府からの正式要請が少ないことであります。

事業団の技術協力は、条約その他の国際約束に基づく政府ベースの協力事業でありますため、まず、相手国政府からの正式要請があることが事業実施の際の前提となっております。さらに、その要請に基づいて、両国政府の関係機関との協議が行われました上で、実施案件が決められる仕組みとなっております。現状では、この前提となる相手国政府からの正式要請が少ない、ということであり、それぞれの国の経済社会開発計画のなかで、原子力関連分野の援助要請に対するプライオリティが他の分野に比べて、相対的に低いのではないか、と推測されます。

第二に、事業団の立場であります。

冒頭に申し上げましたとおり、事業団は、相手国政府からの要請と日本政府との協議があって、それが相手国の経済・社会開発に最適なものであるとの結論を得たものについて、その協力を実施する実施機関の立場にあるものであります。事業団は、開発途上国が高度技術の分野についても、非常に強い要望を有していることは承知いたしておりまして、開発途上国の発展は、先ず、高度技術でない分野から、と考えているわけではありません。

第三に、国内の協力機関との関係であります。

相手国政府と日本との間で合意ができたとしても、日本の国内の官民の協力関係機関、例えば、試験・研究機関や大学、民間企業などの御協力がなければ、この事業を実施することはできません。事業団といたしましては、日本の関係機関に御協力をお願いする立場にあるわけであります。それぞれの関係機関では、その時々の事情によりまして、人的、経費的、時期的な制約が生じることもあろうかと存じますが、今後、原子力分野における国際協力を本格化して行くためには、日本の関係機関におかれましても、国際協力が恒常的に行われるように、その体制なり組織が今後とも一層、拡充・強化されて行くことを特にお願いするものであります。

アジア地域における原子力開発と国際協力

関西電力(株)常務取締役
大石　博

1．最初に東南アジア等近隣諸国の原子力開発とその問題点について一言ふれておきたいと思います。

近年、近隣諸国においては、国内産業の育成、生活環境の向上等により電力需要の伸びは著しいものがあり、また、各国の長期エネルギー見通し、脱石油によるエネルギー供給構造の変革等から原子力発電の開発に対するニーズが顕著になってきておりますことは、御高承の通りであります。　しかしながら、各国とも、巨大プロジェクトである原子力発電の開発にあたっては、巨額の資金調達、産業基盤の整備など我が国が経験したことと同様の課題を長期的視点に立って乗り越えていく必要があろうと思います。

2．　そこで、早速に我が国の国際協力の進め方についてご紹介したいと思いますが、その前に、我が国の原子力発電の導入から定着に至る経緯と現状について簡単にご説明致しておきたいと思います。

①に示すように

(1)　導入に当って、まずはじめに原子力発電の調査研究、人材の養成等、導入基盤の整備・充実を行い、

(2)　第1号機は、海外から導入致しました。

(3)　第1号機の建設経験を通じ、電気事業者、国内メーカ等がプラント全体をまとめ上げる力を蓄積し、国産自主技術の習得に努め、

(4)　第2号機は、国内メーカが主体となって建設を行い、以降国産化比率を逐次拡大しながら、

(5)　日本型軽水炉への改良標準化を推進し、国産技術として定着を図ってまいりました。

原子力発電プラントは現在33基、2,568万KWが運転中でありますが、設備利用率は②に示すとおり1970年代中頃にはトラブルが続発し４０％台にまで落ち込みましたが、各種の改良を加え最近では７０％台の高稼動が定着し、安定した運転を続けております。

③は事故故障による停止回数を示すもので、最近では世界的に見ても極めて少ない回数となっております。

このように我が国の原子力発電は、規模・技術とも極めて高い水準に達しております。

このような原子力発電の導入から定着に至る２０余年の歴史には、多くの貴重な教訓が含まれていると考えますので、これを我が国と地理的、経済的に緊密な関係にある近隣諸国の原子力発電の開発面に生かしていくことは極めて有益であろうと考えます。

今後、具体的に協力を進めるに当っては、各国において、原子力発電の開発が適切かつ円滑に進められるよう、各国の国情を勘案し、真のニーズを踏まえながら的確に対応していくこととしております。

３．　次に我が国の協力体制についてでありますが、昨年３月通産省の総合エネルギー調査会原子力部会によって基本的な国際協力の在り方について報告書がまとめられましたが、その中で国と民間の役割が次のように定められております。

（１）まず、国の役割については、対外的には全体の窓口となると共に国内の総合的なとりまとめを行い、具体的協力の方針を示すこと等となっております。

（2）次に民間の役割については、日本原子力産業会議と海外電力調査会を民間の対外的な協力窓口とし、

・日本原子力産業会議は原子力発電開発を計画中又は検討中の段階にある国との協力窓口、また
・海外電力調査会は原子力発電プラントを建設準備中以降の段階にある国との協力窓口としております。

このように対外的な協力窓口は各国の開発段階に応じて異なりますが、協力の実施は主として電気事業者とメーカ等がそれぞれの役割に応じて行うこととしております。

４．　私は電力会社の一員でありますので、以下海外電力調査会を窓口とした電気事業者としての協力活動を中心にご紹介いたします。

まず、海外電力調査会について概略申し上げますと、⑤に示すとおり海外の電気事業の調査及び電気事業者が行う国際交流、技術協力のとりまとめを行うことを目的として、電気事業者によって昭和３３年５月に設立されました。

また、原子力発電分野の協力を強化するために昭和６０年８月に通産省、電気事業者をメンバーとする原子力技術協力委員会が内部に設置され、私がその委員長を努めさせていただいております。電気事業者としての協力活動はこの委員会が中心となり、国、電気事業連合会及び日本原子力産業会議等と密接に連携をとりながら協力の実施計画の策定及びその実施を行っております。

我が国の原子力発電の推進は国の監督、指導のもとに、電気事業者が中心となりメーカ、工事業者の協力を得て実施しておりますので電気事業者とメーカー等の協力関係についてご紹介しておきたいと思います。

⑥に示す通り電気事業者としては、建設段階においては、発電所の基本計画を策定し、これにもとづいてメーカー等が実施する詳細設計のレビュー及び建設工事の指導監督を行います。

運用段階においては、運転関係は全て電気事業者が行います。　保修工事等は、電気事業者が必要な計画を策定し、メーカー等の実施する工事を指導監督致しております。

最後に近隣諸国に対する具体的な協力内容については、⑦に示すように、

（1）情報提供
（2）技術者派遣による技術指導
（3）シンポジウム、セミナー等の開催、参加
（4）発電所等研修者受入れ
（5）ＪＩＣＡ集団研修原子力発電コースの研修者受入れ
（6）技術者交流

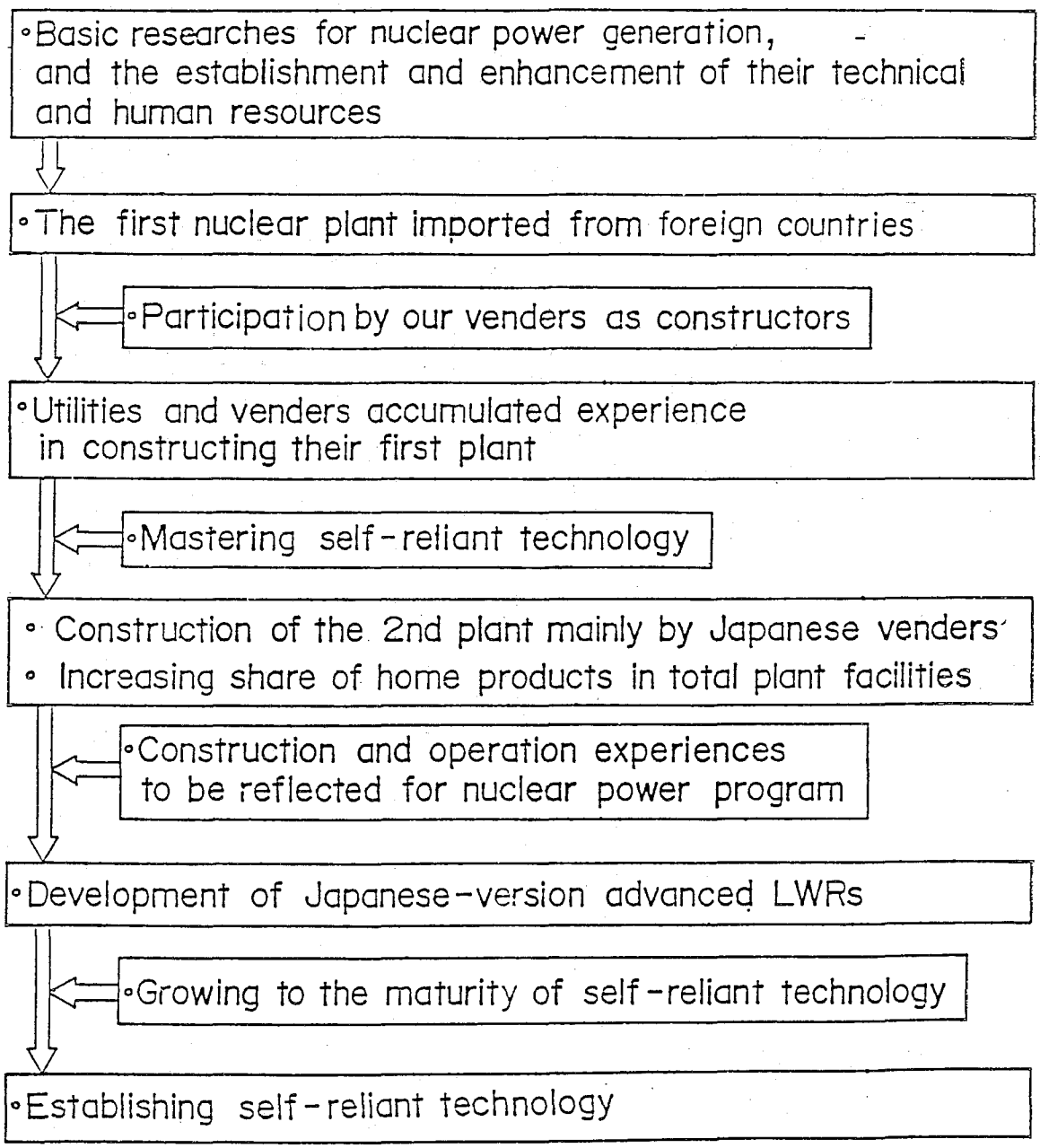
等でありますが、これらを各国の開発段階に応じ、また協力ニーズを踏まえながら技術的・人的基盤の整備充実に重点を置いた協力活動を行なうこととしております。

以上、海外電力調査会を窓口とした、電気事業者としての協力を中心に述べましたが、今後の協力活動の実をあげていくためには各国との相互理解と信頼関係を一層高めていくことが極めて重要なことと考えます。

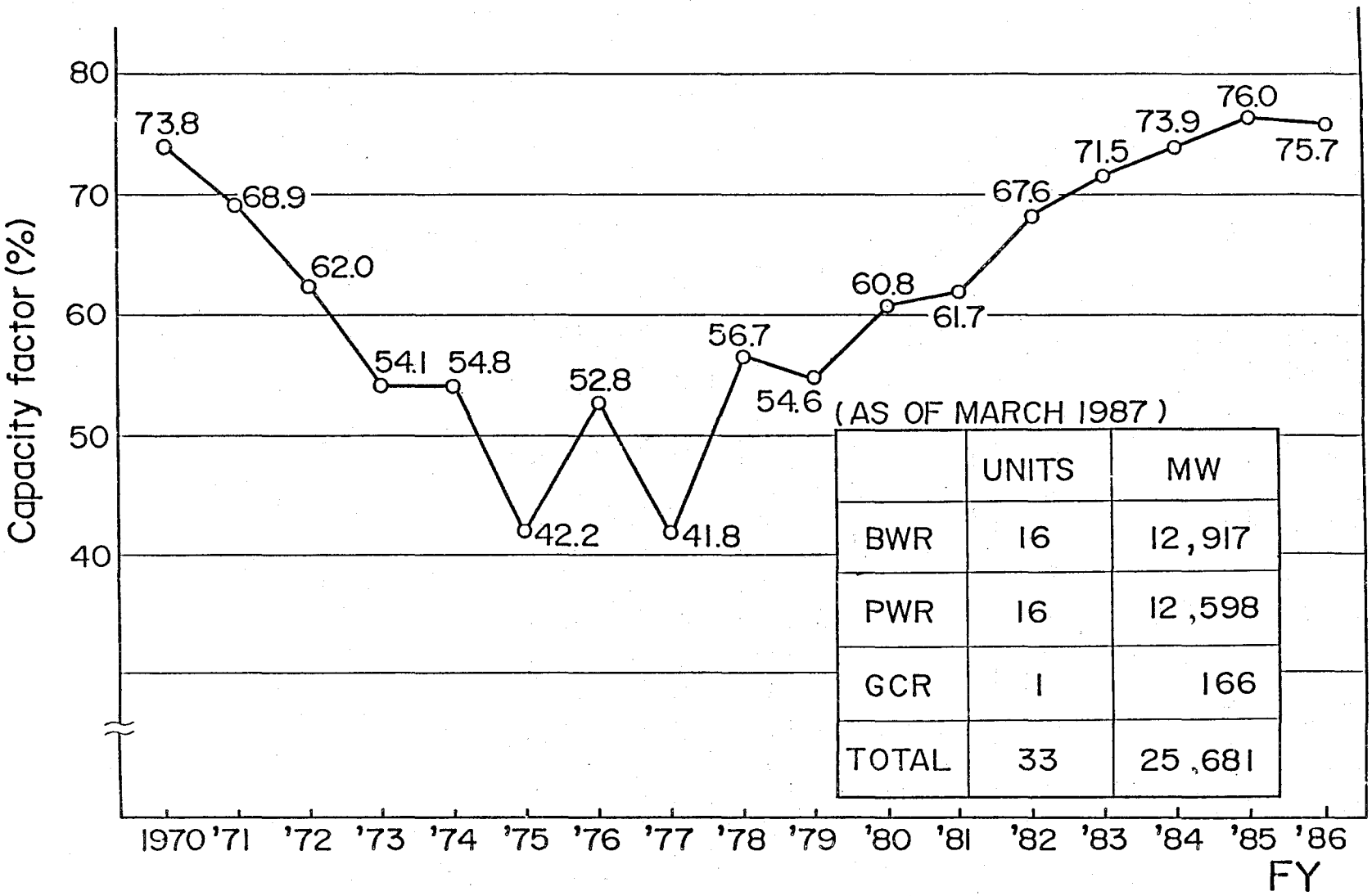
特に、我が国の電気事業者としての技術協力分野に関し、協力の内容、実施体制等について各国の理解を深めながら、過去２０余年にわたり蓄積してきた原子力発電技術を効果的、継続的に提供し、近隣諸国の原子力発電の開発に寄与していきたいと考えております。

以上

MILESTONE ON THE ROAD TOWARDS THE ESTABLISHMENT OF NUCLEAR POWER GENERATION



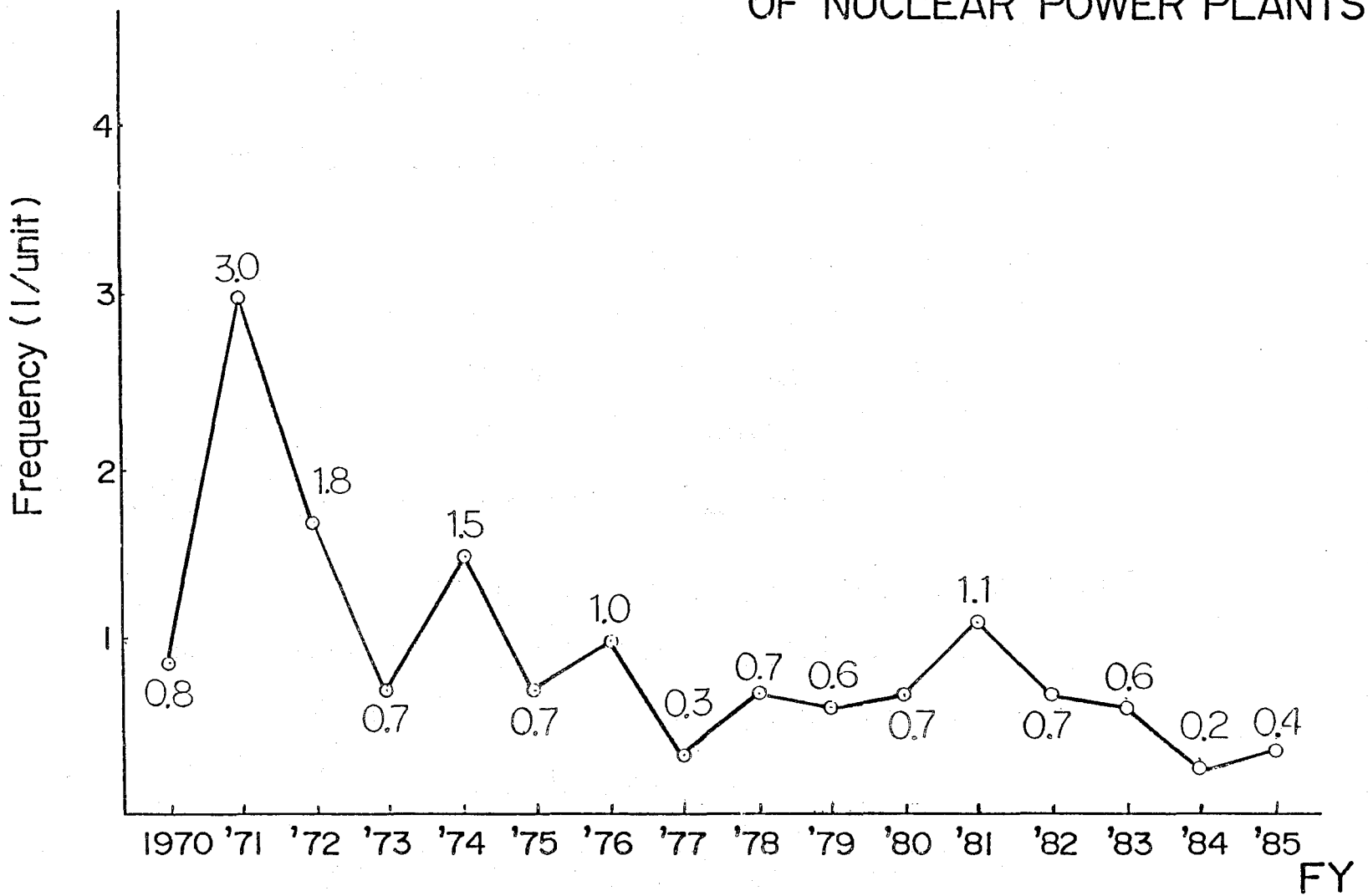
CAPACITY FACTOR OF NATIONWIDE NUCLEAR POWER PLANTS



(AS OF MARCH 1987)

	UNITS	MW
BWR	16	12,917
PWR	16	12,598
GCR	1	166
TOTAL	33	25,681

NATIONWIDE UNPLANNED SCRAMS/TRIPS FREQUENCY OF NUCLEAR POWER PLANTS



INTERNATIONAL COOPERATION SYSTEM

1. ROLES OF THE GOVERNMENT

- A liaison agent in dealing with every foreign country
- Overall management of domestic parties activities
- Establishment in detail the international cooperation policy

2. ROLES OF THE PRIVATE SECTOR

Agents in dealing with foreign countries

- JAPAN ATOMIC INDUSTRIAL FORUM (JAIF)
  - agent in dealing with any foreign party looking for nuclear power program for its nuclear power generation system under planning or study
- JAPAN ELECTRIC INFORMATION CENTER (JEPIC)
  - another agent in dealing with any foreign party looking for program for its nuclear project that has already been beyond preparatory stage of on-site construction

JAPAN ELECTRIC POWER INFORMATION CENTER (JEPIC)

- A cooperation organized by electric utilities (May 1958)
- OBJECTIVES
  - Research for oversea electric Utilities
  - International cooperation program
  - Technical cooperation program
- The cooperation committee for nuclear technology established

  August 1985

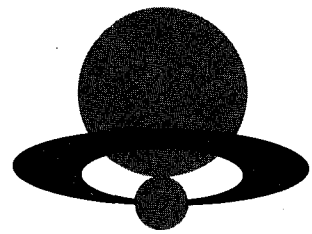
OWNER UTILITY/PLANT MANUFACTURER RELATIONSHIP IN THE FIELD OF NUCLEAR GENERATION IN JAPAN

		OWNER UTILITY	PLANT MANUFACTURER
CONSTRUCTION	PLANNING	◦BASIC PLANNING	
	DESIGNING	◦DESIGN REVIEW	◦DETAILED DESIGN ENGINEERING
	CONSTRUCTION	◦SCEDULE CONTROL ◦OVERALL MANAGEMENT AND WITNESSING OF SITE CONSTRUCTION ACTIVIYIES	◦EQUIPMENT MANUFACTURING ◦EQUIPMENT ERECTION SUPERVISION
	QUALITY CONTROL	◦DEVEROPMENT OF BASIC QC PROGRAMS ◦APPROVAL OF PLANT MANUFACTURER'S QC PROGRAMS AND AUDTING OF DAILY ACTIVITIES	◦DEVELOPMENT AND IMPLEMENTATION OF QC PROGRAMS
OPERATIONS	OPERATION	◦PLANNING OF IMPLEMENTATION	———
	MAINTENANCE	◦PLANNING AND IMPLEMENTATION OF ◦MAINTENANCE PROGRAMS WITNESSING OF CRITICAL WORKS AND INSPECTION	◦WORK IMPLEMENTATION ◦FIELD ERECTION CONTROL
	OTHERS	◦PLANT SAFETY, FUEL MANAGEMENT, REDIOLOGICAL PRTECTING, WATER CHEMISTRY, ETC.	

DEVELOPMENTAL STAGE-WISE COOPERATION PROGRAM MAINLY BY THE ELECTRIC UTILITIES

STAGE	DESCRIPTION	COOPERATIVE APPROACH
PLANNING	∘ BASIC DEVELOPMENT PROGRAM ∘ SITING STUDY ∘ ENVIRONMENTAL STUDY	∘ INFORMATION TRANSMITTAL ∘ TECHNICAL GUIDANCE BY VISITING ENGINEERS ∘ OPENING OF/ PARTICIPATING IN SYMPOSIA/ SEMINARS ∘ TRINING COURSE FOR POWER PLANT OPERATIONS AND MANAGEMENT ∘ OPENING OF NUCLEAR GENERATION COURSE(BY JICA) ∘ RECIPROCATIVE VISIT BY ENGINEER/S
CONSTRUCTION	∘ SCHEDULE CONTROL ∘ QUALTY CONTROL ∘ TEST RUNNING	
OPERATIONS	∘ OPERATION MANAGEMENT ∘ MAINTENANCE MANAGEMENT ∘ QUALITY CONTROL ∘ SAFETY FUEL MANAGEMENT	

セッション4
発展する原子力技術



スーパーフェニックスFBR
仏ノバトム社技術顧問
J．-P．クレテ

日本のデコミッショニング技術
日本原子力研究所東海研究所動力試験炉部長
石川迪夫

原子力発電とハイテクノロジー
三菱重工業(株)取締役
青木禮次郎

スローポークエネルギーシステム：地域熱供給における原子力技術の役割
カナダ原子力公社（AECL）地域エネルギーシステム部長
G．F．リンチ

燃料サイクル施設の遠隔技術
動力炉・核燃料開発事業団理事
植松邦彦

核融合をとりまく新技術
(社)日本原子力産業会議常任相談役
山本賢三

レーザー技術と原子力利用
電気通信大学新形レーザー研究センター長
宅間宏

高エネルギー加速器：その技術と産業応用
高エネルギー物理学研究所副所長
菊池健

SUPERPHENIX 1

VIDEO VIEW INSIDE THE REACTOR DURING PREOPERATIONAL TESTS

Jean-Paul CRETTE

N O V A T O M E

FRANCE

C O N T E N T S

1. INTRODUCTION

2. MAIN DATES OF THE CONSTRUCTION

3. PRESENTATION OF SUPERPHENIX 1

3.1. Reactor Assembly
A - Some characteristics
B - The sodium

3.2. Main vessel cooling system - Oscillations
A - The oscillations of the structures
B - The structures of the periphery of the main vessel

3.3. The hot plenum

4. PLACE OF THE PERISCOPE AND OF THE TV CAMERA

5. MOVIE PROJECTION

6. CONCLUSION

1. INTRODUCTION

You will see a videotape movie showing the inside of the reactor SUPER PHENIX during preoperational tests.

SUPERPHENIX is the LMFBR plant built in CREYS-MALVILLE under a european cooperation.

It reached full power 1200 MW electric on 1986 december 9th.

2. MAIN DATES OF THE CONTRUCTION

FULL POWER	: 1986 DECEMBER 9th
COUPLING TO THE GRID	: 1986 JANUARY
CRITICALITY	: 1985 SEPTEMBER
START OF CONSTRUCTION	: 1977 APRIL

The movie was taken in 1985, during the isothermal tests of the plant.

3. PRESENTATION OF SUPERPHENIX 1

For better understanding of the videotape movie, we give a short description of SUPERPHENIX 1 reactor structures.

3.1. Reactor Assembly

Slide of the reactor assembly (figure 1)

A - Some characteristics

On the slide, you can see the reactor vessel closed by the roof to which it is suspended.

The reactor vessel has a diameter of 21 meters and is filled with 3500 tons of liquid sodium.

You will see on the movie the space above the surface of the sodium through a periscope and a TV camera.

B - The sodium

The sodium is separated by the inner vessels in two areas :

. the hot sodium plenum,
. the cold sodium plenum.

The cold sodium is forced by 4 mechanical pumps through the core where it is heated at full power from 395°C to 545°C.

At the outlet of the core, the sodium is deflected into the hot plenum.

The hot sodium returns to the cold plenum circulating through 8 intermediate heat exchangers and heats the secondary sodium coming from and going to the steam generators.

3.2. Main vessel cooling system - Oscillations

The main vessel is cooled by a small flow of cold sodium :

. coming from the feet of the fuel assemblies,

. going up to the top of the spillway,

. falling down to the "recovery tank",

. going then to the cold plenum.

A - The oscillations of the structures

During the cold isothermal tests, it appeared that the peripherical structures had larger oscillations than expected.

To investigate this problem, we introduced the TV camera close to the main vessel and you will see what happened : hydro-elastic coupling between the liquid sodium free surfaces motion and the steel structures elastic behavior.

B - The structures of the periphery of the main vessel

Slide of this area (figure 2)

3.3. The hot plenum

You can see a part of the structures in the hot plenum, this is to give you a better feeling of how it looks like.

Slide of the hot plenum (figure 3)

4. PLACE OF THE PERISCOPE AND OF THE TV CAMERA

You can see the place of the periscope and of the TV camera.

Slide of the upper part of the deck (figure 4)

5. MOVIE PROJECTION

At the beginning of the movie, you will see through the periscope the free surface of the sodium at 180°C in the hot plenum, circulating inside the inner vessel, around the core cover plug, the intermediate heat exchangers, the pumps, the fuel handling ramp.

At the end of the movie, you will see through the TV camera the periphery of the structures, near the main vessel.

A - Comment

To my knowledge, it is the first time, we can see such a big amount of liquid sodium moving inside a large vessel.

You can trust me :

. it looks like water,
. it flows like water,

but it is sodium.

B - Projection

6. CONCLUSION

The thermal hydraulic tests have given results in good agreement with predictions and confidence in the methods used for the design of such reactors.

We practiced a lot of theoritical and experimental studies, and the experimentation with the reactor itself, filled with sodium is unique : the only way to make progress is to build and operate plants.

We are now ready to make a step further, to design and build a reactor more compact, lighter and cheaper.

SUPERPHENIX 2 could be the next step in the direction of competitivity with PWR : the reactor structures have been reduced by a factor of about 2, from SUPERPHENIX 1 for 1 kW electric.

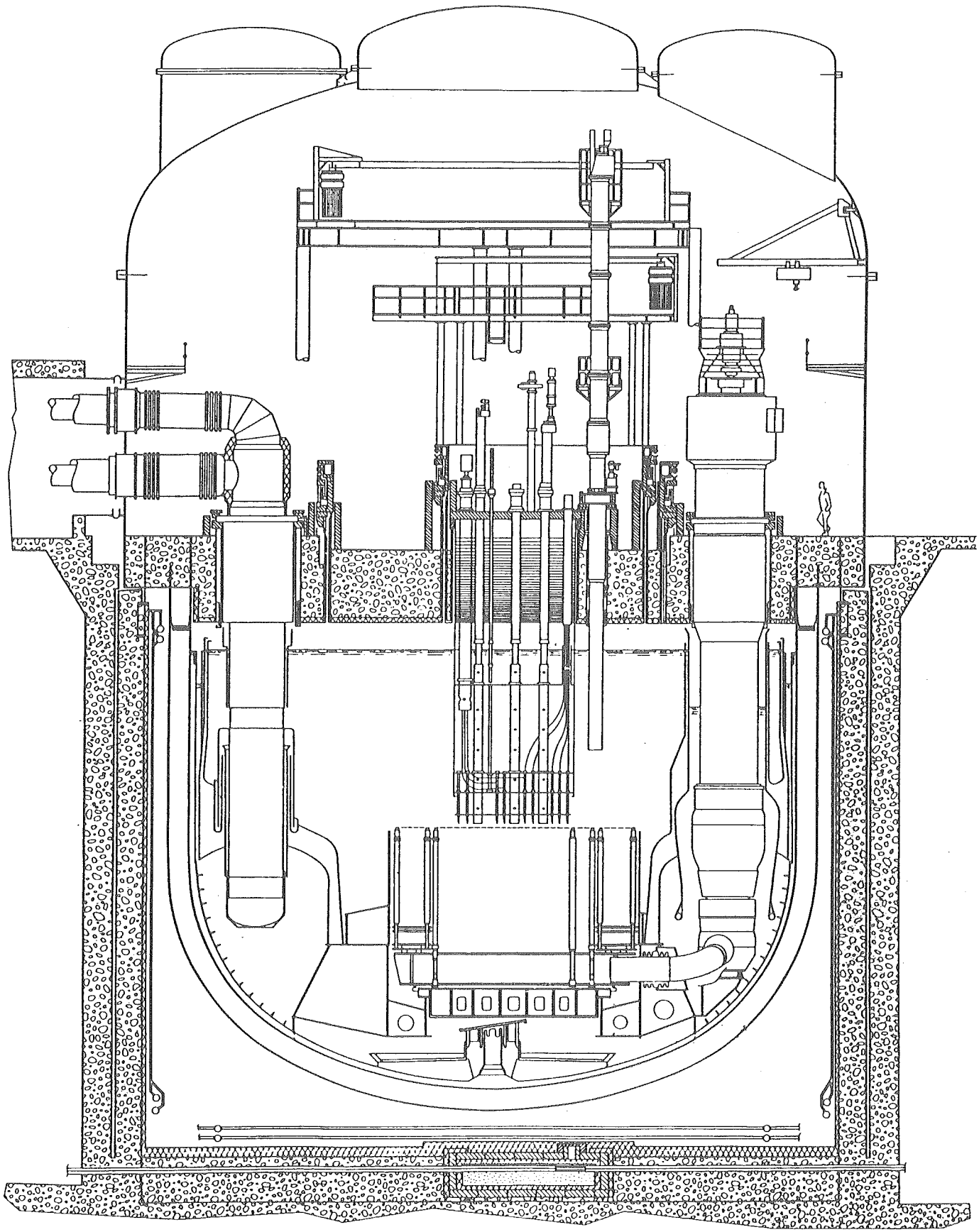


FIGURE 1

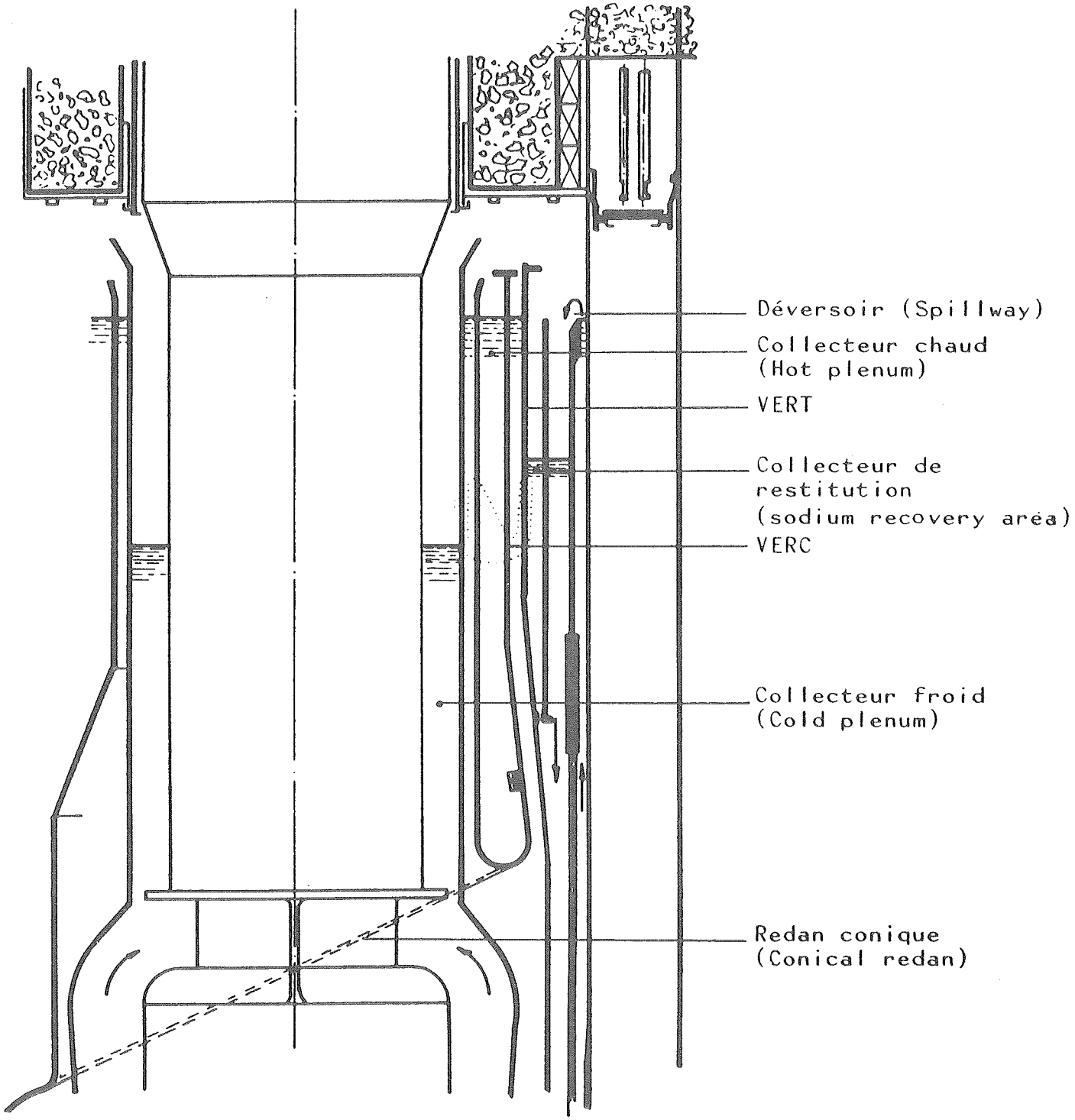

Déversoir (Spillway)
Collecteur chaud
(Hot plenum)
VERT
Collecteur de
restitution
(sodium recovery area)
VERC
Collecteur froid
(Cold plenum)
Redan conique
(Conical redan)

FIGURE 2

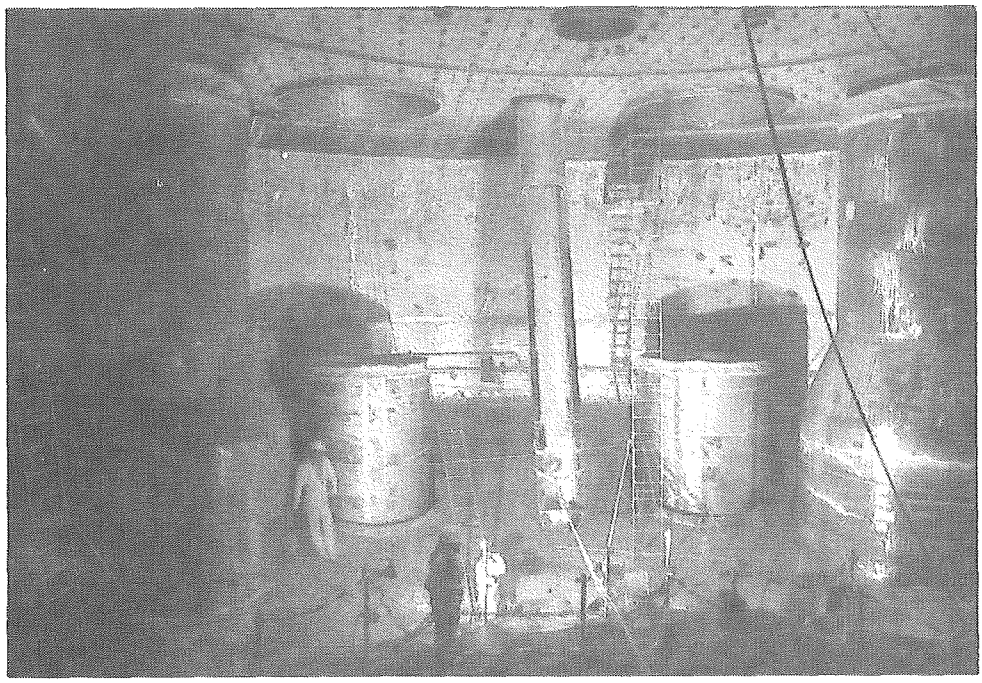


FIGURE 3

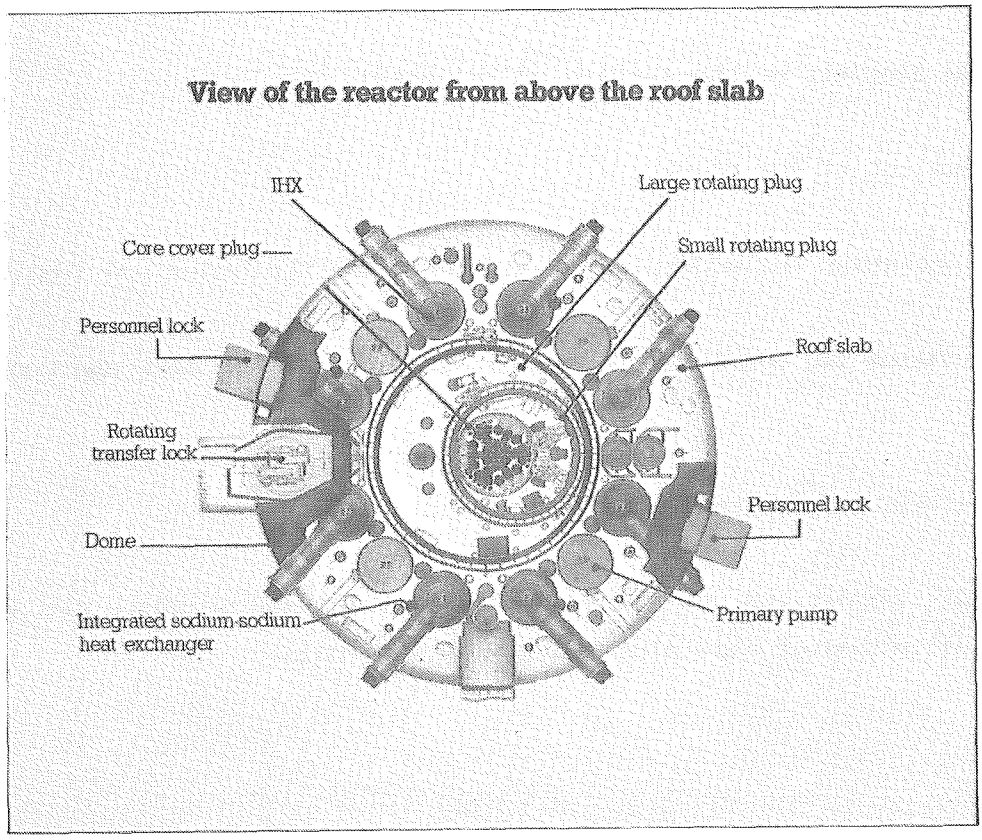


FIGURE 4

SUPERPHENIX 1

V I D E O T A P E

C O M M E N T S

The comments of the video tape are in English

This is the hot Plenum.

The sodium temperature is 180°C.

The foam you see on the surface is sodium oxyde.

On the right the core cover plug.

Some sodium droplets on the surface of the shell.

Sodium flows out of the holes.

In normal operation the sodium level is higher and the holes are immersed.

Though the holes you see the instrumentation pipes of the core and control rods shrouds.

You can see the sodium level inside the plug.

One of the objectives of these hydraulic tests was to check the absence of abnormal vibrations of this plug and of its internals.

No comment

The limite between black and white is sodium level at previous tests made at higher temperature.

Through holes on right, we see the sodium level on the other side of the plug.

Top-Top-Top ... No comment

The shell behind is one intermediate heat exchanger.

Behind, is the chimney of the primary pump.

The free surface of the sodium is clearly seen.

Top-Top-Top.

The sodium flows around the fuel handling ramp.

Top-Top-Top ... No comment

On the back, is the inner vessel.

Top-Top-Top ... No comment

This is the end of the first part.

This view is taken by a TV camera near the main vessel.

In the middle, the sodium level of the recovery tank.

On left the top of the spill way.

On right the inner vessel.

From the spill way the sodium flows down in the recovery tank.

In the recovery tank the surface moves very much due to the big height of the fall.

This view is taken above the inner vessel it shows the relative movements of these structures due to the oscillations of the spill way.

No comment

The sodium flows on the spill way irregularly.

Pay attention, see particularly the local overflow just now.

We continue to increase the flow rate, the oscillations increase also.

The sodium falls down more and more irregularly, look at the top of the spill way.

The sodium level in the recovery tank is oscillating up and down.

No comment

The oscillations of the sodium level and of the spill way shell increase.

We have solved this problem by increasing the level of the sodium in the recovery tank.

This has been done by increasing the flow rate of the sodium which cools the main vessel.

It was a very simple solution.

Of course, today, this area is very quiet.

There is no more any oscillation.

No comment - LOCAL OVER FLOW

The movies which you have seen were very usefull to understand the phenomena of the oscillation in addition of the other measurements.

No comment

This is the end of this movie.

Thank you.

日本のデコミッショニング技術

日本原子力研究所　　石川　迪夫

昨年末、日本原子力研究所において、デコミッショニングに関わる２つの大きな行事があった。その１つは、１２月４日に行われたＪＰＤＲの解体実地試験の開始を祝う記念式典であり、他の１つはＪＲＲ－３改造に伴う原子炉本体の一括撤去工事の恙ない実施完了である。本日は、この２つの工事を中心に、日本のデコミッショニング技術について述べる。

１．ＪＰＤＲの解体技術開発

昭和５７年６月、原子力委員会は「原子力開発利用長期計画」において「今後約１０年位の間に、既に役割を終えた日本原子力研究所の動力試験炉（ＪＰＤＲ）を対象として、将来の商業用発電炉の廃止措置において活用し得る解体技術等を開発し、実地試験を行うものとする」との方針を示した。

原研では上記方針に基づき、科学技術庁の委託を受けて「原子炉解体技術開発計画」を開始した。計画は、昭和５８年度から６１年度にかけて原子炉の解体撤去に必要な技術開発を先ず行い、次いで６１年度から６６年度にかけて開発した技術をＪＰＤＲの解体撤去に適用して各々の技術の有効性等を実証するとともに、将来の商業用原子炉の廃止措置に資する知見及びデータを得る（実地試験）ものである。実地試験計画では、事務建家及び倉庫等を残してＪＰＤＲの総ての構築物及び設備が撤去され、跡地は整地されて更地になる予定である。以上の計画を達成するために、原研では以下の８項目の分野について、必要な技術の開発を進めてきた。

１）放射能インベントリ評価技術
２）配管系内部放射能汚染測定技術
３）解体工法
４）解体関連除染技術
５）解体廃棄物の処理、保管及び処分技術
６）解体に係る放射線管理技術
７）解体遠隔操作技術
８）解体システムエンジニアリング

以下　映像により開発の成果を示す。

〈映　画〉

映像で示したように、ＪＰＤＲの解体に必要な技術は、ほぼ完成した訳であるが、初めての解体撤去作業の万全を期すために、更に念を入れて、原子炉圧力容器等を実寸大で模擬したモックアップ試験を行った後、実地試験に供する予定である。

現在ＪＰＤＲでは、放射線の強い炉心構造物及び圧力容器の解体のため必要となる作業スペース整備のため、炉上面を中心に格納容器内の機器配管等を撤去する作業を行っているが、本年末頃にはロボットの据付を行い、プラズマアークによる炉心構造物切断工事に入る予定である。ＪＰＤＲ解体のスケジュールを図－１に示す。

２．ＪＲＲ－３の原子炉撤去

ＪＲＲ－３は、最近の研究の進展により高度な原子炉利用が求められたため昭和５８年３月運転を停止して、新しい原子炉への改造計画を進めている。この改造は、原子炉建家等の既存施設をできるだけ再利用しながら、世界的にみて最高水準の実験研究が可能な利用性能を有する原子炉（熱出力２０ＭＷ・プール型）を昭和６４年度に完成させるものである。

このため、昭和６０年８月から現有施設のうち改造後に再利用しない原子炉格納施設、原子炉本体及び原子炉冷却系統施設（一次冷却設備）等の撤去工事を開始した。本工事において特に注目されるのは、原子炉本体の一括撤去工法である。この工法は、原子炉本体の開口部をシールした後、炉心構造物を内蔵した炉心タンクを生体遮蔽体ともども一括して撤去し、大型廃棄物保管庫へ移動させ保管するものである。この方法は世界でも初めての試みで、将来の原子炉廃止措置工法の１つとなるものと考えられる。米国のシッピングポート発電所の撤去も、類似の工法で行われる予定であることから、本工事の成否は内外の注目を集め、撤去工事期間中約3,000名の見学客で賑わったものである。工事の状況は以下のスライドで紹介するように、約１ヶ年に渡り行った２５９本のコアーボーリングにより、炉本体及び遮蔽コンクリートを基礎から切り離した後、予め準備した運搬フレームの中に原子炉本体をジャッキにより吊り上げ、コロ引きによって隣設の保管建家に導き、再びジャッキを利用して同建家地下に収納隔離したものである。

現在ＪＲＲ－３は、同時に行った１次冷却系設備の撤去工事も完了し、高性能のスイミングプール型原子炉を新しく設置するための工事に移行している。解体撤去工事としては、放射性機器の保管設備への移送を一部残すだけと言った状況下にあるが、今月迄の作業の総計は、排出された放射性物質総量約 ６，０００トンに対し、作業員の総被曝量は僅か１０人・レムである。

３．まとめ

以上、ＪＰＤＲ及びＪＲＲ－３に関する経験を総合すれば、原子炉の解体撤去は、今日の技術レベルにおいては、入念な計画と準備の許に実施すれば、環境への影響は勿論のこと、作業従事者の放射線被曝も比較的少ない範囲で達成し得ること、及びそれに必要な経費も極端なものではないとの確信を得ている。これらはＪＰＤＲの解体実地試験を通じ立証され、また更に改善されて行くことを述べ、今日の講演を終ることとする。

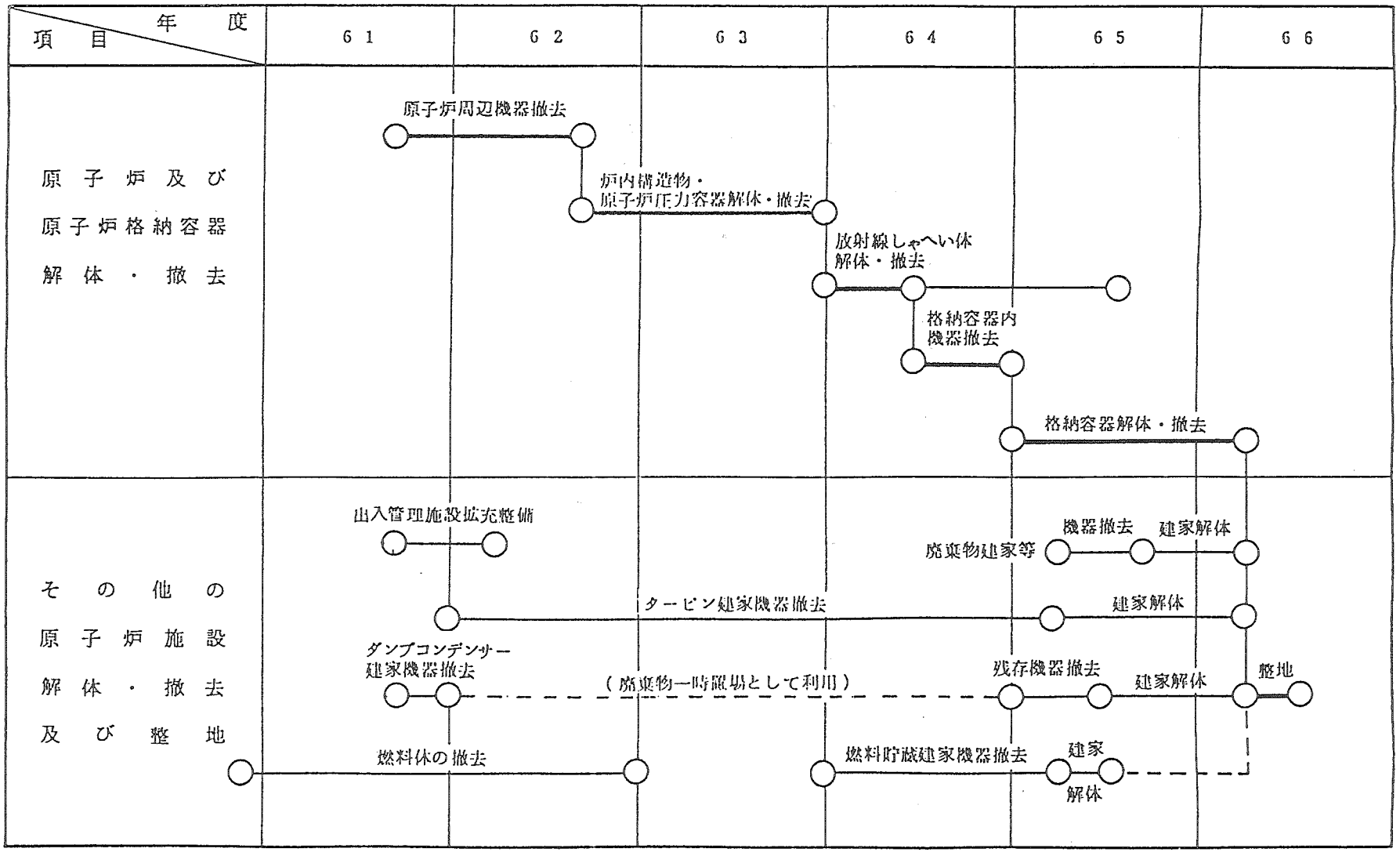


図１　ＪＰＤＲ解体実地試験スケジュール

＜参考＞　映画：原子炉解体技術開発

— ＪＰＤＲ解体実地試験に向けて —

本映画によって、日本原子力研究所における原子炉解体技術開発の成果を紹介する。その概要は、以下のとおりである。

- 原子力開発利用長期計画（昭和５７年）の方針に基づき、日本原子力研究所では、原子力発電所を安全に解体撤去するための技術開発を行ってきた。
- 炉内構造物の解体にはプラズマアーク切断装置を開発し、水中で厚さ１３０㎜のステンレス鋼の切断に成功している。
- 圧力容器接続配管の切断には、配管を内側から切断するための成型爆薬及びディスクカッタを開発している。
- 原子炉圧力容器の解体にはアークソーを開発し、水中で厚さ２５０㎜のステンレス鋼が切断できることを確認している。
- コンクリート構造物の解体には、コンクリートを中の鉄筋ごと切断する機械的切断工法及び水ジェット切断工法を開発している。

ＪＰＤＲの解体撤去は以上紹介した開発技術等を適用して行われ、将来の原子力発電所の解体撤去に適用できる技術基盤を確立するものとして、各方面から期待されている。

原子力発電とハイテクノロジー

三菱重工業株式会社
取締役　青　木　礼次郎

只今御紹介にあずかりました三菱重工業の青木でございます。本日は「原子力発電とハイテクノロジー」と題しまして，

スライド　1，2

㈱東芝，㈱日立製作所，三菱重工業㈱の原子力プラントメーカ三社を代表して発表させて頂きます。

スライド　3，2

我が国の原子力発電，とりわけ軽水炉は国産化とその後の改良，標準化の推進により既に成熟期を迎えています。

スライド　3，4

私共は更に原子力発電の信頼性，安全性，経済性を一層向上し，電力供給の主力として相応しいものにするため，先端技術いわゆるハイテクノロジーを取り入れ乍ら原子力プラントの改良と改善を進めております。

スライド　5，4

ここではハイテクノロジーの内，特に新素材，エレクトロニクス，ロボット等が原子力プラントの改良，改善にどの様に寄与しているか，その一端を御紹介致します。

先づ新素材の活用から始めたいと思います。

((新素材関連))

スライド　5′，6

原子力プラントの構造材料には，火力プラント，化学プラントなどで実績のあるものが主に用いられて来ました。これらを適用し不具合を経験した部分については，故障の再発を防ぐため，熱処理や組成の一部を改善した改良材を開発し，効果を上げてきました。新素材は改良材と共に原子力プラントの信頼性向上，稼動率向上，被曝低減，放射性廃棄物低減に寄与することが期待されています。

スライド　7，6

さて，代表的な改良材として，BWR では配管の応力腐食割れ対策に開発された低炭素ステンレス鋼があります。PWR では蒸気発生器伝熱管の腐食対策等に開発された特殊熱処理を施したインコネルが挙げられます。

スライド　7，8

316 ステンレス鋼の炭素含有量を減らし，窒素を加え，高温でのクリープ破断に至る時間を25倍に高めた316MN ステンレス鋼も開発されています。

スライド　9，10

ゲート弁などの弁座には，耐摩耗性に勝れたコバルトベースのステライトを肉盛しておりますが，放射線量低減のためコバルトを含まないニッケル基合金の肉盛材を開発しました。

スライド　11，12

これはBWR の改良型制御棒です。放射線量低減のためローラー材をステライトからニッケル基合金に換えております。中性子吸収材をボロンカーバイドからハフニウム材に換えて寿命延長を図っています。

以上は改良材の例を御紹介したものですが，

スライド　13，(一)

他産業ではファインセラミックスなど在来材にない優れた特性を持つ新素材が実用化されており，私共は，これら新素材を原子力に適用する研究開発も進めております。

次にその成果をいくつか御説明致します。

スライド　13，14

これは航空機等に多く使用されているチタニウムを用いた原子力プラントの復水器の管板です。最近は海水による腐食に強いチタニウムを復水器の伝熱管に採用するケースが増加しております。この場合，伝熱管と管板とのシール溶接の信頼性向上及び電蝕を避けるため，管板もチタニウム製としております。

スライド　13，15

これはPWR の制御棒駆動装置にセラミックスコーティングを適用した例です。原子力プラントで負荷追従運転を行うと制御棒の作動回数が増加しますので，ラッチ先端にクロムカーバイドをコーティングして，1000万ステップの耐久テストを実施したのち実機に適用しています。

スライド　13，16

これはPWR の燃料取扱設備の水中軸受にファインセラミックスを適用した例です。従来のグラファイト製すべり軸受を窒化硅素製ころがり軸受に換えることにより寿命が3倍に伸びました。

スライド　13，17

これは高分子材料を適用した中空糸（し）膜フィルターの拡大断面と試験用供試体です。中空の細い糸自体がろ過作用をもつので大きなろ過面積が得られます。人工透析などに使われて来ましたが，再生型で大容量のものを開発し，原子力プラントの復水用フィルターとして実用化しました。

スライド　１３，１８

新素材を原子力プラントの機器部品へ適用するため原子力プラントメーカ，素材メーカなど30社から成る技術研究組合が組織され，昭和60年度から９年計画で新素材等約50件のテーマにつき適用研究が始まっています。

このような研究開発を通じ，新素材が今後益々原子力プラントの多くの機器に適用され，信頼性向上などに寄与していくことを期待しております。

次にエレクトロニクスに移りたいと思います。

((エレクトロニクス))

スライド　５′，１９

スライド　２０，１９

原子力プラントの設計・製作分野，運転・保守分野にエレクトロニクスを活用し，プラントの信頼性，稼動率，経済性などの向上を図りつつあります。エレクトロニクスの活用で代表的なものはなんと言ってもコンピュータのハードとソフトであり，将来は人工知能であろうと考えられています。

スライド　２１，１９

先づ設計・製作分野ですが，

スライド　２１，２２

管理面，設計面への，OA機器やテレビ会議などが普及すると共に，CAD 即ち計算機支援設計の範囲が拡がって来ています。

CAD は更に範囲を拡げ計算機支援エンジニアリングに発展しつつあります。また製作面では CADからの情報をそのまま製造側が引継ぎ生産設計等を行い，続いてFactory Automationと結びつける試みも行われています。

スライド　２１，２３

これは過去10年に亘りプラント毎に製作してきたプラスチック模型の一例です。配管やケーブル等を含む総合配置の計画と設計にはこのようなモデルエンジニアリングとCAD が

スライド　２４，２３

併用されて来ました。一方，３次元CAD が実用化されつつあり，これが今後モデルエンジニアリングに置き換わる方向に進むと思われます。

スライド　２５，２６

これは３次元CAD の例です。左は PWRの蒸気発生器室を壁の外から，右は壁を取外して眺めたものです。

スライド　２７，２６

これは更に近づいて眺めているものです。この様に，３次元CAD ではプラント内部を容易に眺めることができ，干渉チェックや保守点検方法の検討及び設計変更が容易に行えます。

スライド　２７，２８

これは BWRの格納容器内配置全体のプラスチック模型です。

スライド　２９，２８

左はプラスチック模型とほぼ同じ範囲を三次元CADでCRT上に表示したものです。

スライド　２９，３０

次は，格納容器内を歩く人の目に映る情景で，人の動きにつれて画面が変化します。

スライド　３１，３０

これは表現方法が違いますがやはり三次元CAD による通路の検討例です。人間を通路に沿って動かし物に当ると，人の絵が点滅して何に干渉したかが表示されます。

スライド　３１，３２

右の写真は，３次元CAD のディスプレイを前に，機械，電気，保守等の関係者がコンピューターと対話しながら多面的に配置設計を進めている所です。

スライド　３３，３２

これは，CAD システムと接続された小口径配管用FAシステムをトレーラーに搭載した写真です。CAD からの情報により現地で配管の曲げ，溶接等の自動加工が可能です。

では次に運転・保守分野に移ります。

スライド　(一)，３４

エレクトロニクスは運転分野で中央制御盤のマン－マシンインターフェイスの改善と運転支援機能の拡充に大きな効果を上げています。また保守・補修分野では，検査，診断機器，遠隔自動機器の高度化に寄与しています。

スライド　３５，３４

最新型の中央制御盤の特徴は CRTを数多く用いマンマシンインタフェイスを改善していることです。また将来型の特徴はAIを用い運転支援機能を拡充することと云えます。

スライド　３５，３６

これは従来の中央制御盤で，監視用にはアナンシェータと指示計，記録計が主体であり盤サイズも大型です。

スライド　３５，３７

これは最新の制御盤で，アナンシエータ，指示計等に代りカラーCRT が増え自動化の範囲も拡がり，盤の小型化とマンマシンインターフェイスの向上が図られています。

スライド　３５，３８

これは将来型の制御盤です。自動化と盤の小型化が一層進み，代りに大スクリーンCRT が

登場し，必要な画面を同時に多数表示することもできます。AI即ち人工知能をプラントの異常診断，運転ガイド，表示法に活用し運転支援機能を一層強化してます。

推論や学習機能を発揮するAIの活用研究は原子力発電分野でも急速に進められています。

スライド　３５，３９

これはAIを応用した運転中の機器異常診断に関するＲ＆Ｄの一例です。主給水系に異常が発生した場合，AIの手法により制御弁や計測制御機器の異常な部品，と原因を推定し，その後の運転法と保修法を迅速に提供することを目的としています。

次に，ハイテクを総合的に活用するロボットについて御紹介致します。

((ロボット関連))

スライド　５‘‘‘，４０

原子力プラントへのロボット導入は，運転時と定期検査時の保守・点検作業の信頼性向上，効率向上，被曝低減，等を目的としており，私共はこの目的に沿ってロボットを開発してきました。

スライド　４１，４０

半導体集積回路，小型センサ，新素材等の活用で小型軽量化，多機能化が進み，高機能専用ロボットが既に実用化されています。更に知能ロボットに向けた研究開発が進められています。

先づ現在原子力プラントで実用中及び試作済ロボットの一部を御紹介致します。

スライド　４２，４０

これは，BWR での燃料自動交換機です。定期検査時に，水面下16ｍで厳しい位置精度が要求される燃料の交換作業に用いられ，既設プラントにも順次バックフィトされています。

スライド　４３，４４

これはPWR で実用中の汎用マニピュレータとそれを操作する制御盤です。マニピュレータは極めて軽量化されており自重の⅓の負荷々重を扱うことが出来，工具等を自動ガイドし蒸気発生器の伝熱管の保守作業等に効果を上げています。

スライド　４５，(一)

左は自動超音波探傷装置で，自動データ処理装置と接続し，原子炉圧力容器や各種配管の検査に広く採用されています。なお，ホログラフィ技術を用い超音波探傷データを計算機で処理し，鋼材の内部欠陥を三次元的に表示することも出来ます。

スライド　４５，４６

右の超音波探傷装置は試作品で，配管自体をガイドとし直管，曲管を自在に走行し検査を行います。

次は将来に向けたロボットの開発状況です。

スライド　４７，４１

現在利用できる要素技術を用い，ロボットの機能向上と知能化を目標に試作したプロトタイプロボットの一部を御紹介致します。

スライド　４７，４８

これは，巡視点検の自動化を目的としたモノレール式小形点検ロボットです。超小型カメラとAIの活用により物体の認識や異常事象の発見が自動的に行えます。

スライド　４７，４９

これは，人が近づきにくい容器の溶接部を検査するロボットです。真空吸着式で，球形壁面を任意の方向へ移動できます。

スライド　４７，５０

写真の左は既に発表した負荷々重20kgの移動式軽作業用マニピュレータで，小型弁のボルトの増締めなどができます。右下はEXPO85に出品した４脚歩行ロボットを無線化したものです。右上は真空吸着式の４脚壁面歩行ロボットです。

スライド　５１，５０

右の３つのロボットの特徴を組合せ，巾40cm，重量20kgにまとめた無線式点検ロボットが左の写真です。一台のロボットで床，階段，梯子，垂直壁面を移動出来るよう世界で初めて実現したもので，超小型であるためプラント内目標物への接近性を大巾に向上させています。

スライド　５１，５２

次は超音波センサとAIにより障害物を回避しながら，平坦部は車輪で階段は五本の足で歩行するロボットです。これは連続写真で移動の軌跡を示しており，最短経路を自ら探して目標に到達しています。

以上御紹介したロボットはまだプラントに適用されていませんが，今後の開発に対し多くの示唆を与えていると考えます。

スライド　５３，（一）

現在，私共が研究組合に参加し，国の極限作業ロボット研究開発プロゼクトとして昭和58年度から８年計画で進めている原子力用ロボットの開発の内，代表的な要素技術開発について御紹介致します。

先ず視覚情報処理技術ですが，

スライド　５３，５４

左は，弁のテレビ画像です。左の画像からパターン認識の一つとして楕円と平行線とを用い弁の特徴を示す輪郭を抽出したのが右の画像です。

スライド　５５，５４

この様な方法でテレビカメラが捕える情景から色々な物体の輪郭を抽出し，それと予め記憶された特徴データとを，AIの手法により高速で比較し，目標物体をさがし３次元的に認識します。これにより，ロボットが移動や作業を自律的に行うことを支援します。

スライド　５６，(一)

写真は，高速で歩く４脚ロボットを目指した縮尺1/4 の実験機です。重心を移動させ倒れる方向に足を運び，慣性力を使って移動するので，エネルギー効率に優れた高速移動が期待されます。

スライド　５６，５７

これは４本指をもつハンドの試作機で，ネジ回しを使っているところです。各指に多数の触覚センサが取付けてあり，ネジ回しやスパナなどの汎用工具を自在に操ることが出来ます。このハンドは，

スライド　５８，５７

左の図の様なアームに取付けられます。人間が指に力感覚を感じながら，テレビ画像やCAD の様な支援画面を見て遠隔操作で動かします。更に人間を介さず，ロボット自身の判断即ち自律制御でも動かせる様にする予定です。

以上に御紹介したプロトタイプロボットや要素技術の開発状況からみて，将来の原子力プラントでは，保守・点検作業で現在人に頼っている部分の多くが，知能ロボットなどに置き換えられて行くものと思われます。

スライド　５９，(一)

エレクトロニクスとロボットに関連して御覧頂いたように，今後はAIの活用研究が一層進み，原子力発電の各分野で，知的な作業に対する支援機能が強化され，業務の信頼性と効率が更に改善されると考えます。

((おわりに))

スライド　６０，６１

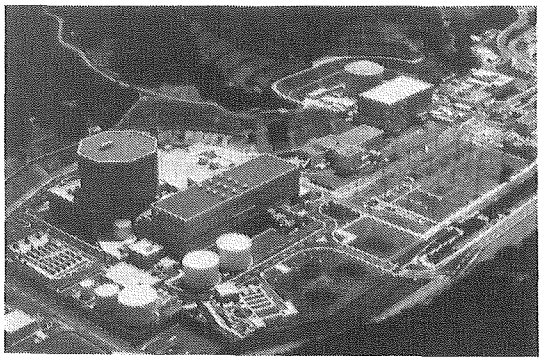
本日は原子力発電におけるハイテク活用の一面を御紹介致しました。私共東芝，日立製作所，三菱重工業の３社は皆様方の御協力のもとに，このような先端技術の応用の巾を更に拡げ，原子力発電の高度化に努めて行く所存で御座居ます。皆様方の今後一層の御支援をお願いして私の講演を終わらせて頂きます。御清聴有難うございました。

以　上

(1)

NUCLEAR POWER GENERATION and HIGH TECHNOLOGY

(2)



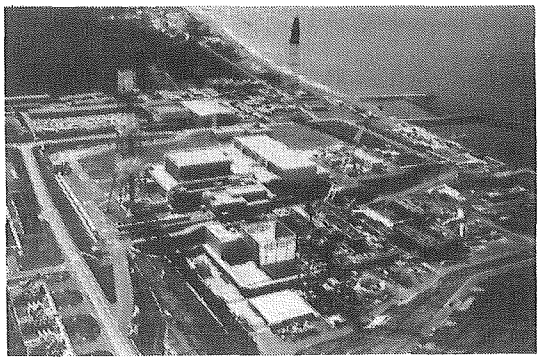
(3)

NUCLEAR POWER GENERATION

- Domestic Production
- Improvement
- Standardization
- Upgrading

HIGH TECHNOLOGY

(4)



(5)

HIGH TECHNOLOGY

- Advanced Material
- Electronics
- Robotics

(5')

HIGH TECHNOLOGY

- Advanced Material
- Electronics
- Robotics

(6)

ADVANCED MATERIAL

Improved Material
Advanced Material

- Improve Reliability
- Improve Availability
- Reduce exposure
- Reduce Radwaste

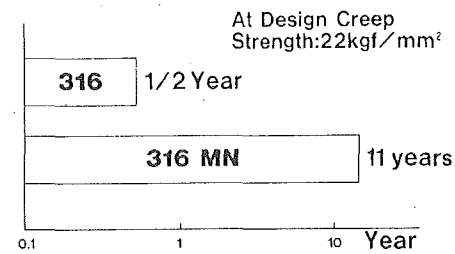
(7)

TYPICAL IMPROVED MATERIAL

- Piping SCC: Low Carbon Stainless Steel
  304 → 316 Nuclear Grade
- SG Tube IGA: Improved Thermal Treatment
  Inconel 600 → TT600, TT690

(8)

550°C CREEP RUPTURE TIME



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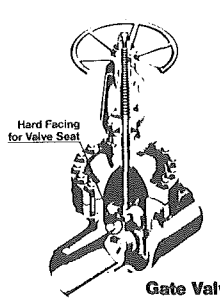
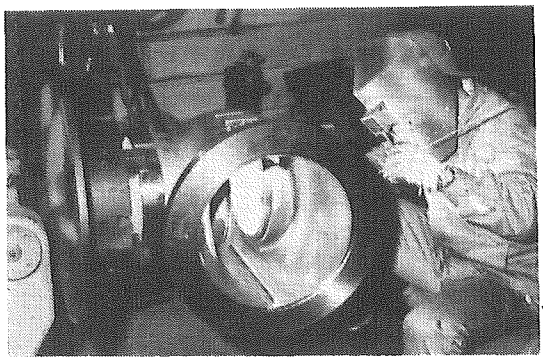




(10)

Fuel Transfer Equipment

Bearing:
Fine Ceramics
Si_3N_4

(16)

ROLLER and PIN

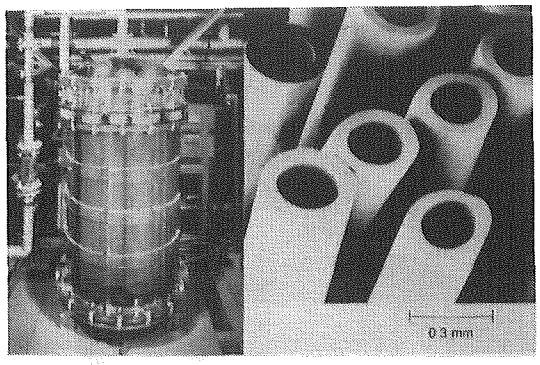
- Lower Co Content

ABSORBER

- Longer Life

(11)

(12)



(17)

TYPICAL ADVANCED MATERIAL

- Metallic Material: Titanium Alloy
- Composite Material: FRP, FRM
- Fine Ceramics & Coating: Si_3N_4, Cr_3C_2
- High Polymer

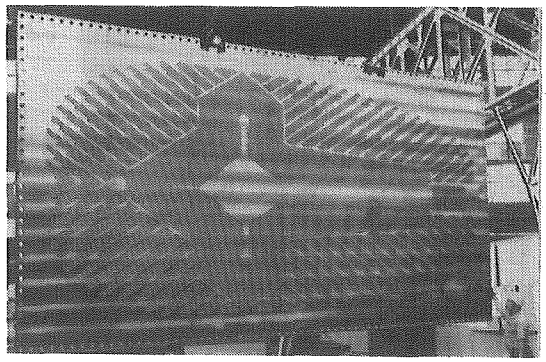
(13)

National R & D Project

Advanced Nuclear Equipment
Research Institute

A Technical Research Association

(18)



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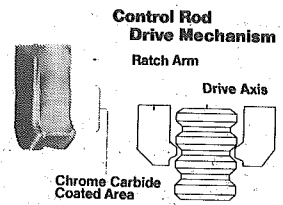


(15)

HIGH TECHNOLOGY

- Advanced Material
- Electronics
- Robotics

(5")

(19)

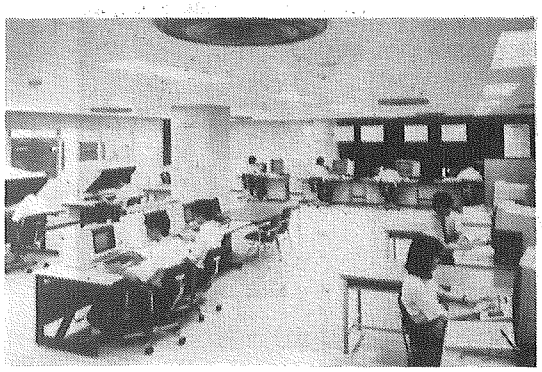
ELECTRONICS

Reliability / Availability / Economy

Design & Manufacturing — Operation & Maintenance

COMPUTER — INFORMATION PROCESSING — AI

(20)

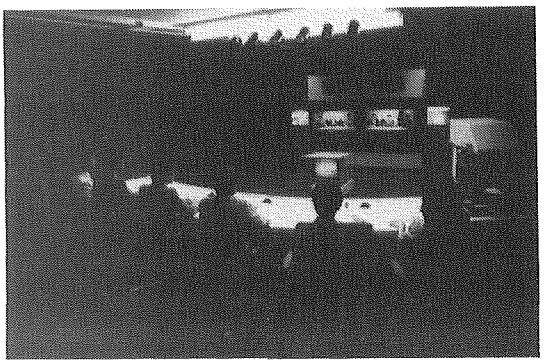


(21)

DESIGN & MANUFACTURING

- Administration —— OA
- Design —— CAD, CAE
- Manufacturing —— CAM, FA

(22)



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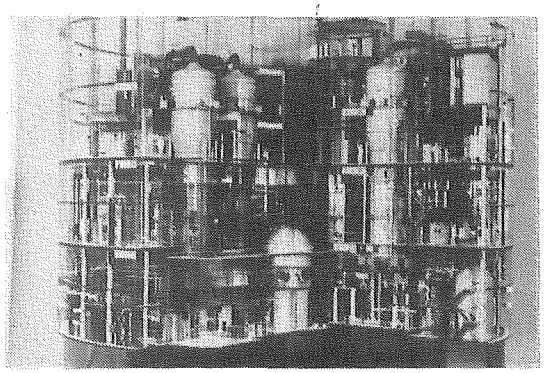


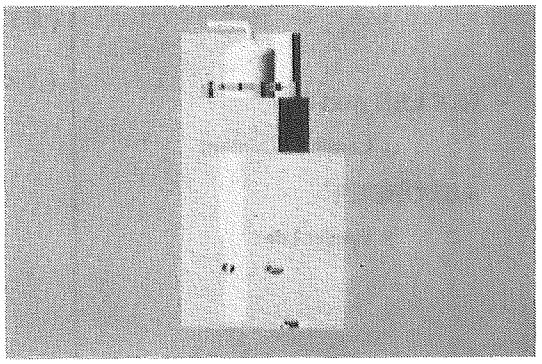
(24)

PLANT LAYOUT & PIPING

Model Engineering CAD → Manufacturing

3-D CAD → CAM FA

(25)



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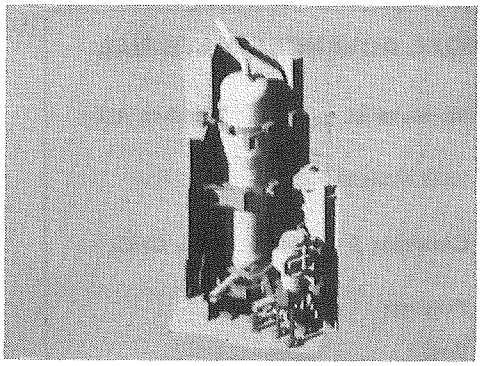

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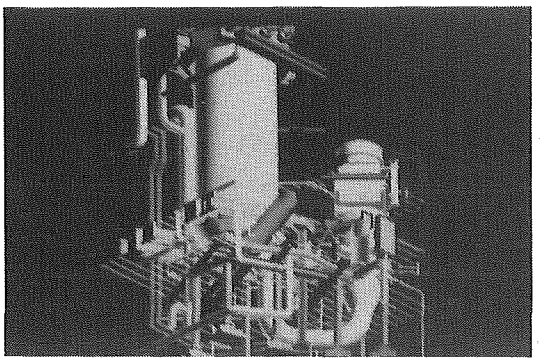

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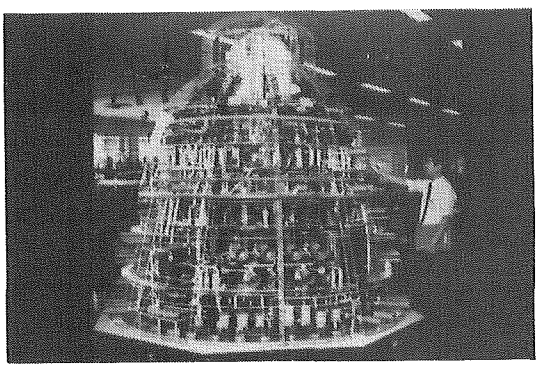

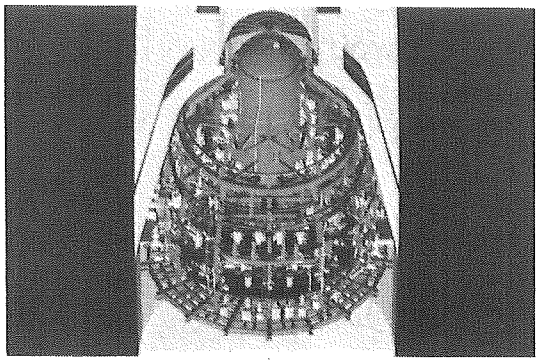

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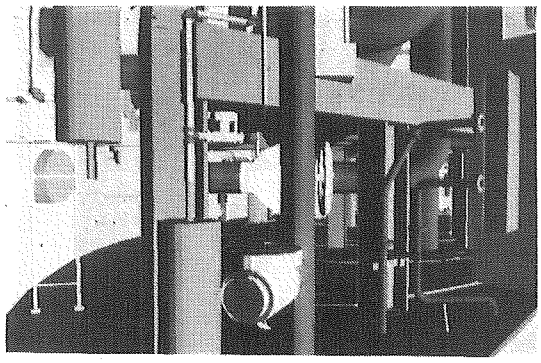

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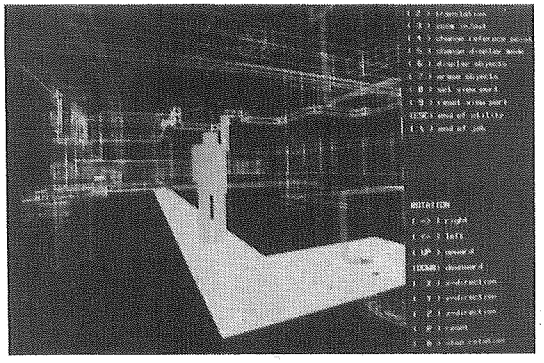

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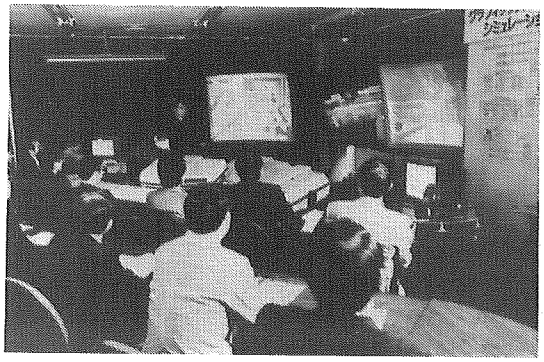


(32)

(33)

OPERATION & MAINTENANCE

Operation
- Man-Machine Interface
- Operation Support Function

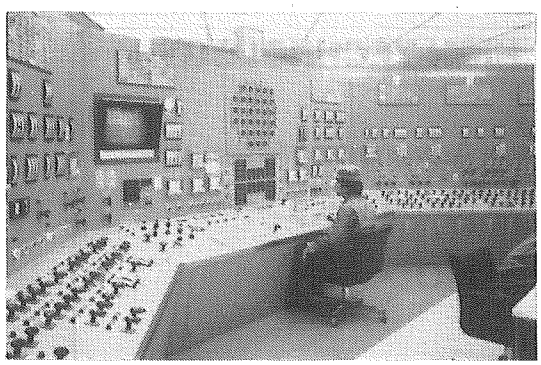
Maintenance
- Automatic Inspection & Diagnosis

(34)

MAIN CONTROL BOARD

Advanced	*Future*
▪ Man-Machine Interface	▪ Operation Support Function
• Colored CRT	• Large Screen
• Expanded Automatic Control	• AI
• Digital Control	• Digital Network

(35)



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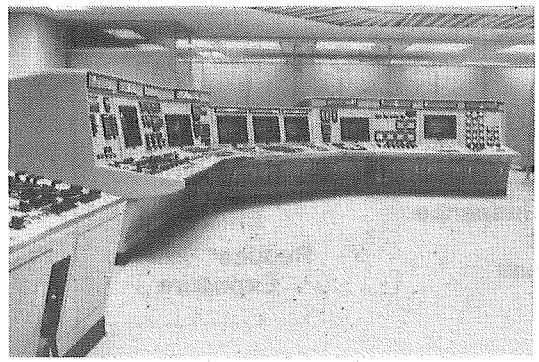

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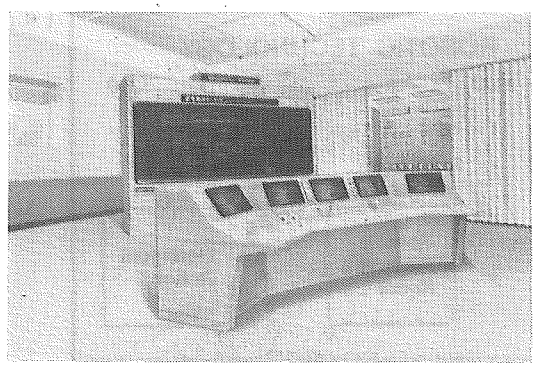

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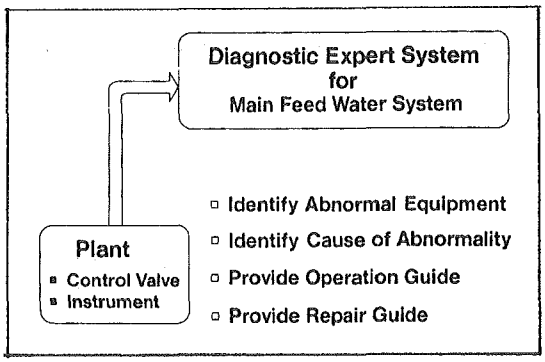

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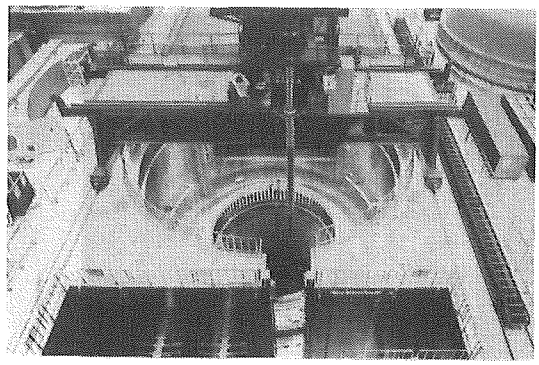

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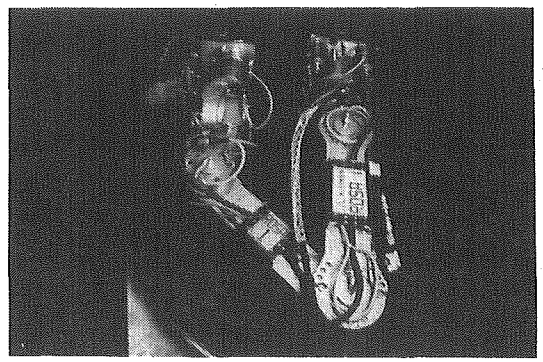

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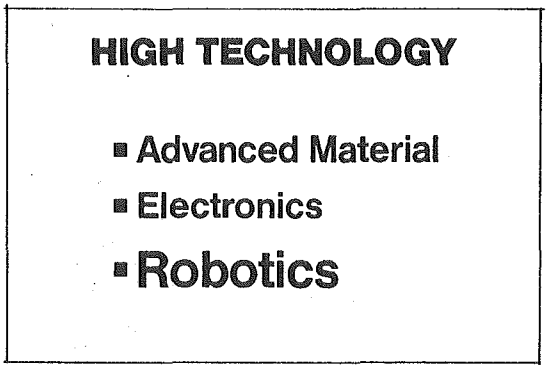

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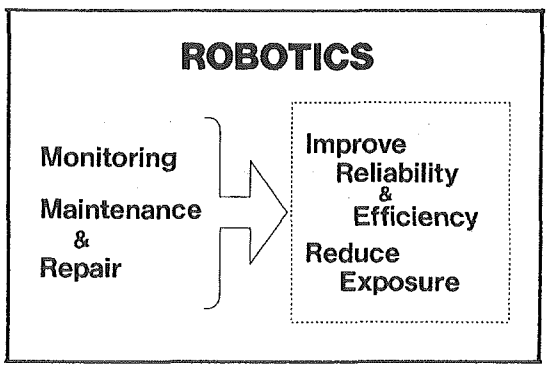

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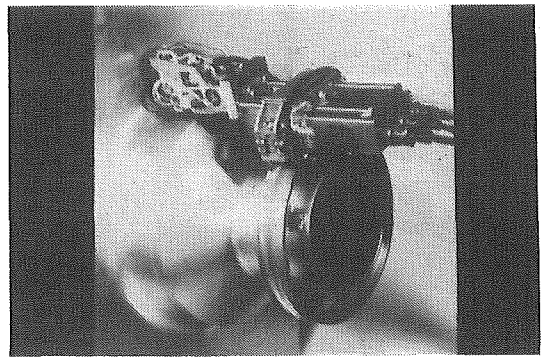

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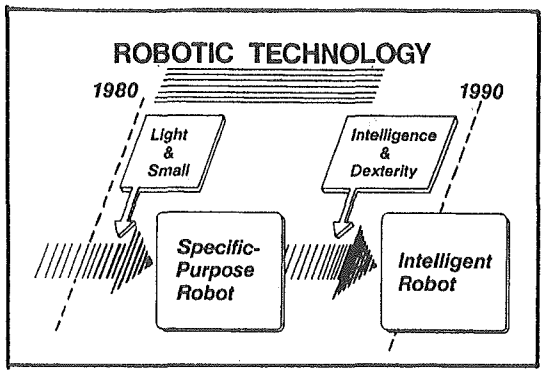

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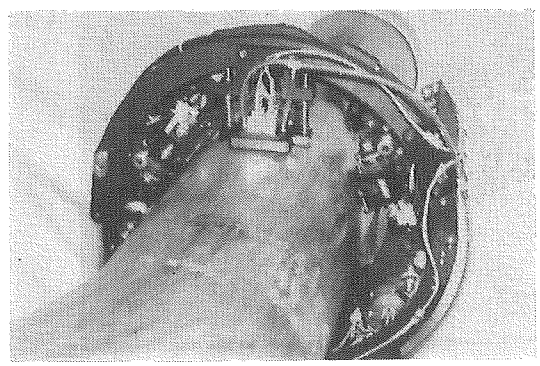

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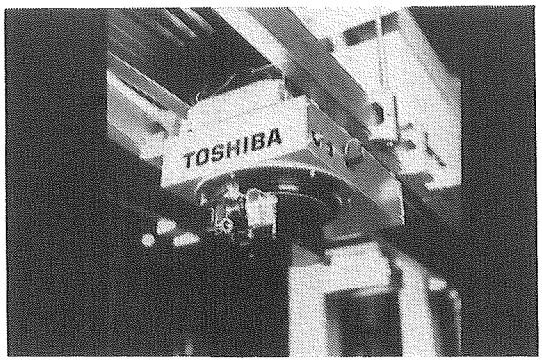
PROTO-TYPE ADVANCED ROBOT

(48)



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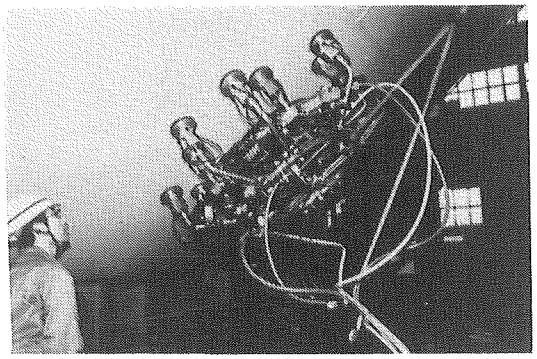

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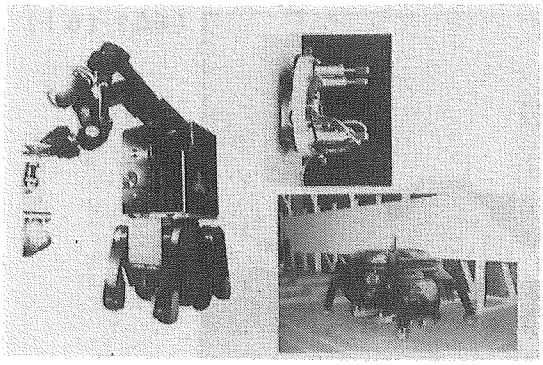

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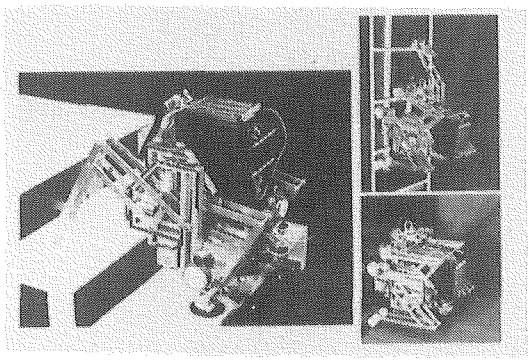

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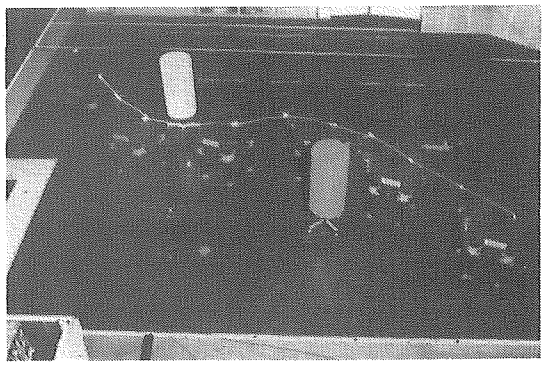


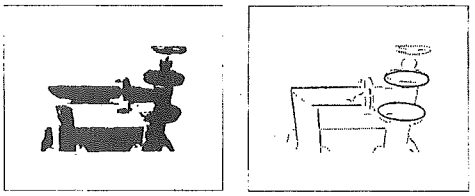
(53)

FUNDAMENTAL ROBOTIC TECHNOLOGY

- Visual Recognition
- Autonomous Control
- Multi-Legged Walking
- Intelligent Fingered Manipulator

Promoted by Advanced Robot Technology Research Association

(54)



Original image　　Computerized image

(55)

3-D HIGH SPEED VISUAL RECOGNITION

Camera System (Plant Scene)

▽

Characterization of Edge

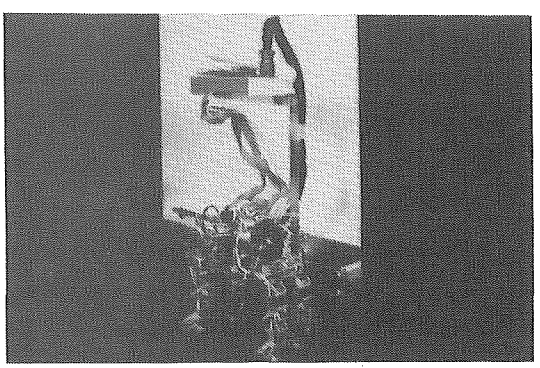
▽

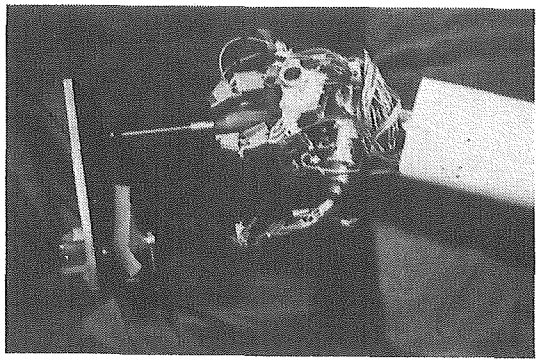
Recognition of Object

▽

Robot Action Planning (Autonomous Control)

(56)





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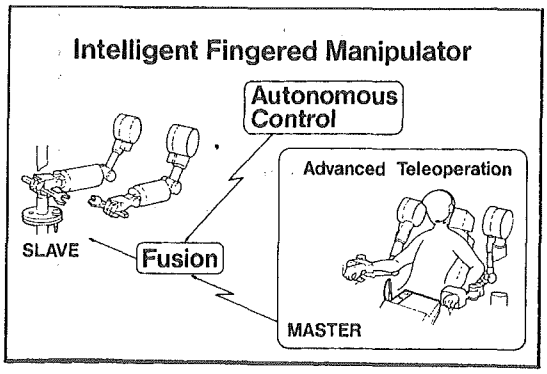
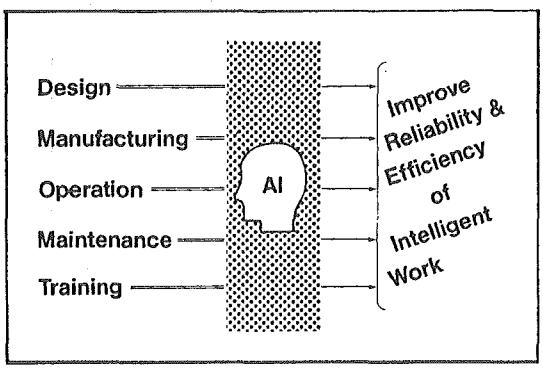
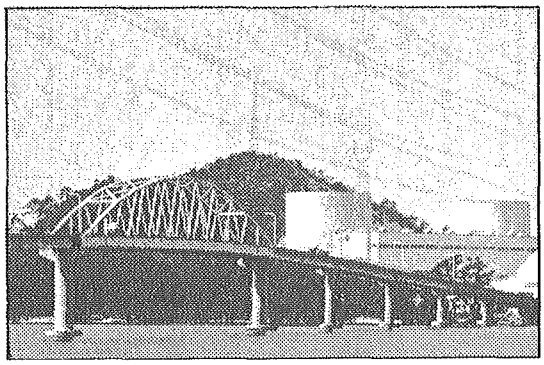
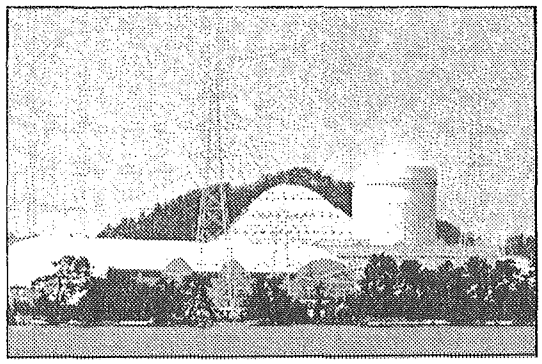

Intelligent Fingered Manipulator
Autonomous Control
Advanced Teleoperation
SLAVE
Fusion
MASTER

(58)


Design
Manufacturing
Operation
Maintenance
Training
AI
Improve Reliability & Efficiency of Intelligent Work

(59)





(60) (61)

SLOWPOKE

A ROLE FOR NUCLEAR TECHNOLOGY IN DISTRICT HEATING

G.F. Lynch
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada
K0J 1J0

1. INTRODUCTION

Economically viable, small nuclear energy systems have been a long sought after goal. The successful development of such systems will allow nuclear technology to contribute to energy sectors beyond those that are currently supplied by central nuclear generating stations. The SLOWPOKE reactor which has been developed in Canada over the last 20 years is at the forefront of the demonstration of this technology.

This paper describes the successful application of the SLOWPOKE concept to satisfy the heating needs of institutions and building complexes. Although the load factor for heating in Japan may not be as high as those experienced in other countries of the northern hemisphere, this particular application clearly demonstrates that small, special purpose, ultra-safe nuclear energy sources are technically and economically viable. They can be designed for easy operation and maintenance, to be located in urban areas and remote communities, thereby satisfying a broad spectrum of energy needs that cannot be served by central nuclear electrical generators.

2. THE NUCLEAR ENERGY FUTURE

To put this particular development in perspective, it is useful to review the future trends in world energy demand and assess the overall potential contribution of nuclear technologies.

2.1 World Energy Requirements

The availability of abundant energy at affordable prices is a major contributor to industrial development and national economic growth. However, as the world population expands and industrial development proceeds, the global energy requirements in the year 2020 are predicted to exceed 700 Exajoules (1). This represents more than double the annual global energy consumption for 1982. Such a growth in energy demand will considerably strain our ability to provide it unless prudent decisions are taken in time to implement the new systems that will be required.

The main incentive of most national energy programs is to develop alternatives to an increased dependence on fossil fuels. All forecasts anticipate a significant expansion in the role of nuclear energy. For example, a 1980 study by the International Institute for Applied Systems Analysis has predicted that the energy from the nuclear fission process will be providing up to 50% of the world's primary energy requirements by the year 2050 (2).

2.2 Nuclear Energy Prospects

To appreciate how nuclear technology can realize its full potential, it is necessary to consider the end use of the energy.

During the last forty years, the emphasis for commercial nuclear power development has been targeted at electricity generation. By the end of 1985, there were 374 operating reactors with a total generating capacity of approximately 250 Gigawatts. With this available capacity, the global nuclear share of the total electricity generated amounted to 15% (3). However, it is important to note that less than 30% of the primary energy consumption is used in electricity generation. Thus, the contribution of nuclear power to the world's energy requirements in 1985 was less than 5%. Even with the high growth scenarios of the International Atomic Energy Agency, the nuclear electrical contribution to the world energy requirements for the year 2000 still amounts to less than 10% (3).

The longer-term forecasts for established nuclear nations, such as Japan, indicate that nuclear generated electricity will contribute over 25% of the country's primary energy requirements by the year 2030 (4). However, it is also generally recognized that nuclear energy should also be used in areas other than electrical generation such as process heat for industry and building heating.

Many of the large industrial processes which are energy intensive, require steam at the pressure and temperature conditions similar to conventional

electrical generators. Thus, for some industrial applications, the existing power reactor technology can be used directly. A good example in Canada is the provision of steam from the Bruce "A" Nuclear Generating Station to the nearby heavy water production facility (5).

In assessing the prospects for applying nuclear energy to heat buildings, both the magnitude of the possible contribution and the technical match must be considered.

Many countries in the northern hemisphere consume in excess of 25% of their primary energy supply to satisfy their building heating requirements (6). Since the majority of the population live in urban centres, a significant fraction of the heating requirements can be satisfied by distributed or district heating systems, should low cost heat sources be available. Unlike the transportation industry, this is an energy sector which is amenable to substituting nuclear energy for the traditional fossil fuels, provided certain technical, economic and safety criteria can be met and public apprehension overcome. Thus, the potential for nuclear heating from a global energy point of view must be considered of a similar magnitude to that which is being achieved by nuclear electrical generation.

2.3 Criteria for Nuclear Heating

Since the fundamental requirement is to supply low grade heat to end-users who are geographically distributed throughout a series of buildings or

building complexes, there are a number of key design requirements that differentiate nuclear district heating from nuclear electricity generation.

Since the ultimate end use of the energy is heat at 20°C, the heat source can operate at a relatively low temperature. Existing district heating systems use both hot water with supply temperatures in the range 90°C to 160°C, and steam with pressures typically in the range 400 to 3000 kPa. Although there are advantages and disadvantages for both techniques, experience has shown that the advantages of hot water transmission far outweigh the disadvantages in most cases (7). Consequently, future district heating systems are almost certain to use hot water.

The economics of hot water heat distribution systems dictate that the heat source must be located close to the load and hence to people. This implies that a major factor must be unquestionable safety. Radiological protection must be achieved by the action of processes that are intrinsic to the heat source and not dependent on specially engineered electro-mechanical systems. The goal is to limit the consequences from all credible and even incredible accidents to a level that is acceptable to the people who live closeby. In addition to the engineering challenge, this presents a social challenge in expressing the safety features in a language that is readily understood by people with limited knowledge of nuclear technology.

The daily and annual load-following requirements depend on changes in the outside air temperature and variations in heat loss from the buildings and heat delivery system. The system dynamics are dominated by the rate of

change in the temperature of the large volume of water in the heat distribution piping. Since these time constants are measured in hours, the response time of the reactor control system can be very slow.

On the basis of such factors, it has been concluded that the optimum power level for gaining public acceptance of the nuclear district heating concept is in the 2-10 MWt range. At this size, the reactor can be designed with many inherent safety features that cannot be achieved at higher power levels.

Thus, the design criteria for nuclear heating systems are very different from those for conventional nuclear power stations. It is also anticipated that this development will establish important precedents for a range of small local energy systems based on nuclear technologies.

3. EVOLUTION OF THE SLOWPOKE CONCEPT

In a major departure from traditional nuclear power technology, Atomic Energy of Canada Limited (AECL) has developed the SLOWPOKE Energy System - a 10 MWt nuclear heat source specially designed to meet these local heating criteria.

The concept has the advantage of a sound technological base. For over twenty years, AECL has been involved in the development of small nuclear reactors. This program has lead to the progressive evolution of the

SLOWPOKE concept. The first product was the SLOWPOKE Research Reactor which was introduced commercially in the early 1970s and remains part of the AECL product line (8).

3.1 SLOWPOKE Research Reactor

The SLOWPOKE Research Reactor is a low cost, pool-type reactor used primarily for neutron activation analysis and as a university teaching and research tool. Since the startup of the prototype at the Chalk River Nuclear Laboratories in 1970, eight units have been installed.

The SLOWPOKE Research Reactor has a high degree of inherent safety, arising from the negative temperature and void coefficients of reactivity, limited maximum excess reactivity and restricted access to the core by users. As a result, the reactor does not require an automatic shutdown system, neutron ionization chambers or low power startup instrumentation. The reactor is controlled automatically by a single, motor-driven absorber rod responding to a self-powered neutron detector.

The seven units which are operating in Canada have accumulated over 60 reactor-years of reliable operation. All the units are located in urban areas. They are also the only commercial reactors in the world to be licensed for unattended operation for periods up to 72 hours.

3.2 Demonstration Heating Reactor

The realization that many of the key design criteria of the research reactor were similar to those required for a heating reactor, led the developers to optimize the reactor for heat production rather than neutrons and yet retain the essential safety features of the concept. This work culminated in the 1985 decision to construct the SLOWPOKE demonstration heating reactor at the Whiteshell Nuclear Research Establishment in Manitoba (9).

The SLOWPOKE Demonstration Reactor (SDR) was designed to operate at 2 MWt and incorporates the key technical features of the research reactor, namely: atmospheric pressure, natural convection cooling, beryllium reflector, remote monitoring instead of an on-site operator and unquestionable safety. The primary purpose in designing, constructing and testing this facility is to validate, in a very demonstrative way, that the technical, economic and safety criteria for the nuclear heating reactor concept can in fact be met.

The SDR facility, shown schematically in Figure 1, is housed in a 14 m by 12 m building. The pool is 4 m in diameter and 10 m deep. The core consists of a 2x2 array of fuel bundles inside the beryllium reflector. The fuel is enriched to 4.9% U-235.

SDR is being operated and tested to validate the computer models and the design codes that have been used for the design and safety analysis of the

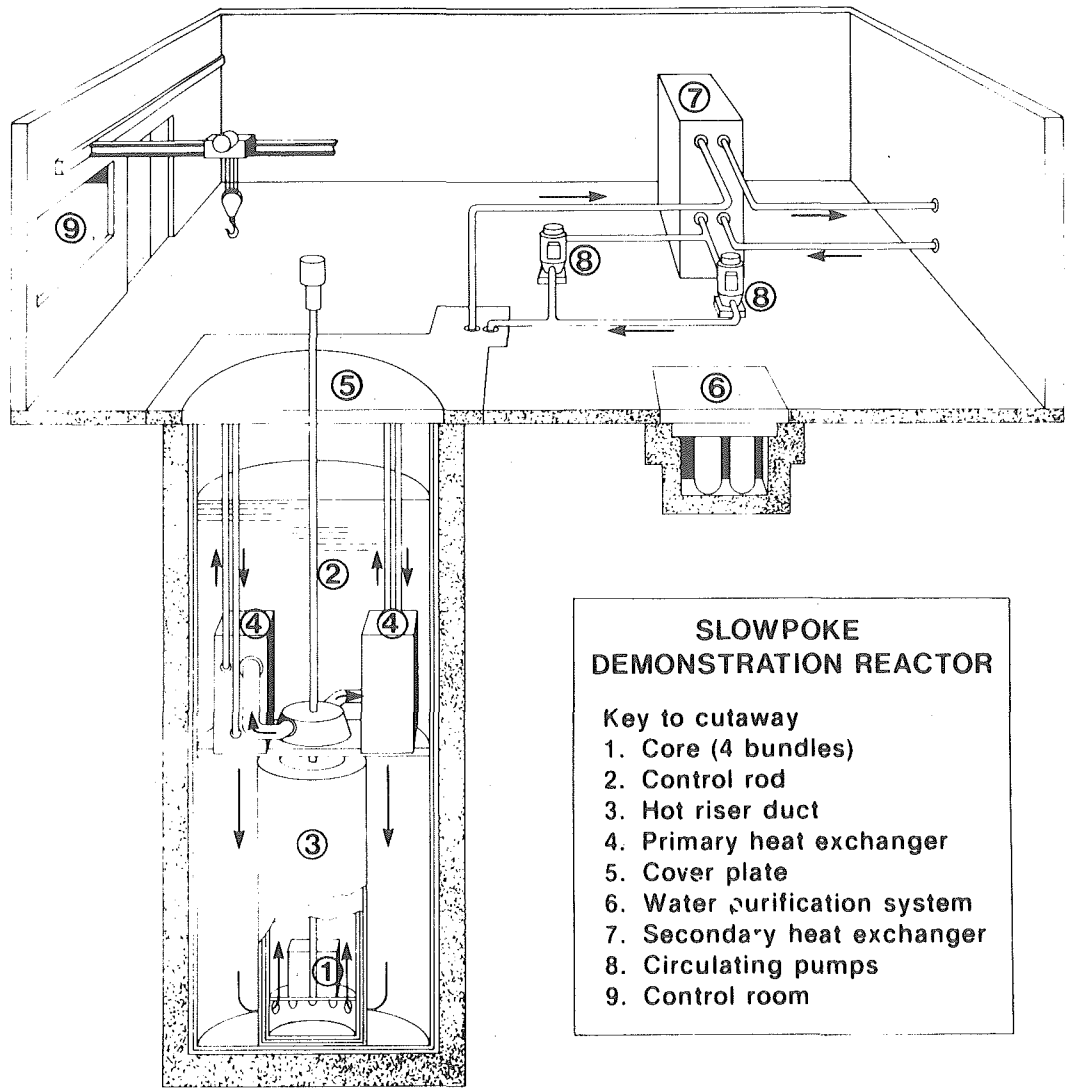


Figure 1: The Essential Features of the SLOWPOKE Demonstration Reactor

commercial SLOWPOKE Energy System. Steady state and transient tests are being carried out over the full range of anticipated operating conditions. The facility will also be used to demonstrate the consequences of power transients and fuel element failure. When the first core has been removed from the reactor, selected fuel elements will be examined for dimensional and metallurgical changes.

Drainage tiles under the concrete pool structure collect ground water which is sampled routinely. The soil surrounding the pool is being sampled through a hole in the concrete floor of the reactor building. Gases from the reactor are monitored continuously before being released to the atmosphere.

These tests, supported by a comprehensive data base on reactor conditions, are being used to confirm the effectiveness of controlling all possible radioactive releases to the environment.

In addition to being used as an experimental and developmental tool, SDR is to be used as a full scale demonstration of building heating. Several of the buildings at the Whiteshell site have been converted to hot water heating to use the full 2 MW of thermal energy in a base load capacity.

3.3 SLOWPOKE Energy System

The SDR test and demonstration programs have been designed to verify all the essential features of reliability, availability and maintainability of SLOWPOKE Energy Systems in commercial applications.

In keeping with these requirements, the 10 MWt SLOWPOKE Energy System, designated SES-10, is a pool-type reactor designed to operate at atmospheric pressure. This eliminates the need for a nuclear pressure vessel. Consequently, loss-of-coolant caused by depressurization is impossible.

As shown in Figure 2, the reactor core, coolant riser duct and the primary heat exchangers are installed in the pool contained inside a steel-lined concrete vault. This double containment of the pool water prevents loss-of-coolant caused by leakage.

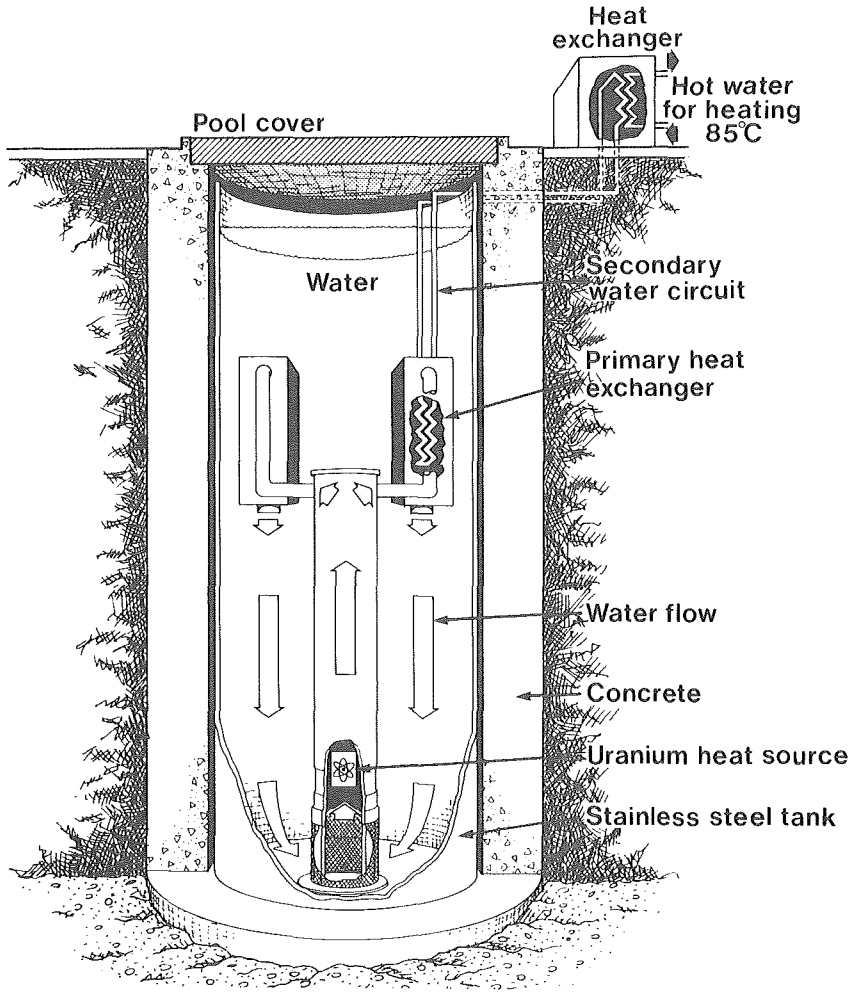


Figure 2: Schematic Diagram of the SLOWPOKE Energy System

The pool water serves as both the heat transfer medium and the shielding. Primary heat transport from the core is by natural circulation of the pool water through the plate-type heat exchangers. There is therefore no risk of loss-of-cooling by mechanical or electrical failure.

The secondary circuit delivers the heat to the building by way of the secondary heat exchanger. Thermal power is measured in the secondary circuit for the purpose of metering and calibration of instrumentation in the primary circuit.

To compensate for fuel burnup, shim absorber plates are used for periodic core reactivity adjustments by the licensed operator. In addition, a

central absorber rod is used for automatic control of the pool water temperature. The rate of removal of all absorbers is limited by the speeds of their electric motors and by a timer requiring manual reset. The use of a fully redundant control system reduces the probability of unwanted shutdowns to an acceptable level.

The large pool volume delays core temperature rise following loss of secondary flow. As a result, any thermal transients take hours. This feature, combined with unique design features that limit reactivity change rates to very low values, eliminates the need for fast acting shutdown systems that are essential for pressurized power reactors.

A liquid absorber release system will shut the reactor down over a period of 5 minutes. Gadolinium nitrate solution flows into the pool by gravity alone, through two temperature actuated valves. These valves require no external power supply and will be set to open automatically at a core outlet temperature of 98°C. The temperature sensors and the valves for the liquid absorber system are fluidic throughout and fail safe.

The pool water is continuously pumped through ion exchange columns to maintain water chemistry and control corrosion. The ion exchange columns can also remove fission products from defective fuel and gadolinium nitrate should the liquid absorber shutdown system be triggered.

The reactor pool is covered by an insulated lid, enclosing a gas space over the pool. The air and water vapour are continuously circulated through a purification system and hydrogen recombiner. After filtering and monitoring, a small

fraction of the circulating cover gas is vented by way of the building ventilation exhaust system.

The goal of the SES-10 design was to fully automate all essential systems, thus allowing the unit to be operated for extended periods of time without an operator in the reactor building. Essential instruments will be monitored at one or more remote locations and a licensed operator will always be on call, either by telephone or personal paging system. A single remote monitoring centre would manage the heating and ventilating requirements of many building complexes in a number of towns, cities or regions.

Local staff would be responsible for maintaining and testing equipment and responding to specific alarm conditions. It is anticipated that these local responsibilities will be undertaken by the existing heating plant staff. Although the local staff will have the authority to shut the reactor down in the event of an abnormal condition being observed, the licensed operator will have to be present for startup.

4. SAFETY PRINCIPLES

One of the fundamental driving forces of the design is the safety philosophy. The primary goal is to meet all Canadian regulatory requirements in a manner that permits unattended operation with remote monitoring for periods of weeks or longer. This implies system diversity and a rigorous defence in depth of the overall safety analysis.

The main objectives of the safety design for the SES-10 are to:

- limit the release of radioactive fission products from the facility under all circumstances to an acceptable level; and

- ensure that for any event there is an adequate low probability of damage to the fuel, structures and equipment that could lead to significant radiation exposure to plant personnel or members of the general public.

To meet these objectives it is essential that:

- the reactor can be safely shut down and maintain shutdown under all circumstances;

- the reactor core is adequately cooled at all times; and

- radioactive releases will not only be maintained within regulatory limits but also kept as low as reasonably achievable.

These requirements are achieved by operating at a low power level; selecting appropriate operating conditions; and utilizing inherent safety features, engineered systems and administrative practices.

Of fundamental importance is the fission product inventory. By restricting the power level to 10 MWt, this inventory is less than 0.3% of that of most of the existing power reactors. Thus, the consequences of even the most severe reactor accident, no matter how improbable, are significantly less. Combining this

feature with the fact that for very small reactors such as the SES-10, advantage can be taken of important inherent safety characteristics that cannot be implemented in reactors of much higher power levels.

Much of the fission product inventory is held up by the uranium oxide, diffusion resistant, ceramic fuel. A small fraction of the volatile species is released to the gas gap between the fuel and the Zircaloy sheath. Power reactor fuel sheaths have been designed to withstand the stresses resulting from the fuel expansion, fission gas release and the mechanical loads applied during refuelling. Advantage has been taken of this experience in the design and manufacture of SES-10 fuel. Moreover, since the SES-10 fuel is operating at much lower temperatures and pressures, adequate sheath integrity is thus assured.

The inherent safety features of the SES-10 design include negative fuel and coolant temperature reactivity coefficients, both of which attenuate power transients following loss-of-regulation. In addition, the primary heat transport system is a natural circulating system requiring no external power source to maintain coolant flow through the core during operation or shutdown.

The engineered systems include:

- the robust fuel,
- a double containment pool with no penetrations,
- a large pool volume to mitigate the consequences of any transients,
- slow reactivity addition rates,
- a fully redundant control system,
- separate and diverse shutdown systems dedicated to safety, and
- a cooling system to remove fission product decay heat during shutdown.

The normally accepted codes and standards have been used for the design and fabrication of components and systems. A quality assurance program has been instituted for all aspects of the commercial installations.

5. ECONOMICS

The final key criterion is economic competitiveness. In assessing the overall economics, the analysis must include the capital cost of the heat source, the entire heat distribution and delivery system together with the fuelling, operating and maintenance costs. These are not totally independent parameters and to a large extent depend on such demographic factors as population density, climatic conditions and lifestyle.

A SLOWPOKE Energy System naturally requires a substantially lower capital investment than a nuclear electric power station such as a CANDU or a PWR. However, it is also very important to note that the capital investment in terms of $/MW of thermal capacity is also significantly lower. This is the result of many factors including elimination of the complexity of pressurized systems and short construction times (approximately one year). This leads to the conclusion that dedicated nuclear heating systems, such as SES-10, are economically competitive even with large nuclear cogeneration plants.

This low capital cost, when combined with the low operating expenses resulting from unattended operation, results in the unit cost of heat supplied by a SLOWPOKE Energy System being as low as 1.2 cents/kW.h.

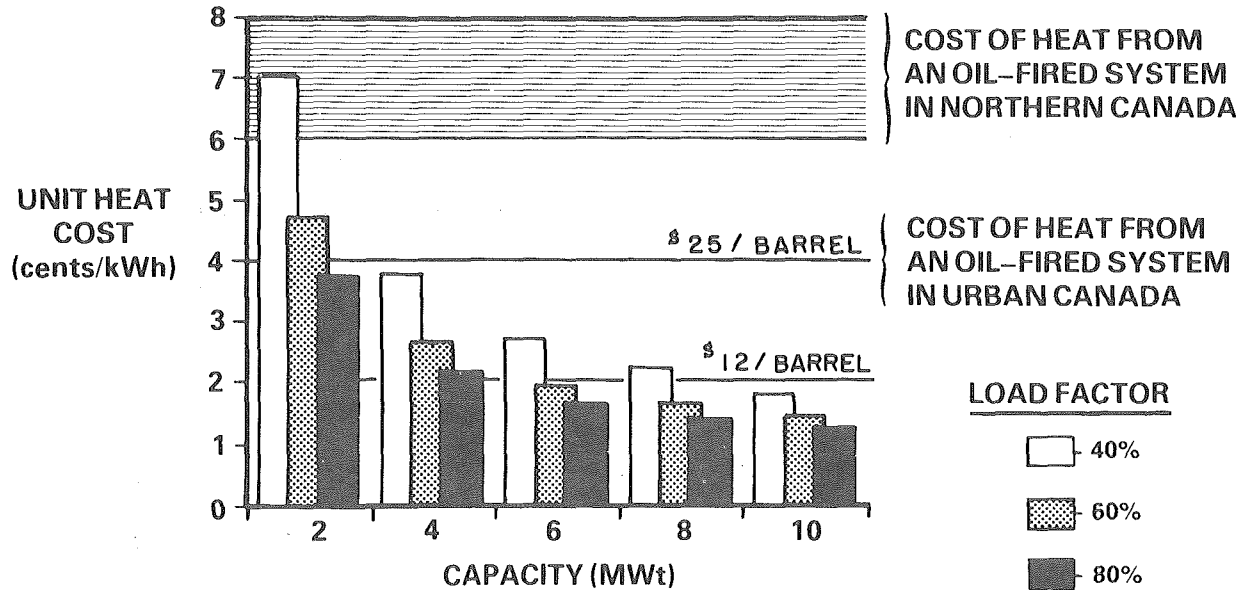


Figure 3: Unit Heat Cost from SLOWPOKE Energy System

The actual cost for a specific application depends on unit size and load factor, as shown in Figure 3. For example, an SES-10 system used to heat a building with a 40% load factor could provide hot water for heating at approximately 2 cents/kW.h. As evident in Figure 3, the cost of heat from systems greater than 6 MWt is competitive with oil fired systems even with oil prices as low as Canadian $15 per barrel (equivalent to US $12 per barrel).

Furthermore, from an analysis of the annual heat load curves in many buildings in several countries, it has been concluded that a nuclear heating system satisfying approximately 50% of the peak heat demand and used in a base load capacity could provide up to 90% of the annual heat requirements. By using a low capital cost, fossil fired system to satisfy the peaking requirements and acting as a backup to the more capital intensive nuclear heating system, the overall system redundancy requirements can be met at a cost which is very competitive with fossil fuels.

6. CONCLUSION

The building heating market in many countries is large and growing. Small nuclear heat sources are ideally suited to satisfying the demands of this energy sector but to be technically viable the detailed design criteria must match the end use application.

By keeping the power level low, much of the complexity of the larger nuclear electrical generating stations can be avoided thus allowing small, ultra-safe nuclear systems to be economically viable.

The demonstrated performance of the SLOWPOKE research reactors in university communities over the last 16 years, together with the successful operation of the SLOWPOKE demonstration heating reactor provides the confirmation of unquestionable safety that is required for public acceptance. This acceptance is not only essential for the widespread adoption of the local nuclear heating reactor concept but it could also play a major role in pioneering the introduction of a range of small reactors that will be required if nuclear fission power is to achieve its ultimate contribution to satisfying the broad range of needs of our energy hungry world.

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燃料サイクル施設の遠隔技術

動燃事業団

理事　植松邦彦

1. 概　要

燃料サイクル施設のうち，使用済燃料の再処理や高レベルの放射性物質を取り扱う施設等では，主要なプロセス機器類は，高い放射線量環境下にある為，しゃへいを施したセル内に設置されており，通常の状態では人間のアクセスは不可能である。従って，万一セル内機器が何らかの原因により故障した場合には，点検・補修・交換等に大幅な時間と労力を要することがあり，その結果として施設利用率の低下を招く場合がある。また，補修作業時には，作業員の放射線被曝量を増大させる可能性も考えられる。このため，これら再処理関連施設における経済性，ならびに安全性向上には，プロセス機器類の故障頻度の低減化，故障時の補修時間の短縮化，および作業員の放射線被曝量の低減化を追求することが重要である。

故障頻度の低減化については，材料開発，プロセス設計・装置設計・製作技術の改良，運転技術の改善等により，一層の向上が期待できる。

一方，補修時間の短縮化，および作業員の放射線被曝量の低減には，近年，従来の人間の手作業による直接保守方式に代わるものとして，セル内プロセス機器の補修，改造，交換等の作業を，安全かつ効率的に行うことのできる，高度な遠隔保守技術の確立が重要であるとの認識が広まり，日，米，独等で開発が進められている。

2. 遠隔保守技術の概念

セル内設備や機器の保守技術は，原子力技術開発の進歩と共に，その時代における経済性，ニーズ，技術力等に影響を受けながら変遷を重ねてきた。

米国において，1940年代から1950年代に建設されたプルトニウム分離工場には，クレーン・キャニオン法と呼ばれる保守方式が開発・採用された。これは，キャニオンと呼ばれる超大型セル（幅10～20m，高さ10～20m，長さ 200～300 m）内に，プロセス機器をモ

ジュール化して組み込んだラックを多数基並べ，故障発生時には，クレーンを用いてラックごと交換する方式である。この方式は，施設利用率向上に多いに役立ったが，反面，建設コスト，運転コストが非常に高い事から，以降に建設した再処理施設には採用されなかった。

1960年代から現在までに，西欧諸国ならびに日本に建設された主な核燃料再処理工場には，直接保守セル法が採用された。プロセス機器類は，いくつかの小型セル内に設置されており，補修には作業員がセル内に直接アクセスする方式がとられた。この保守方式は，人間がセル内にアクセスできるようになるまで，セル内を除染する必要があるため，保守時間および労力の点から，現在見直しをせまられている。

以上の方法に代わるものとして，日，米，独でそれぞれ独自に開発中の方式に遠隔保守キャニオン法がある。操作具には，クレーン以外に高性能なサーボ・マニプレータを用いる。人間の腕並みの機能を持つサーボ・マニプレータの採用により，セル内のラックに収納したプロセス機器を，現位置で保守することも可能になり，予備ラック・部品の削減，ラックのコンパクト化，ならびに大型セルのコンパクト化が可能となった。本方式は，今後建設を予定している西独の再処理工場（ＷＡ－350)，日本の動燃事業団におけるガラス固化技術開発施設ならびに高速炉燃料再処理関連施設等で採用されようとしている。

以下に，動燃事業団が開発を進めている，遠隔保守キャニオン法の概念と，これを実現させる上で必要となる遠隔技術について示す。

遠隔保守キャニオン法では，大型セル内に，プロセス機器が数基のサイズの標準化されたラックに，モジュール化されて組み込まれており，操作具としてインセル・クレーンおよび両腕型サーボ・マニプレータが装備される。また，従来のセルでみられる内部観察用のしゃへい窓の代わりに，耐放射線性の優れたＴＶカメラが視覚機能をになっている。これらの操作は，ＴＶモニター，インセル・クレーンのコントローラ，両腕型サーボ・マニプレータのマスターアーム等を装備した，セルから離れた場所に配置されている，遠隔操作室から行う。

3. 主な遠隔技術

(1) 保守システム

保守システムは大きく分けて両腕型サーボ・マニプレータやインセル・クレーン等の操作具，耐放射線性ＴＶを中心となる視覚システム，セル内へ電力・制御信号を供給するシステム，およびマン・マシン・インターフェイスから成る。このうち，本システムの中核をになうのが両腕型サーボ・マニプレータである。マニプレータシステムは，小型軽量性，高信頼性，高操作性および自己保守が可能な構造を持つことが要求され，最終的には成人男子の両腕と同等な機能を持つことを目標に開発を進めている。現在までに開発した試作機では，動作速度，取扱荷重，耐放射線性等については，ほぼ目標値に達しており，今後さらに小型化，信頼性，および経済性の向上を図る予定である。視覚システムとしては，マニプレータの操作およびセル内機器類の点検・監視を目的として，高品位ＴＶカメラの耐放射線化および小型化の開発を進めている。高品位ＴＶは，従来のＴＶに較べ，走査線の本数が２倍以上のものであり，解像度は35㎜フィルムを上回る高性能カラーＴＶである。

このシステムをセル内で使用可能とする為に，耐放射線性の高い電子部品の開発をはじめとして，カメラヘッド部の簡素化，放射線による信号異常を補正する回路の付加等を行っている。

大型セル内には，マニプレータ，ＴＶシステム等のメカトロニクス機器，電子機器類が設置されるため，セル壁を通して極めて多くの信号回線数が必要となる。このケーブル使用量の増大に対応する為に，光ファイバー使用による信号多重化の開発を行っている。

(2) 保守対象システム

大型セル内に設置する機器類およびその部品類を，遠隔操作により容易に交換できるようにする為には，接続部分の工夫が重要な問題であるが，これを解決する方法として，ラックシステムならびに遠隔継手の開発を進めている。

プロセス機器をモジュール化し，収納した構造体をラックと呼んでいる。ラック内の機器は，これに接続する配管やケーブル類とは遠隔継手で継がれており，ラック全体の着脱だけでなく，機器およびその部品，センサー類の交換もできるようになっている。

また，小型機器，継手およびセンサー類への，両腕型サーボ・マニプレータのアクセス性を考慮し，配置・形状の検討も行っている。

継手には，ケーブルコネクタと流体用配管継手とがある。双方とも数多くのタイプが，一般産業界において使用されているが，原子力分野への適用にあたっては，遠隔着脱性，高信頼性および耐放射線性を考慮して，選定もしくは改良開発を行う必要がある。特に流体用配管継手は，現在の技術レベルでは遠隔で配管の切断・溶接を行うことは難しい為，遠隔で着脱できてしかも信頼性の高い遠隔配管継手の開発が必要となる。今までに国内では，遠隔配管継手の設計・製作・実用実績が皆無であったことから，耐震性，耐久性等の特性データの整備ならびに設計・製作・検査および保守基準の検討を行ってきた。

(3) その他関連するシステム

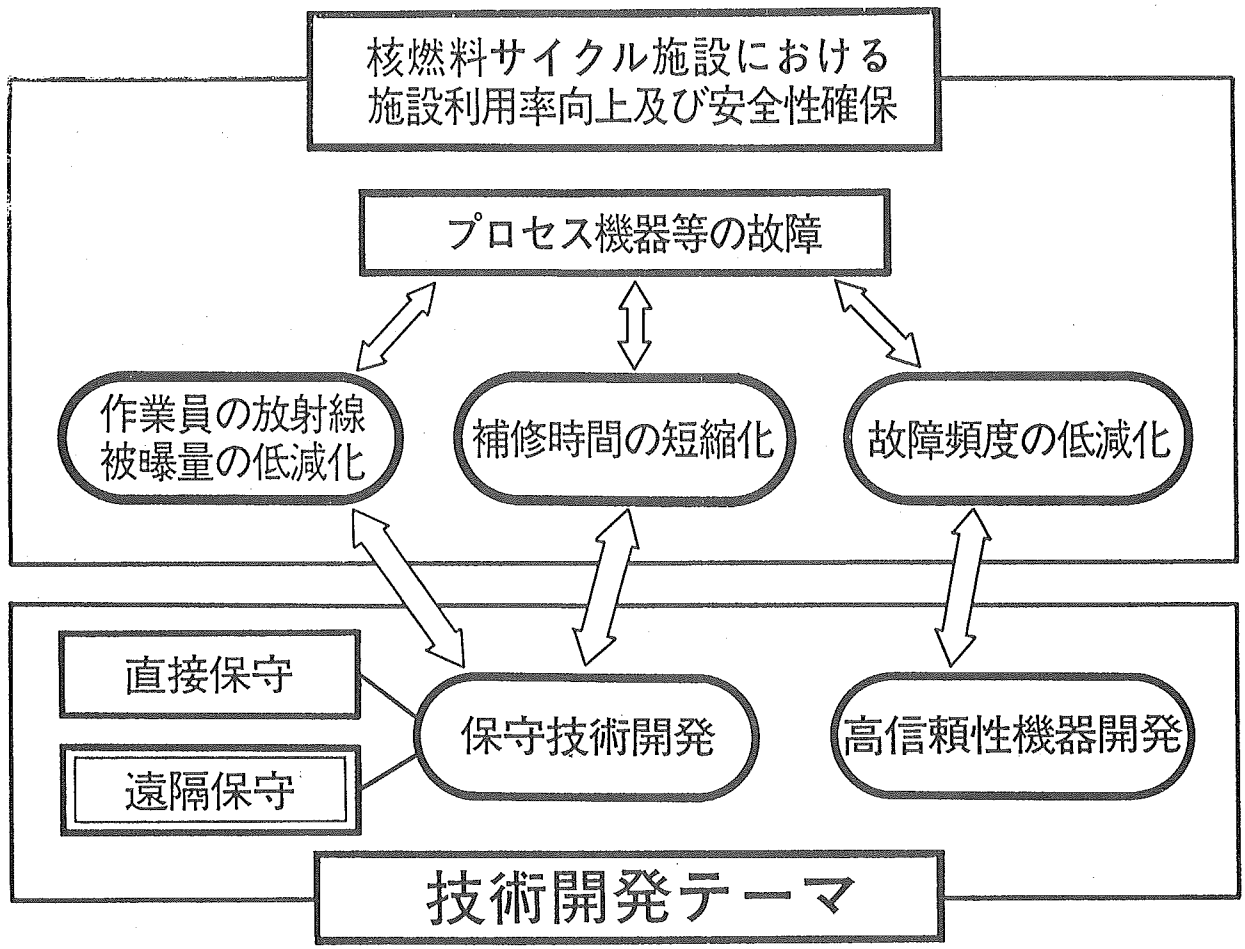
遠隔保守キャニオン方式の施設では，省力化，自動化等を進める上で，前述の2つのシステム以外にも，いくつかの新しいシステムの採用が図られている。再処理施設等では運転に際して，工程管理上および核物質量管理上，定常的なサンプリング・分析を行うが，多くの場合サンプリングは，手動によって行っており，分析所もプロセス機器が設置されているセルから離れていた。遠隔技術の採用により，サンプリングはサンプリングロボットによって行う事ができ，分析についてもインライン化により，プロセス内での直接分析ができると期待されている。特に後者については，ニア・リアルタイムでプロセスの管理が可能となる為に，運転の効率化に及ぼす効果が大きい。現在，いくつかのインライン分析装置の開発は実証段階にある。この他に，プロセスを管理する技術として供用中設備検査システムがあり，プロセス流体の配管からの漏洩検知，プロセス機器の腐食検知等の技術開発を進めている。

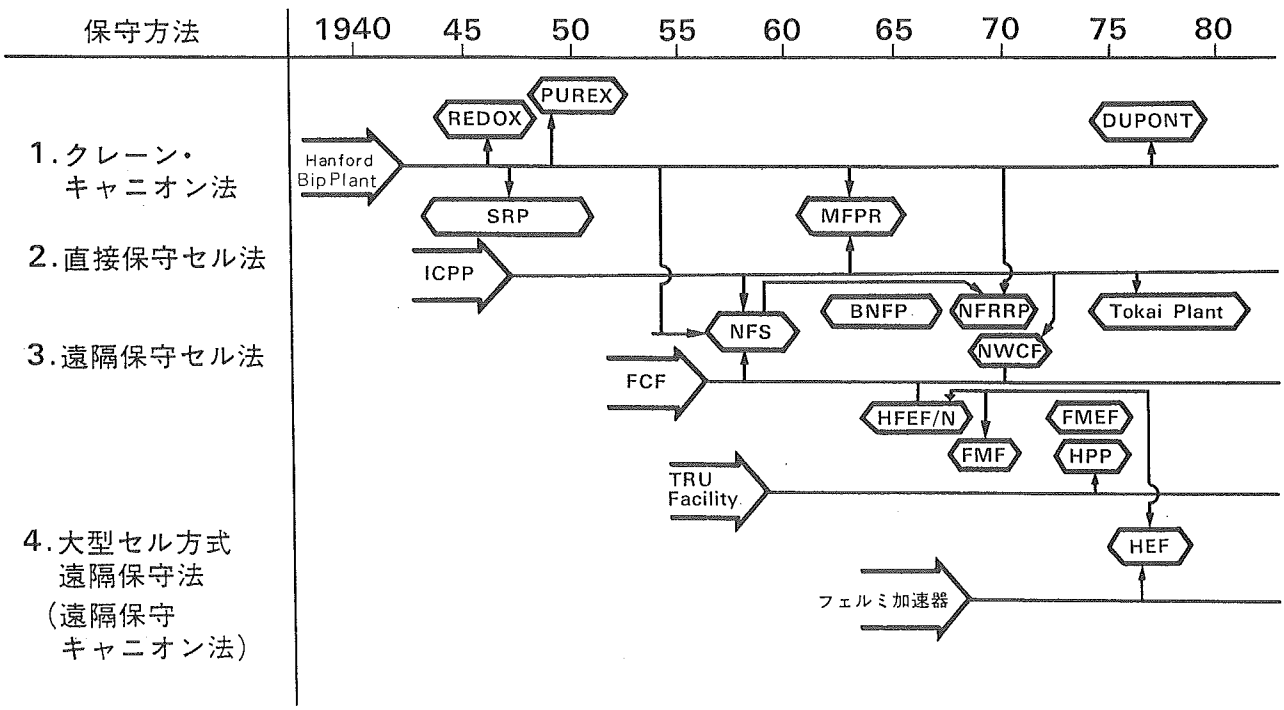
また，大型セルの採用によって，開発が重要となった技術として，低流量セル内換排気システムがある。大型セルはセル容積が大きい為，従来の小型セルの換排気方式では総排気量が大きくなる。従って，換排気系統の処理能力を大幅に上げる必要があるため経済的でない。そこでセルの換気回数を1日1日程度とする，低流量セル内換排気システムを構築する為，セル内の熱流動解析，セルの負圧維持方法の検討等を行ってきた。

4. まとめ

核燃料サイクル施設における遠隔保守技術の必要性，ならびに動燃事業団が開発を進めている，遠隔保守キャニオン法の概要および遠隔保守キャニオン法の実現化に係る，主な遠隔技術について簡単に述べた。これらの多くは，現在の科学技術における先端技術の一つであり，実証段階を迎えれば原子力分野のみならず宇宙開発分野や他の一般産業分野への波及効果が期待される。

従って，今後のより一層の研究開発の推進の為，今まで以上の，産官学の協力や諸外国との技術情報交換等を行ってゆきたいと考えている。

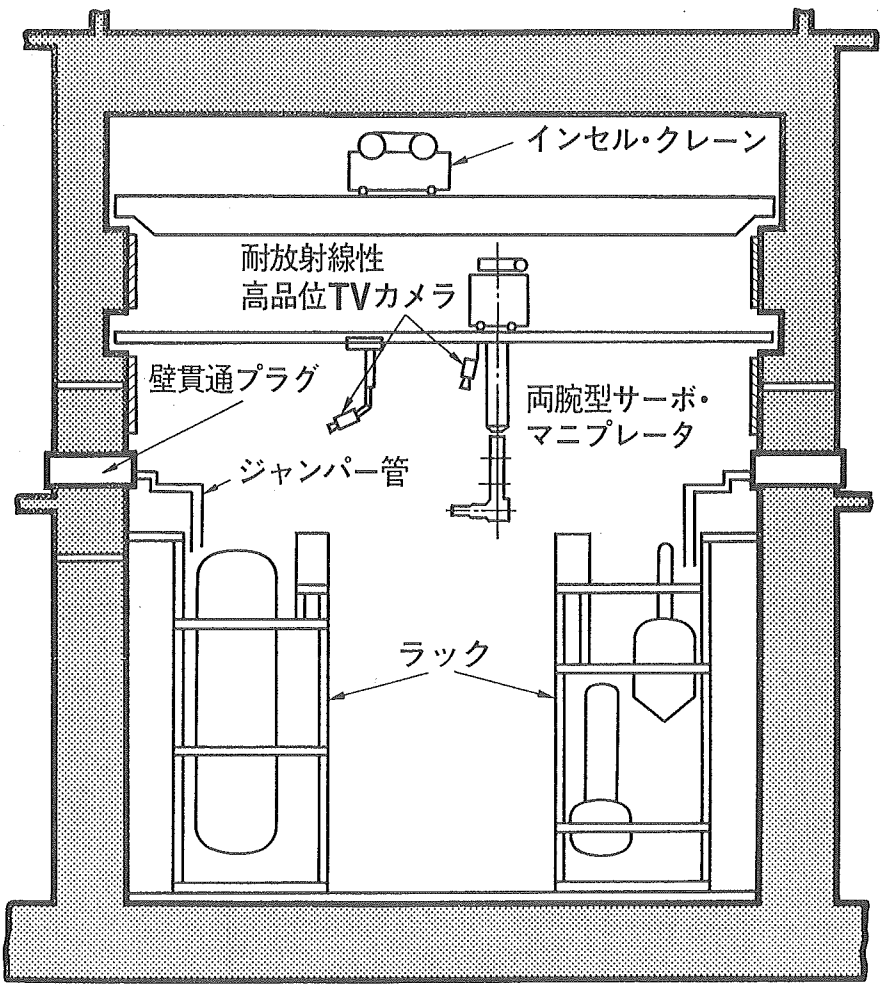

核燃料サイクル施設における
施設利用率向上及び安全性確保
プロセス機器等の故障
作業員の放射線
被曝量の低減化
補修時間の短縮化
故障頻度の低減化
直接保守
遠隔保守
保守技術開発
高信頼性機器開発
技術開発テーマ


保守方法
1940
45
50
55
60
65
70
75
80
1.クレーン・
キャニオン法
2.直接保守セル法
3.遠隔保守セル法
4.大型セル方式
遠隔保守法
(遠隔保守
キャニオン法)
REDOX
PUREX
DUPONT
Hanford
Bip Plant
SRP
MFPR
ICPP
NFS
BNFP
NFRRP
Tokai Plant
NWCF
FCF
HFEF/N
FMEF
FMF
HPP
TRU
Facility
HEF
フェルミ加速器

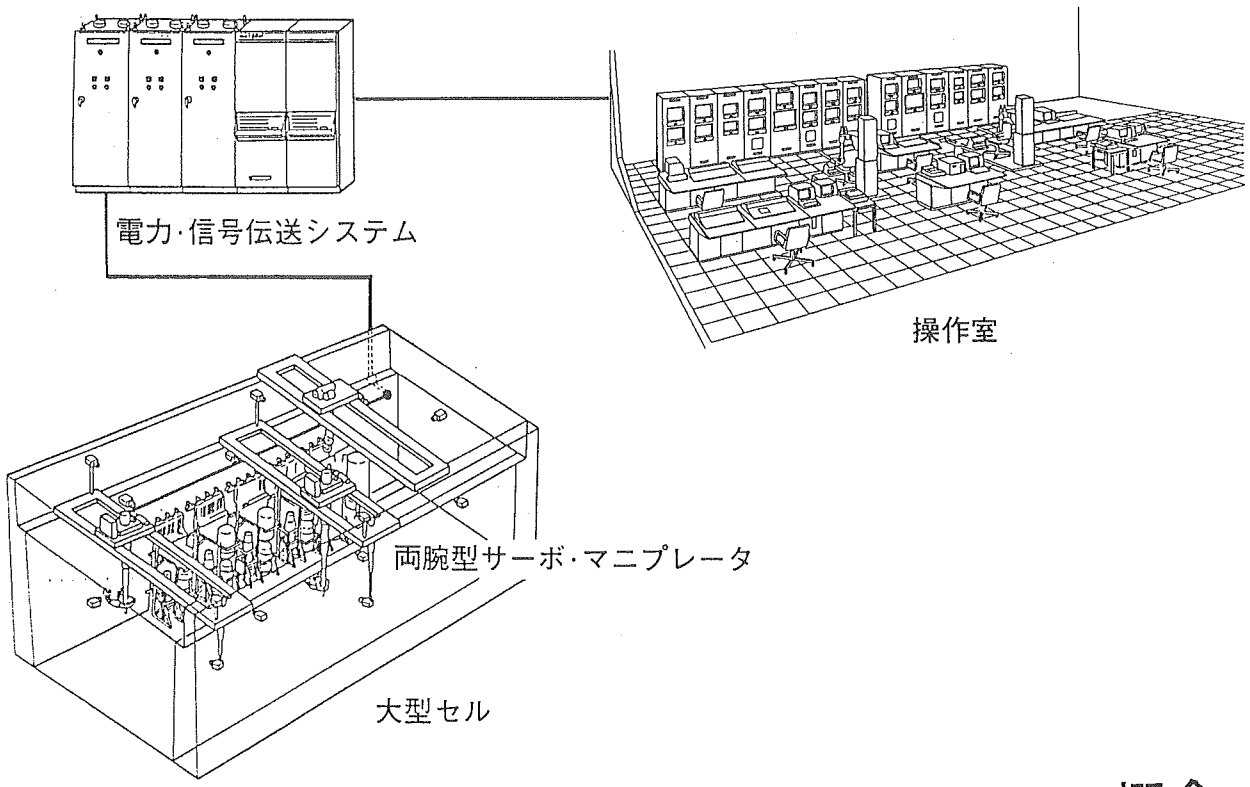
保守方法の系図

施設利用率の大幅向上
建設コスト&運転コストの低減
作業員の放射線被 暴量低減

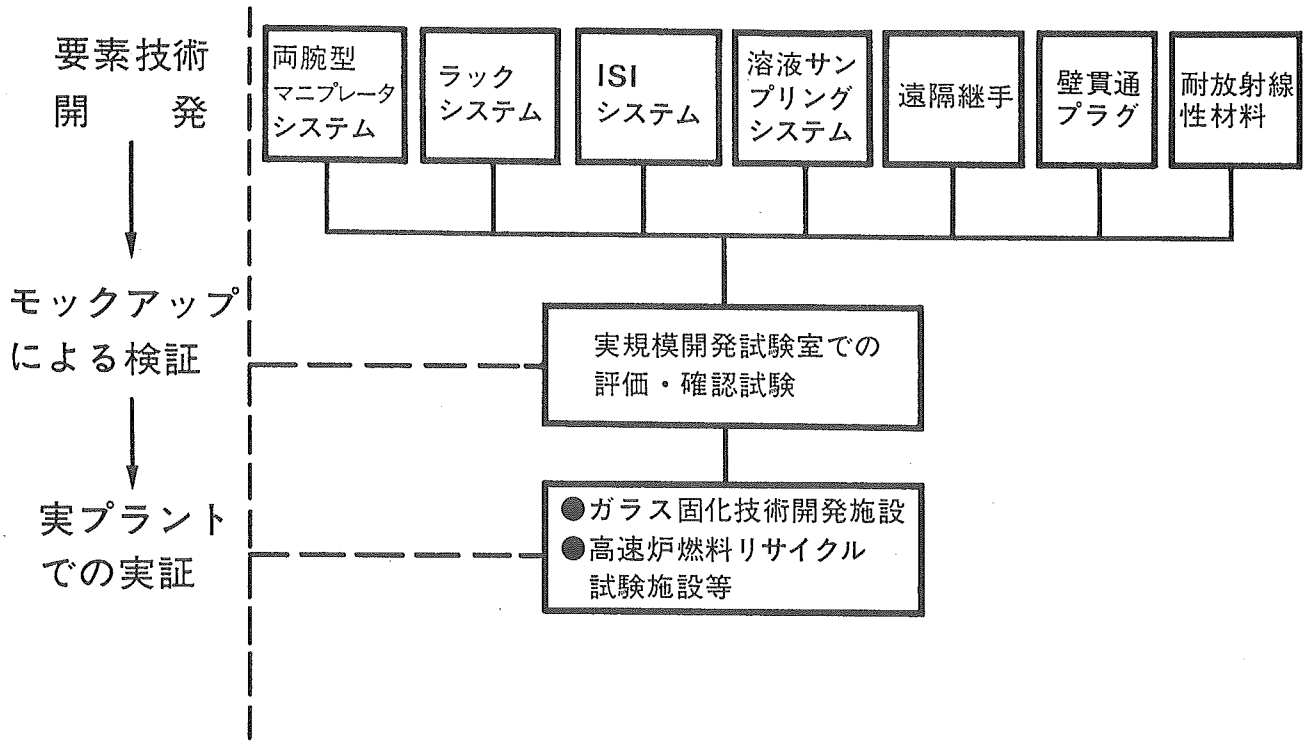
大型セル方式遠隔保守法の確立



遠隔保守システムを採用した
大型セル内断面図



大型セルを用いた全遠隔保守システムの概念



技術開発のステップ

両腕型サーボ・マニプレータの開発

○目　的

・セル内作業の全遠隔操作化

○開発項目

・操作性（バイラテラル機能，動作速度等）

・信頼性（耐放射線性，耐久性等）

・自己保守性

ラックシステム&遠隔継手の開発

○目　的

・プロセス機器類へのアクセス性

（点検・補修・交換等）

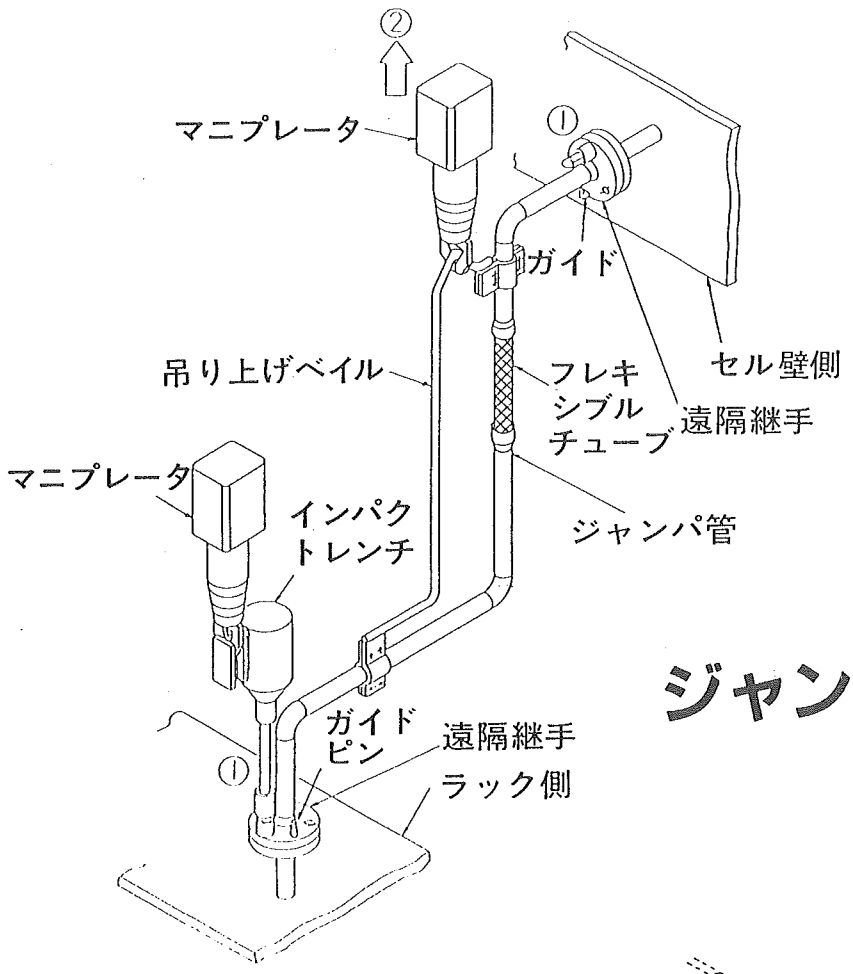
○開発項目

・耐震設計

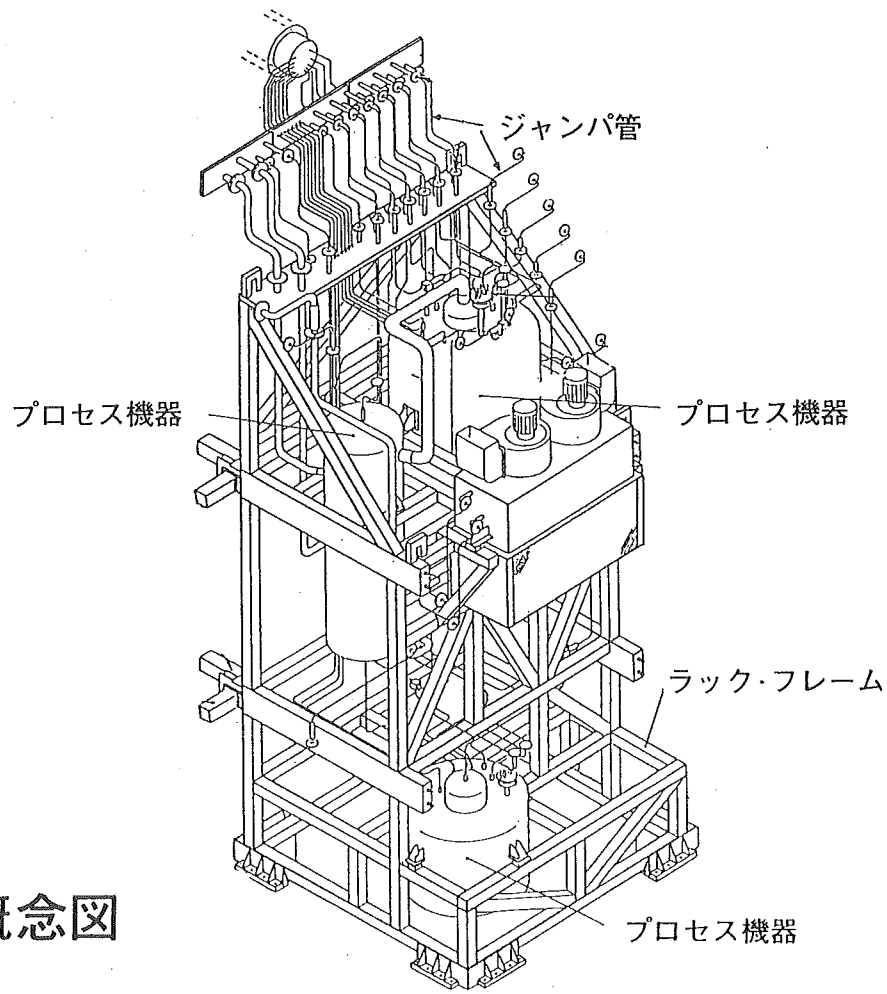
・マニプレータ，クレーンによる遠隔操作性

（ラック内配置，形状等）

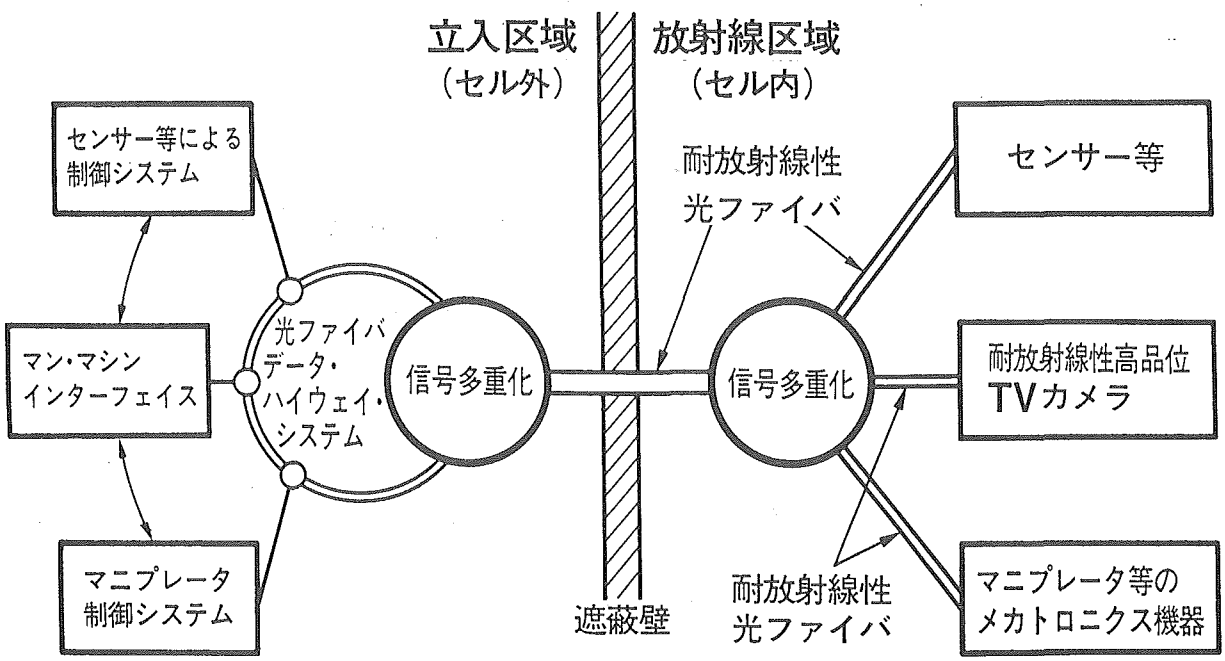
・継手の信頼性



ジャンパ管鳥瞰図



ラック概念図



耐放射線性光ファイバ信号伝送システム

耐放射線性光ファイバー信号伝送システムの開発

○目　的

- セル内ケーブル数の低減
- ノイズの低減

○開発項目

- 耐放射線性（光ファイバー，光電変換器等）
- マニプレータによる遠隔操作性
  （小型化，コネクタの着脱性等）

視覚システムの開発

○目　的

・セル内監視及びマニプレータ操作時の視認性

（高解像度，色再現性）

○開発項目

・高品位カラーTVカメラの耐放射線化

・電送ケーブル数の削減化

・小型・軽量化

核融合をとりまく新技術

（社）日本原子力産業会議

常任相談役　山本　賢三

1．核融合の概観

核融合の実現には物理の研究とともに全く新しい技術の開発が必須である。両者が車の両輪のようになって今日まで研究開発が進められてきた。ここではその諸技術について紹介したい。

Ｔ－ｎτ
（スライド１）

核融合の正味出力を得るには，重水素－三重水素混合燃料気体について，密度（ｎ）・閉込め時間（τ）の積と温度（Ｔ）とがある限界を越えなければならない。その限界は臨界条件といわれる。例えば10万～ 100万分の１気圧の密度をとればτ～１秒，Ｔ～１億度程度となる。さらに自己点火のおこる炉の条件はより高い値が必要となる。

実現の方法には２つの方式がある。磁気閉込め方式にはトカマク型，ステラレータ型，ミラー型などがあり，その中トカマクが最も優れた性能を示している。技術開発は主としてこの型に関連して行われている。他の方式は強力なレーザービームなどを使う慣性閉込方式であって，本日別の講演で紹介されるのでここでは触れないことにする。

研究実験装置
（スライド２）

核融合研究は，これまで各国とも主として中規模実験装置を建設して行われてきた。ＪＦＴ－２Ｍはその一例で，プラズマ断面は楕円形（70cm× 106cm）で，トーラス大半径Ｒ＝131cmという大きさである。

トカマクプラズマの比例則
（スライド３）

トカマクにおける（炉心）プラズマについての物理量の関係として，

（ｉ）　$\tau \propto n \cdot a$（プラズマ半径）$\cdot R^2$ であって，臨界条件のτ～１秒となるにはａ～１ｍ，Ｒ～３ｍ程度でよく，核融合が現技術で手の届くものであることがわかった。

（ii）　磁界（Ｂ）による閉込め効率β＝プラズマ圧力／磁気圧$\propto$プラズマ電流I_P／ａ・Ｂであって，β＝５～10%が実用・経済上望ましい。なお，Ｂ＝５Ｔで磁気圧は100 気圧となる。

（iii）　核融合出力密度$P \propto \beta^2 B^4$。出力を増すには物理の研究によるβの向上と技術の研究によるＢの向上とがある。

臨界プラズマ試験装置
ＪＴ－60
（スライド４）

臨界条件を満たすよう設計されたＪＴ－60は昭和60年に建設され目下実験中である。同種の米国ＴＦＴＲ，ＥＣ　ＪＥＴも同じく稼動中である。

以下で述べられる技術開発はＪＴ－60建設に関連して行われたものが多い。

2．ＪＴ－60用電源

閉込め用磁界発生とプラズマ加熱のために，制御のできるかってない大電力システムが開発された。

電源システム
（スライド５）

275kV 送電線より変電所，電動発電機，整流器を経てＪＴ－60装置に電力が供給される。全電力は1,300MW という巨大なものである。その中送電線からの直接受電は198MVAで，他はフライホイール付電動発電機３台（全貯蔵エネルギー８GJ）により10分間隔で10秒間放出されるパルス電力である。

中央制御室
（スライド６）

このような大電力が，実験の手順にしたがい，計算機による高速制御を行いつつ，実験装置に供給される。それに応じて計測される実験諸量に対する実時間データ処理が行われる。これらは全て中央制御室にて統括される。

フライホイール付
電動発電機
（スライド７）

貯蔵エネルギー４GJ(1,000kwh)という前例のない容量の電動発電機がつくられた。

フライホイール
（スライド８）

それにつけられるフライホイールは１枚 107ｔ，直径 6.6ｍの円板で，これが６枚重ねられる。

真空バルブ型
直流遮断器
（ＶＣＢ）
（スライド９）

直流遮断用に真空バルブ型のものが開発された。定格は25kV 92kAという高いもので，これによる直流遮断でおこる誘導起電力でプラズマ電流2.7MA を発生させる。この高性能は世界で高い評価をうけ，米国の核融合施設でも重用されている。直流送電技術としても有用な要素となろう。

大容量サイリスター
（スライド10）

外径15cm（ウェーハー10cm)，４kV，３kAという世界最大容量のサイリスターが開発された。これを全数 2,200個使用，設備総容量1,110MW という前例のない容量のサイリスターＡＣ－ＤＣ変換装置がつくられた。直流送電技術として有用であろう。

3．加熱技術

プラズマ加熱のやり方に中性粒子入射（ＮＢＩ）方式と高周波（ＲＦ）方式とがあって，何れも有効な方式として開発されている。

ＮＢＩ
（スライド11）

ＪＴ－60用にイオン源として35Ａという大電流のものが開発され，それに基づいて35Ａ×２，75kV加速のイオンビームをつくり，中性化し，その中性粒子ビームをプラズマに打込んで加熱する。その際余剰の中性ガスを吸収するため大容量のクライオポンプが使われる。ＪＴ－60ではこの加熱装置が14基装着されている。

イオン源
（スライド12）

このためイオン引き出し口径30cmという巨大なバケット型イオン源が開発された。これは工業用として目下材料や半導体の表面処理，改質，加工など各種応用に進展している。

ＩＶＤ
（スライド13）

イオンビームミリング
（スライド14）

大電流イオンビーム利用の一例として基板上にTiの蒸着とＮイオン注入を併用して表面に薄膜をつくる（ＩＶＤ，イオンミキシング）。これによって摩耗に強い表面となる。このほかにスパッタリングによる膜形成，半導体ウエーハーへのイオン注入，イオンビームミリングなど工業化している。

大電力クライストロン
増幅管
（スライド15）

ＲＦ加熱およびプラズマ電流駆動（current drive)として低域混成波（lower hybrid wave)が有効なことがわかり，2GHzで出力１MW（10秒）という大出力増幅管が開発された。電流駆動というのはトカマクのように定常電流の流れぬプラズマに電磁波を加えて直流を発生させることをいう。

ジャイロトロン
（56GHz）

別のＲＦ方式は，ミリ波領域の利用で，そのための発振管Gyrotronが近年盛んに開発されている。いま56GHz（波長約

（スライド16）

超電導マグネット付
ジャイロトロン
（スライド17）

5㎜）出力 200kWが完成されており，また 120GHz (2.5㎜)，200kW が開発中である。この球に強いソレノイド磁界が必要であって，超電導マグネットが役立っている。

以上のようなＵＨＦ，ミリ波領域で 100kW～1MW という大電力管が研究用につくられるようになったので，今後諸応用が見出されることになろう。

4．材料と加工

一般に核融合装置における材料は高熱負荷，強電磁力，14MeV 中性子照射に耐え，また低誘導放射能のものであることが望まれ，それらの研究・開発は今後いよいよ本格的に行われる。

低Ｚコーティング
（スライド18）

当面の問題としては，高温プラズマでは不純物が混入すると，その原子番号Ｚの３乗に比例する放射損失がおこるので，プラズマ容器内面用として，例えば表面を低ＺセラミックTiC（またはSiC，Cなど）で覆被したMo板ライナーをつかう。このコーティングは新たに開発されたプラズマＣＶＤ法によるもので，表面は極めて優れた耐熱性，耐食性，耐摩耗性をもつので，今後の工業上の応用が期待される。

ＪＴ－60真空容器内面
（スライド19）

ＪＴ－60の内面は上記でつくられた板が内張りされている。その他SiC と金属との大面積の接合技術に成功し，これはＭＨＤ発電用電極として極めて良好な性能を発揮している。また電磁力下用にすぐれた性能の非磁性鋼が開発された。これは磁気浮上列車などに有用である。

一方加工として，ＪＴ－60本体や架台のような厚物(150㎜級)の精密加工溶接のため110kW という大容量の電子ビーム溶接機がつくられ商用化された。

5．真　空

核融合装置は大容量且つ超高真空が一つの特徴である。

ヘリウム・スニファ
漏洩検出
（スライド20）

その場合重要な技術として極めて微少な漏洩の検出を可能とするHe-sniffer法が考案された。これはフレキシブルなＳＵＳ細管，モレキュラーシーブ封入のソープションポンプを経てHe-leak detectorを働かせるもので，検出感度は10^{-10}atm, cc/s程度で在来の 10^{3}～10^{4} 倍向上した。

セラミックポンプ
（図面と写真）
（スライド21，22）

真空ポンプとして大型クライオポンプ(10^{6}ℓ/s) がＮＢＩで多用され，技術経験を豊富にした。また磁界中で使用可能なセラミック回転体のターボ分子ポンプ(100ℓ/s) が試作され成功した。これは磁界中，耐熱，耐腐食，耐放射線などの長所があるので，今後応用が拓かれよう。

6．超電導

ＬＣＴ計画
（スライド23）

ＪＴ－60につぐ次期装置（実験炉）では通常導体に代って超電動マグネット使用となる。その準備として国際協力のＬＣＴ計画が進められている。寸法3.5m×4.5mという大型コイル６ケを参加国で夫々自作し持寄り，トーラス状に組み上げて各種試験を実施中である。

B_T コイル，B_P コイル，
パルスコイルの進歩
（スライド24,25,26）

核融合用超電導コイルは大型且つ強磁界が必要であり，その方向に段階的に開発が進められている。また時間的に電流の変化するポロイダルコイル，パルスコイルについても同様に計画的に性能向上が計られている。その延長として商用周波数に耐える交流用導体も近い将来実現することになろう。

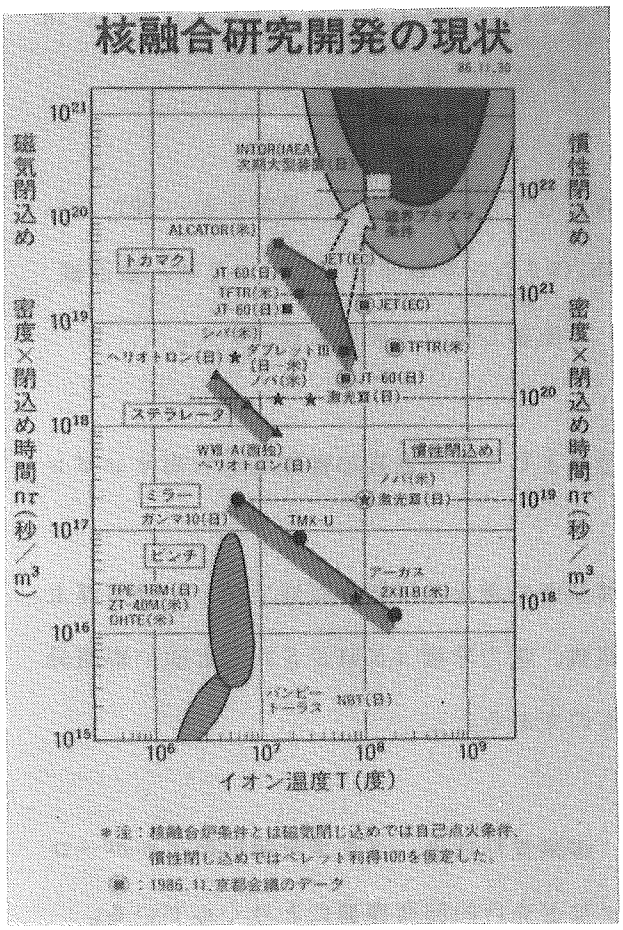
小型超電導トカマク （スライド27）	最新の超電導体であるNb_3Sn コイルのトーラス装置TRIAM-IMが世界ではじめてつくられ，運転中である。
$Nb_3A\ell Ge$の特性と 同テープ （スライド28,29）	次世代の超電導体としてはNb_3Sn より一段高いHc～30T, Jc～$10^4A/cm^2$をもつ$Nb_3(A\ell Ge)$ が有望視されるに至り，最近線材化（テープ状）に成功したので実用に近づいた。
	この他極低温構造材として世界最高の性能をもつ高マンガン鋼が開発された。 このような超電導技術の進歩は核融合だけでなく，磁気浮上列車，超電導発電機，電力貯蔵（ＳＭＥＳ）など広い応用分野に活かされるものである。

その他重要な技術として核融合炉用ロボット，遠隔操作技術，プラズマ解析用スーパーコンピューター，国際間コンピュータネットワークなど先行的開発課題にとりくんでいる。

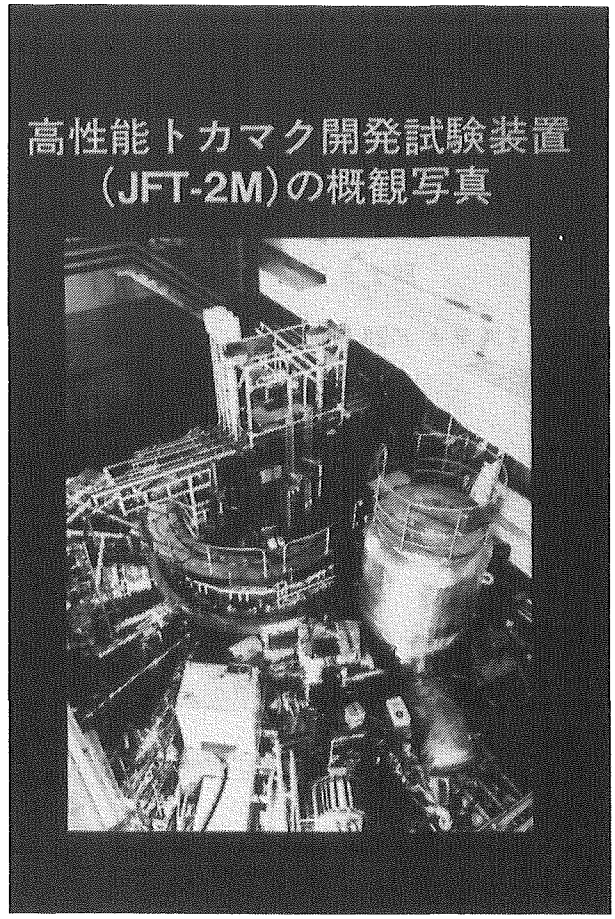
7．むすび

日本の核融合技術は産・学・官の協力により非常によく進展し，とくにこの協力における産業界の役目・特徴は世界で高く評価されるほどに発揮されている。また産業界の中での分担体制，協同作業も円滑に行われている。

以上の諸技術は核融合として固有に開発されたもののほか，他分野からの知識や協力により開発されたものも多いが，一方得られた成果はひろく核融合以外の分野に使われることになろう。その点で核融合はわが国の科学・技術一般の振興に役立ち，推進役をつとめるプロジェクトとみてよいと思う。



（スライド１）



（スライド２）

トカマクの比例則

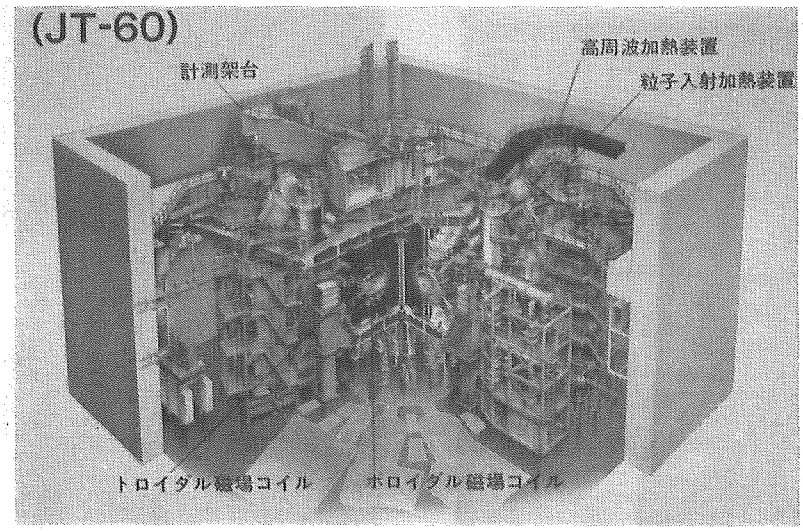
閉込め時間(τ)∝密度(n)・小半径(a)・大半径^2(R^2)・安全係数(q)

ベータ値(β_C)∝プラズマ電流(I_P)/小半径(a)・閉込め磁界(B)

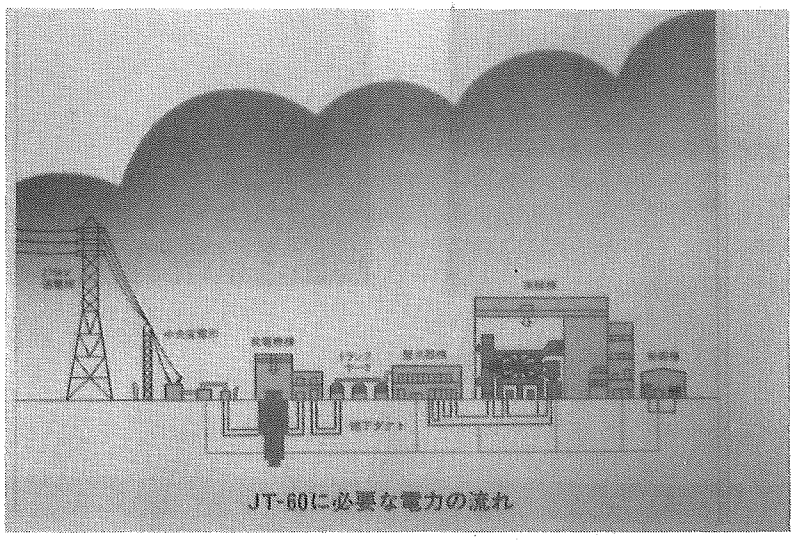
核融合出力(P)∝ベータ値^2(β^2)・閉込め磁界^4(B^4)/安全係数^4(q^4)

但し　$\beta = \dfrac{\text{プラズマ圧力}}{\text{閉込め磁気圧}} = \dfrac{nkT}{B^2/2\mu_0}$

（スライド３）

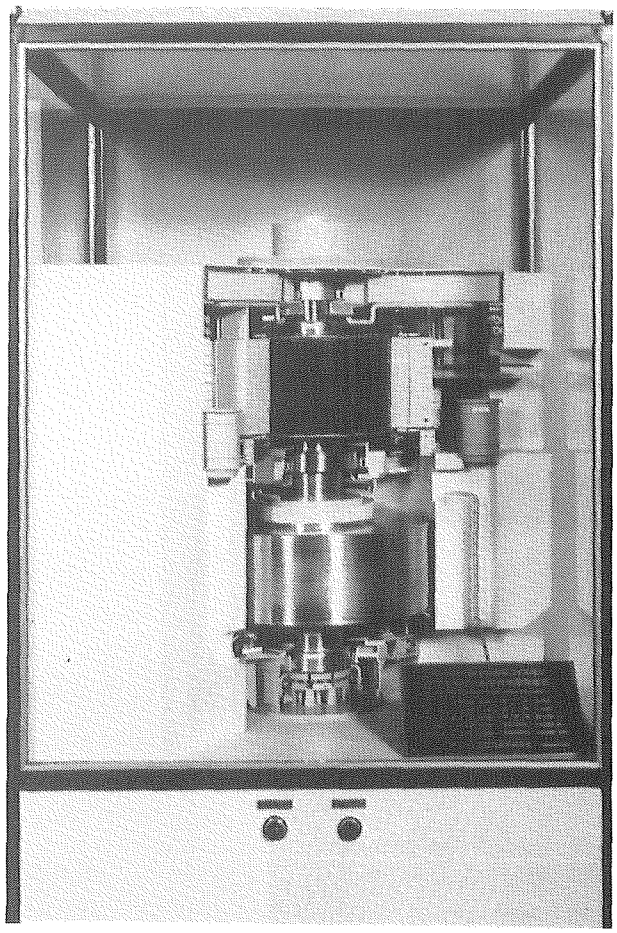


（スライド４）

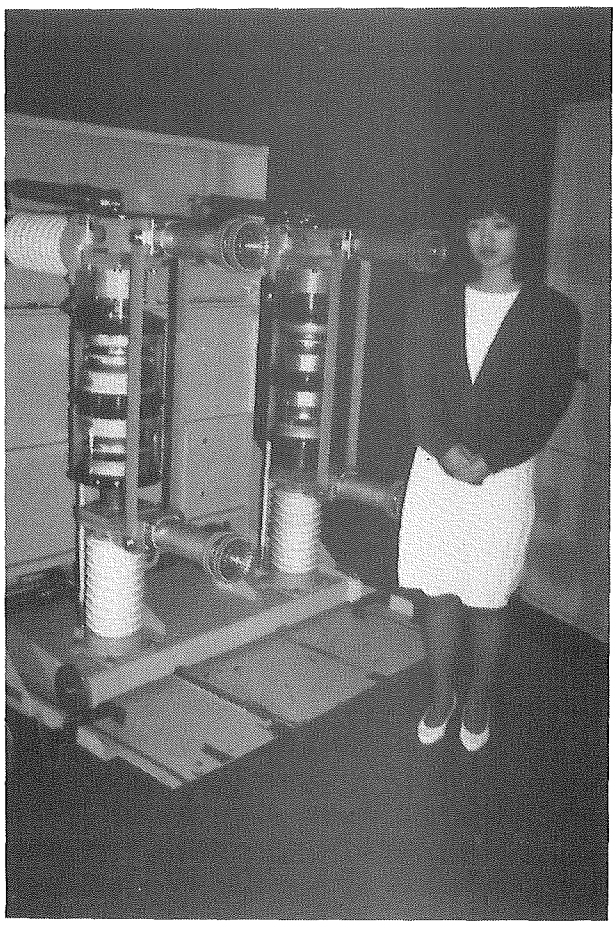


（スライド５）

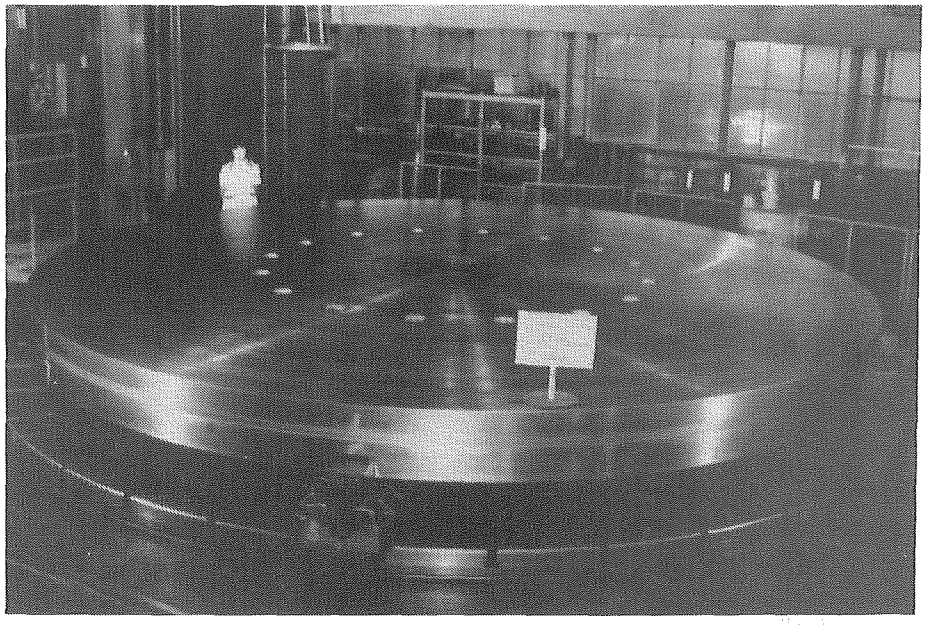
（スライド６）



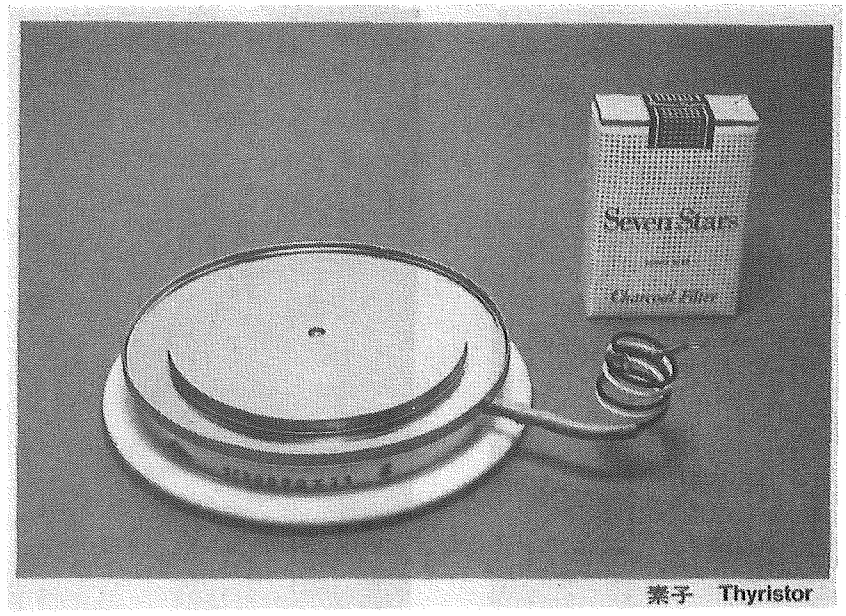
（スライド７）



（スライド８）



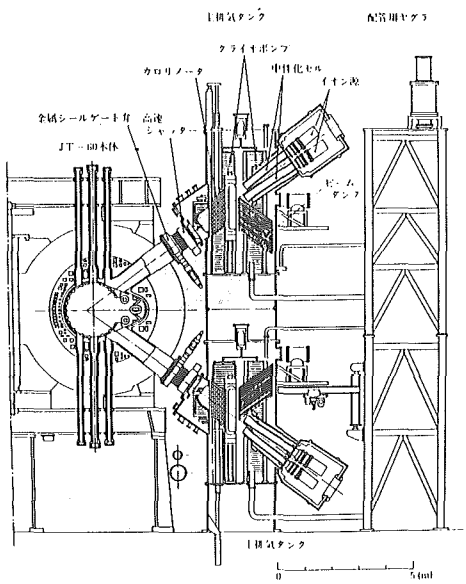
（スライド９）



（スライド10）

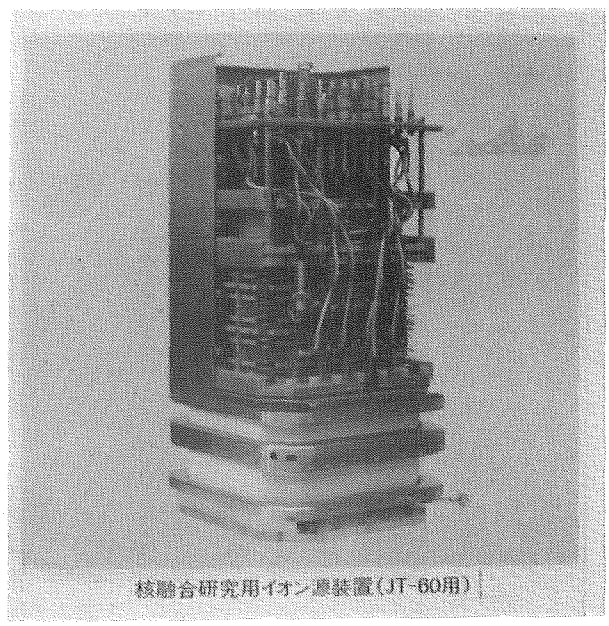
JT－60粒子入射加熱装置の主要諸元

中性粒子ビームエネルギー	75 KeV（50 －100 KeV可変）
全中性粒子ビーム出力	最大　20 MW
ビームパルス幅	最大　10 s
クライオポンプの排気速度	1,300,000 ℓ／s （1ユニットあたり）
粒子入射装置のユニット数	14 基

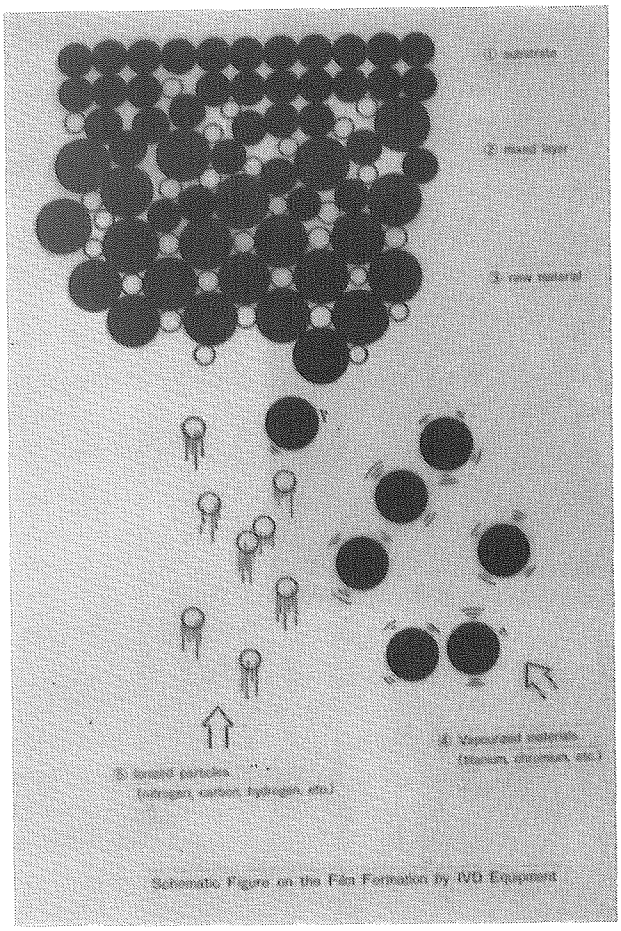


JT　60粒子入射加熱装置断面図

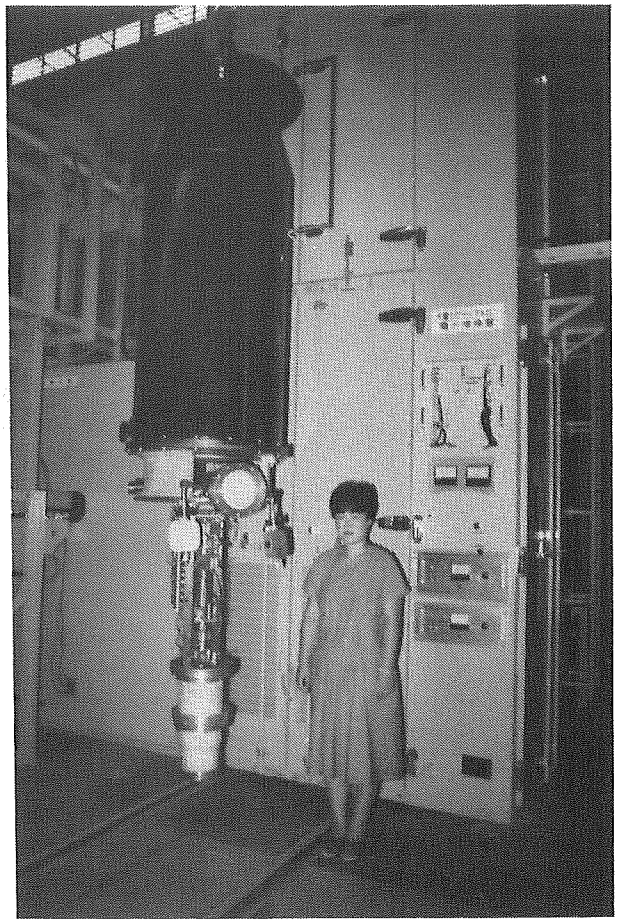
（スライド11）



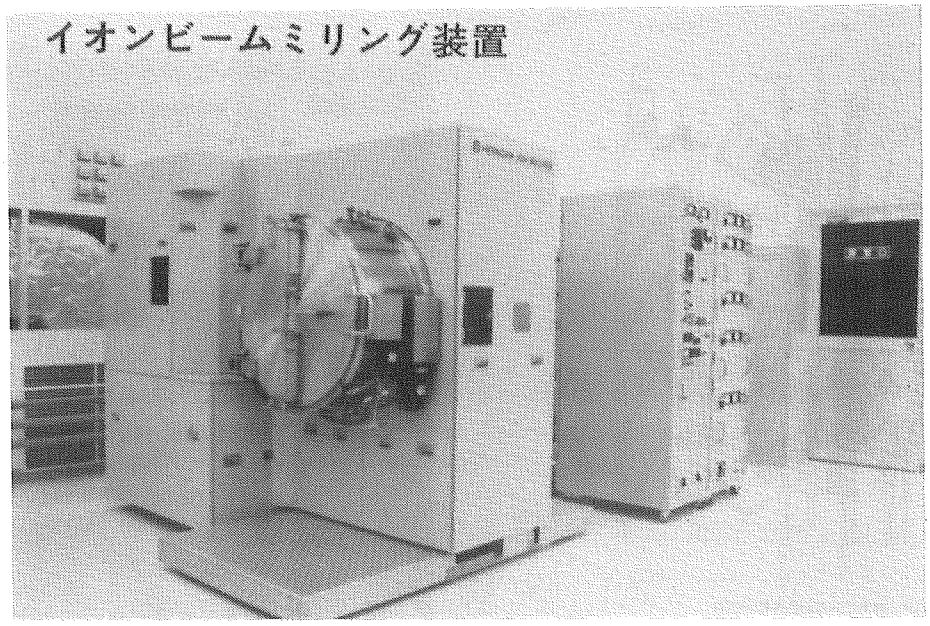
（スライド12）



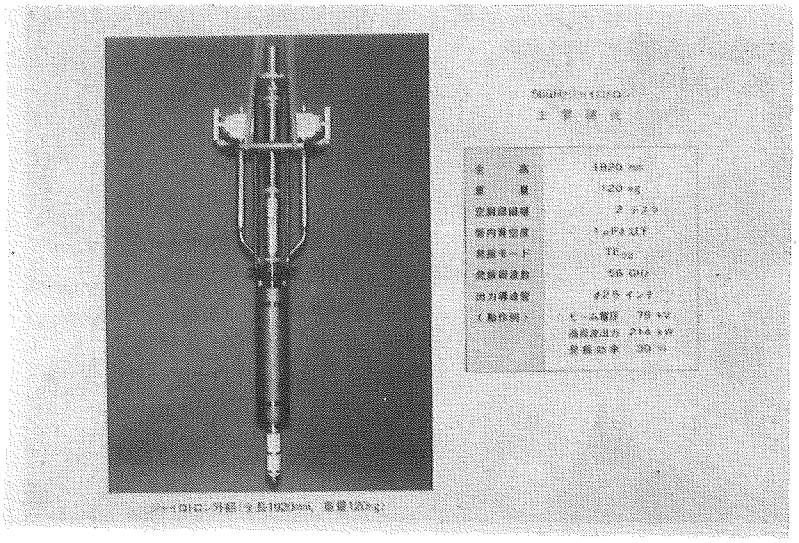
(スライド13)



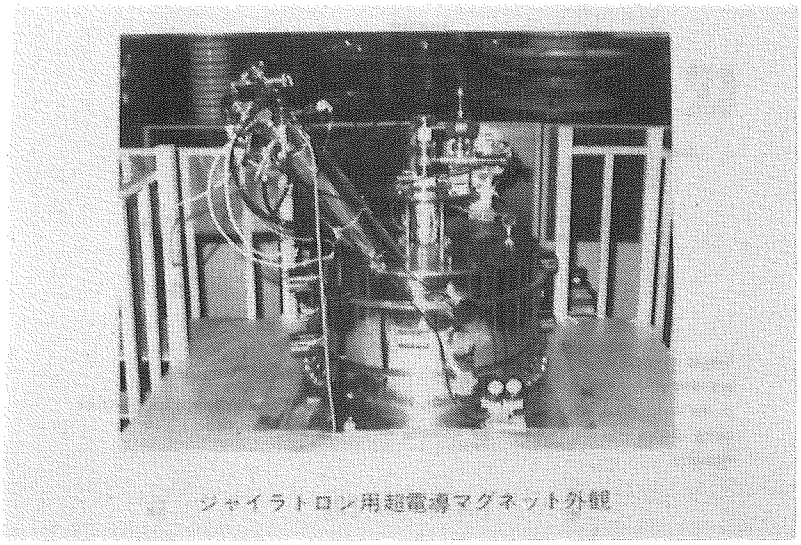
(スライド15)



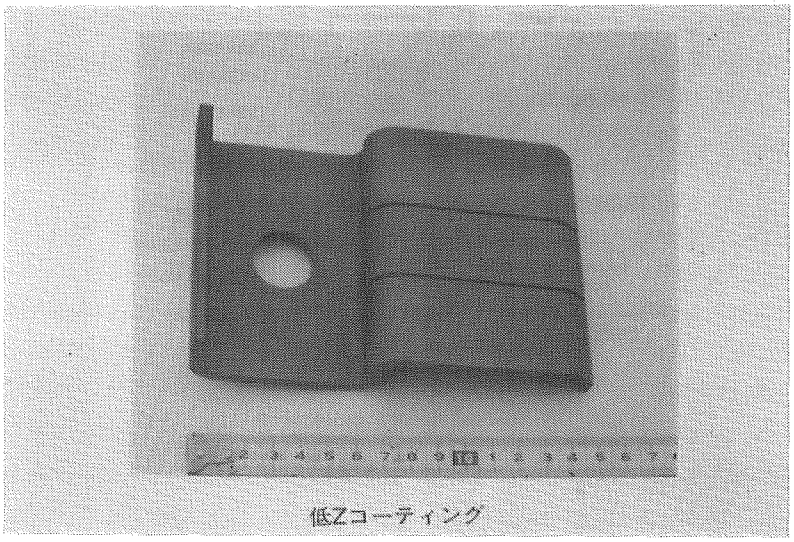
(スライド14)



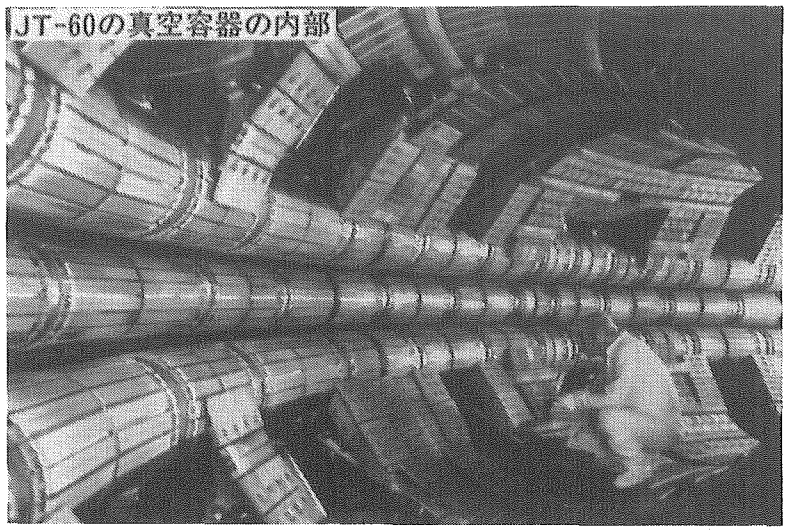
（スライド16）



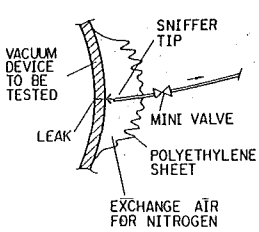
（スライド17）



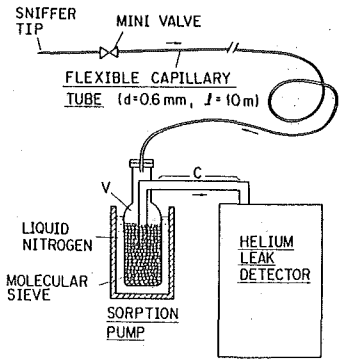
（スライド18）



(スライド19)

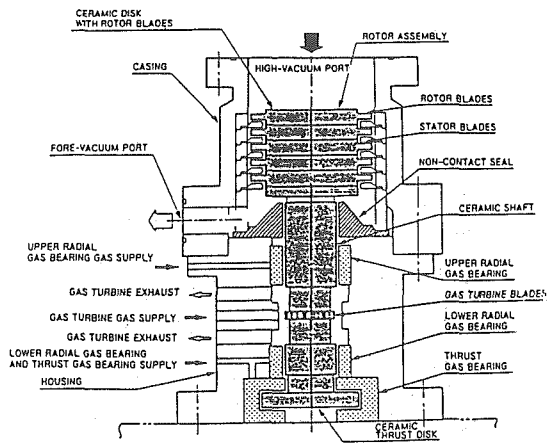


Simple method for preventing the helium in the natural air from being drawn into the detector.



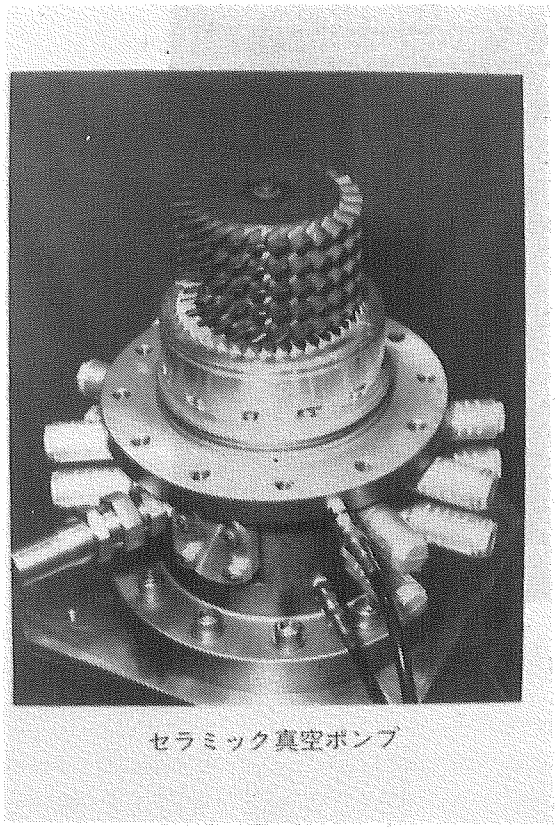
Schematic diagram of the new helium sniffing device for locating very fine leaks.

(スライド20)



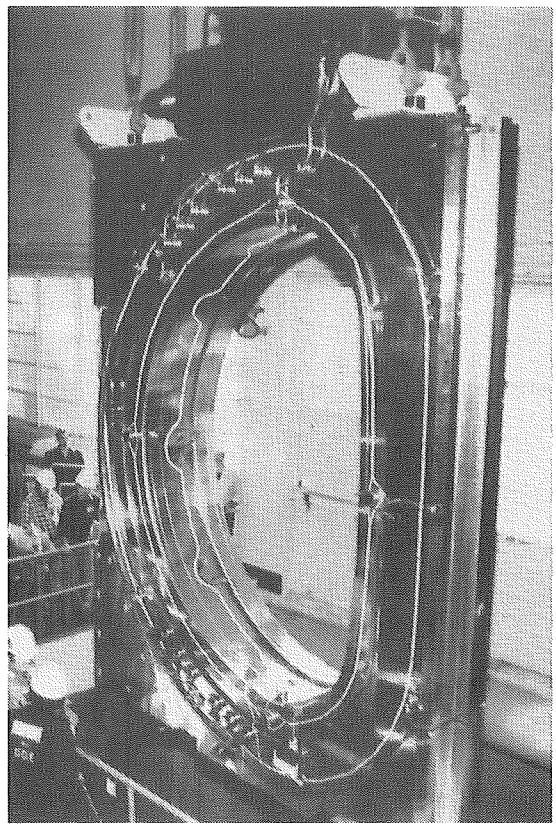
Cross-sectional view of the test machine

(スライド21)

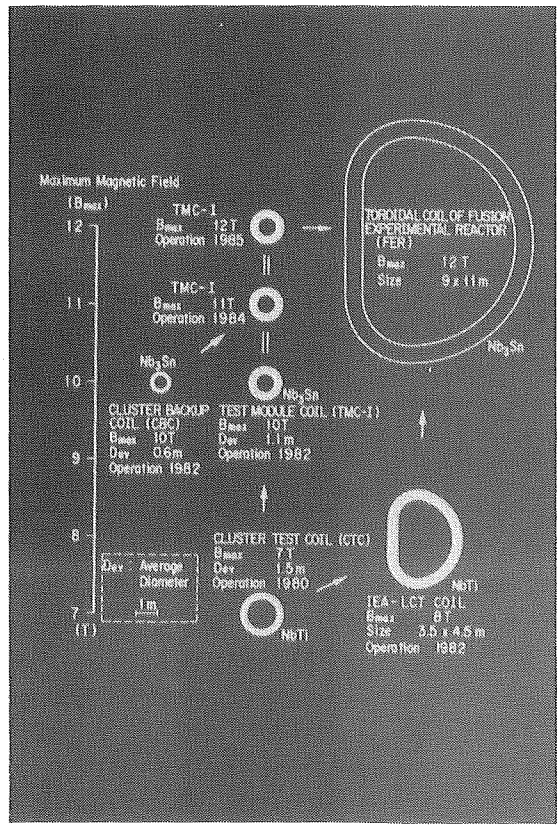


セラミック真空ポンプ

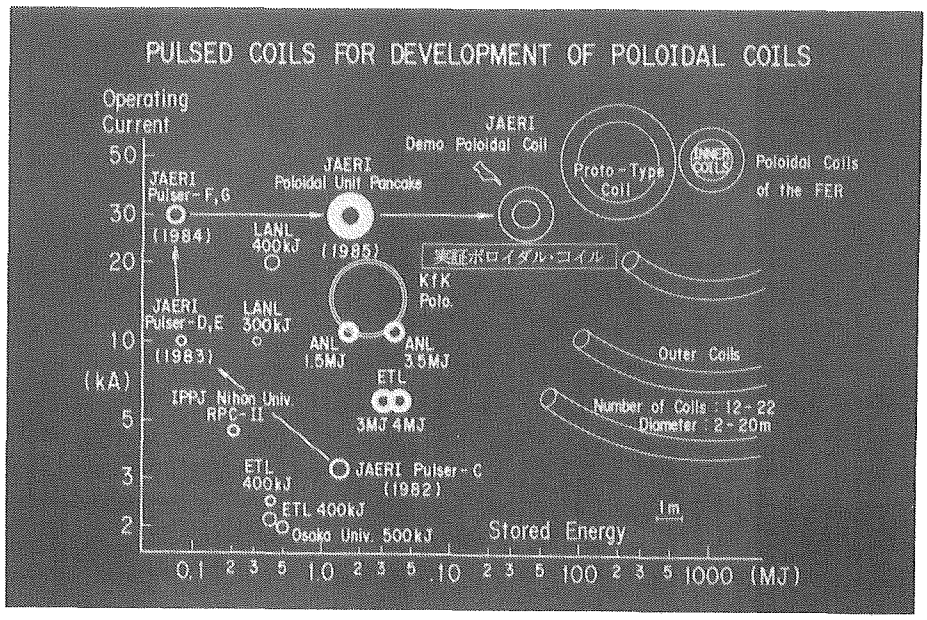
（スライド 22）



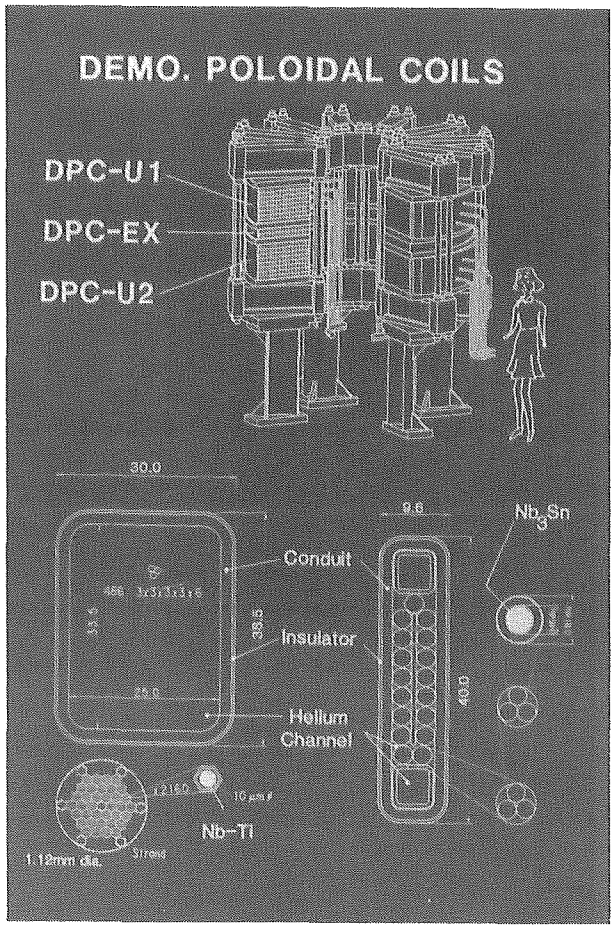
（スライド23）



（スライド24）

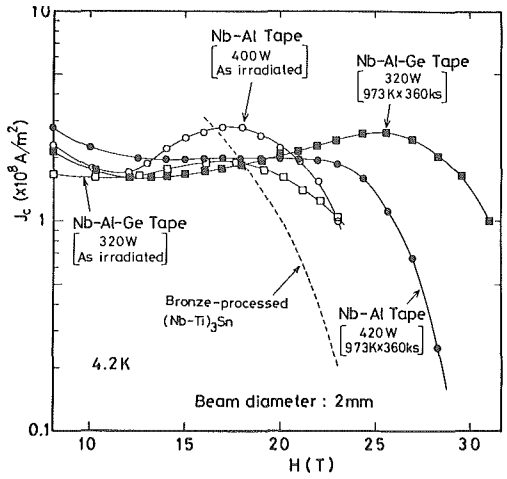


（スライド 25）

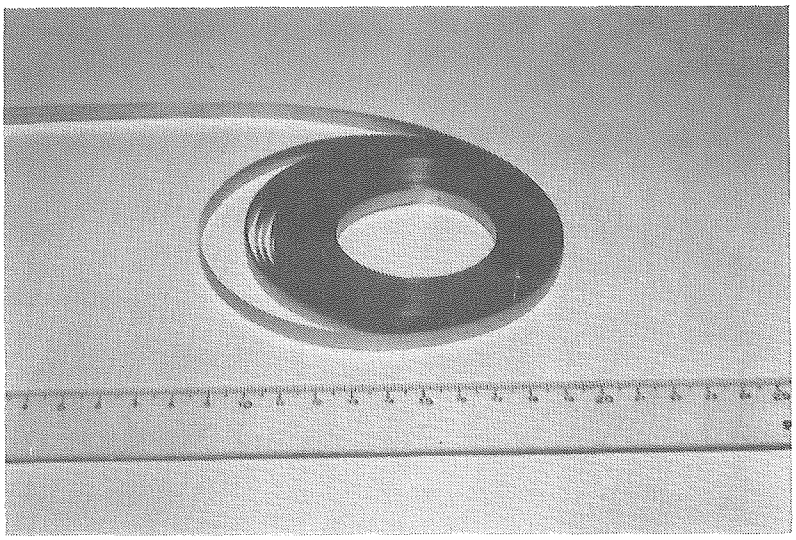


（スライド 26）

(スライド27)



(スライド28)



(スライド29)

レーザー技術と原子力利用

電気通信大学
教授　宅間　宏

初めてのレーザー発振がルビー結晶によって実現してから４半世紀余りを経て、レーザー技術はその深さにおいても、多様性においても著しい進歩を遂げ、すでに欠くことのできない社会的要素となりつつある。その応用分野を大きく分けると、小型でシステムに対する適合性に富む半導体レーザー等の応用分野である通信・情報処理・計測等と、比較的高出力のレーザーを必要とする加工・化学工業等への応用、広範囲のレーザーが多様に活用される医学への応用などが現実に重要となっている。いっぽうで、極限的高出力レーザーシステムを必要とする慣性核融合が近年顕しい発展を見せていることも、現在工業化の段階にあるレーザー法ウラン濃縮とともに、レーザーの原子力への利用として見逃し得ない意義を持つと考えられる。ここではレーザー技術の現状と展望の概略に触れた上で、この二つの重要な応用分野に関して論じることとする。

レーザーによって発生され、利用可能な波長領域は、波長数ミリメートルの遠赤外から、千オングストローム以下の真空紫外に及び、最近ではまだ初歩的段階で大型の高出力レーザーシステムが必要とはいえ、波長１００オングストローム程度の軟Ｘ線領域でのレーザー作用さえも確実に観測されている。

レーザーの種類も半導体レーザー、気体レーザー、固体結晶及びガラスレーザー、色素（液体）レーザー、さらには加速器による自由電子レーザーと、極めて多様である。さらにレーザー光のみに適用可能な非線形光学的効果の応用によるレーザー光のてい倍、混合などの操作によって、レーザー光の多様性が広げられている。

レーザーがこのように多様な応用分野を持つ理由は、その光源としての顕著な特質にある。すなわち、１．可干渉性に富み、２．回折限界に近い平行性を持ち、３．波長（周波数）巾が極めて狭い（単色性に富む）。これらの性質は、電磁波である光の波としての性質があらわに光が従来の高温の物体の発光と異なり、マイクロ波やラジオ波の発振器出力のように、連続的する純粋な正弦波に近い事を示している。波長はマイクロ波の数万倍分の一、したがって周波数はマイクロ波の数万倍なので、通信用の搬送波として数万倍の超高速が可能となることから、レーザー光の通信技術における重要性が理解される。光の波長

の短いことは光干渉計測の精度の高いことを保証するが、レーザー光を光源として用いれば、従来の光源、例えば波長標準として使われたクセノン放電管の輝線スペクトルよりはるかに明視度の高い干渉縞を容易に観測できるので、長さ測定の精度は容易に波長の１０分の１を越える。

光の記録は写真技術が使えることから極めて簡便であり、ホログラフィー等の画像記録や、フォトレジストによる半導体微細加工のような重要な応用分野が開かれているが、レーザー光はホログラフィーを実用のレベルに引上げ、また半導体のサブミクロン加工を実現するなど、画像処理の能力を飛躍的に向上した。高度の平行性を持つビームはまた無収差の短焦点レンズで収束すると、波長程度の直径まで小さく集光できる。したがって、レーザー光はバイナリーの情報を高密度で記録する能力を持つ。その最もポピュラーな例はコンパクトオーディオディスク（ＣＤ）である。またこのことは大規模なシステムによって発生する高出力レーザー光についても同様で、照射密度にして10^{18}W／cm^{2}以上の高照射密度を得ることができる。このような高照射密度下では、物質は高温のプラズマ状態となり、慣性核融合方式の根拠を与える。

レーザー光の第３の特徴である単色性は、分光学とその応用に関して極めて重要である。従来の分光法では、広い波長範囲のスペクトルを持つ光源を用い、モノクロメーターによって単色光を得る。このような光源では、分解能を上げるためにスペクトル巾を狭めるに従って光エネルギーが弱まり、自ずから限界が生じます。また、高分解能を得るには、モノクロメーターは余りにも大きく、かつ高価なものになって、非実際的となる。いっぽう、レーザー光はそのエネルギーが総て非常に狭い波長範囲に集中しているので、モノクロメーターを必要とせず、非常に高い分解能を与えます。そのような性質を巧みに使う事によって、ネオンサインのような低圧ガス放電管から放射される原子の輝線スペクトルよりはるかに鋭いスペクトル巾を観測することが可能となり、分光学の能力は飛躍的に向上した。このようにして、レーザー分光法はその超高感度、超高分解を活かして公害分析などで大いに活躍した。

レーザー分光法の工業的応用としては、まず核燃料の濃縮が挙げられる。すなわち、特定のアイソトープ、例えばウラン２３５だけにレーザー光を吸収させてイオン化することもできるので、レーザー出力を十分強くすれば核燃料の濃縮にレーザーを応用することが可能となる。このような分光学へのレーザーの応用が本格的になったのは、近赤外から可視・近紫外に致る広い領域を完全

にカバーできる波長可変の色素レーザーが開発されたからである。

ウラン濃縮を行なうには、先ずウラン２３５のスペクトル線にレーザー光の波長を合せてウラン２３５原子だけをエネルギーの高い状態へ励起し、励起状態だけが吸収してイオン化されるような波長のレーザー光によって電離に導き、正のイオンとなったウラン２３５をマイナス電極に電気力で引きつけ、凝固させる。この方法の大きな特徴は分離すべきウラン２３５だけにレーザーエネルギーが吸収されることで、たの方法が不用なウラン２３８を含む原料全体を熱したり高速回転したりするのと比べ、原理的に高効率である。通常は、３種類のレーザー波長によって３段階の励起を行ない、最終的に電離に導く。

このような原理によれば分離係数は１００％になり得るが、現実の濃縮プラントで必要なのは、軽水炉用の濃縮核燃料である。処理速度を高くすると、ウラン２３５のイオンとウラン２３８原子との衝突によって電荷交換反応が起き、回収されるウラン２３５の濃度が低くなる。このような効果と経済性とを考慮してプラントを設計することになるが、そのためにはレーザーによる励起や、電荷交換の速度を与える定数を正確に知っておくことが必要である。このようにウラン原子のスペクトルを用いるレーザー濃縮法をＡＶＬＩＳ　(atomic vapor laser isotope separation)とよぶ。

ＡＶＬＩＳに必要な色素レーザーの励起には、現状では励起効率が高く、１０ｋＨｚ程度の高速繰り返し発振が可能な銅蒸気レーザー（ＣＶＬ）が使われている。濃縮プラントの建設には、これらのレーザーの長寿命化、交換の容易なパッケージ化、維持費の軽減などが必要なことは言うまでもない。これらを考慮して遠心分離法との経済性の比較を行なった結果、ローレンス・リバモア国立研究所（ＬＬＮＬ）でＡＶＬＩＳを選択したことは、この方法が工業化の段階に発展したことを意味し、世界に大きなインパクトを与えた。ＡＶＬＩＳには、フランスが先ず熱心に取組む姿勢を見せ、我が国においても長期にわたる原研での工業試験研究のための準備研究の後、官民の協力によって研究が進められている。

いっぽう、ＡＶＬＩＳは非常に蒸気圧の低いウラン金属を３、０００度近い高温に熱してウラン蒸気を発生する必要があり、レーザーよりは原料加熱に電力を必要とする。その点もし六フッ化ウランのような分子が使えれば非常に有利となる。分子の振動スペクトルは顕著な同位体効果を示す。ウランの場合は同位体の質量比が１に近いため通常の気体では同位体の分子振動スペクトルの

分離は不十分であるが、ノズルから真空中に気体を噴出させて冷却することによって振動スペクトルを単純化すれば十分な分離が得られ、適当な方法があれば濃縮に応用する可能性は十分存在する。このように分子性気体を用いる濃縮法をＭＯＶＬＩＳ(molecular vaopor laser isotope separation)とよぶ。

ＭＯＶＬＩＳは工業化が可能ならばＡＶＬＩＳより高い効率が期待されるので、次世代のレーザー濃縮法と考えられ、研究されている。研究されるべき問題点は、①分子の振動スペクトルが存在する赤外領域の、工業化可能な高出力波長可変レーザーを開発すること、②赤外レーザー光を吸収した同位体分子を、工業的規模で効率よく分離する方法を開発することである。

ＭＯＶＬＩＳに適当な六フッ化ウランの分子振動スペクトルは１６ミクロンの赤外線であって、この領域で連続的に波長可変で高出力が期待されるレーザーは現在では知られていない。しかし、１０ミクロン領域で多数の発振線をもち高出力・高効率発振が可能な炭酸ガスレーザー出力によって、水素ガス中で誘導ラマン効果を起こさせれば、ちょうどよい波長の高出力赤外光を得ることが出来る。理化学研究所では実験的にこの方法でかなりの高出力の発生に成功しており、光源に関しては一つの解決法が見出されたと考えられる。

レーザー光を吸収した分子の選別法としては、多光子解離、すなわち一度に多数の光子を吸収して分子を分解させる方法が最も注目されている。この場合赤外光だけで分解する方法と、赤外光を吸収した分子を紫外線レーザーの助けを借りて分解する方法とが試みられている。現在、少なくとも実験室的規模では、分子を選択的に分解することは可能であるが、分解生成物をどのようにして回収するかが残された問題である。このことは分解の方法とも密接に関係しているので、総合的に検討する必要がある。振動励起状態の分子は化学活性が高いことを利用して分離する可能性もある。現在西独ではレーザー濃縮法を研究段階としてとらえ、分子法の研究に主力を注いでいる。

レーザー法による同位体分離は核燃料に限定されたものではない。特に水素と重水素は質量比が２と最も大きいので、分子を用いる同位体分離の対象としては最も適したものといえ、理研における研究実績が注目されている。その他、医学的応用として非放射能トレーサーとして用いられる同位体の分離にも将来の応用が期待される。レーザー濃縮を技術として広くとらえると、レーザー化学工業の１種と見ることが出来る。核燃料のように、単価の高い原料の生産、特に通常の方法では合成し難い医薬品などにレーザー光合成法が用いられる可

能性も期待されている。

慣性核融合はレーザーの原子力産業への応用の中でも、究極的なものと言えよう。現在研究されているレーザー核融合の主流は、球形の燃料ペレットの表面を高出力レーザー光の高密度照射によって高温プラズマ化し、その膨張の反作用で燃料球を圧縮（爆縮）し、固体密度の１，０００倍もの高密度状態にした上でその中心に核融合反応を点火し、燃料の大部分を燃焼させる。

このようなシナリオが実現されるには、①パワーについてもエネルギーとしても十分な出力を与えるレーザーが存在すること、②レーザー照射によって十分な爆縮を行ない得るだけの圧力が発生し得て、③ペレットの爆縮が最後まで安定に行なわれ、④爆縮された高密度の燃料の中心に核融合反応を点火し得ること、⑤核燃焼がペレットの大部分に広がることが必要である。さらに実用炉としての経済性が成立つためには、⑥レーザーの効率が、核融合によって発生するエネルギーの１部を消費するだけで十分なほど高いことが要求される。

先ず、レーザー光のプラズマへの吸収係数は、短波長の可視光あるいは紫外線領域のレーザー光に対しては高密度照射下でも非常に高く、燃料ペレットの内部を過熱せずに爆縮に十分な圧力を発生し得ることが実験的に示され、爆縮のシミュレーションコードも開発されている。最近の成果の中でも注目すべきものは、阪大において開発された高アスペクト比ペレットによる爆縮法で、多量の中性子を発生する、いわゆるスーパーショットを可能とする方法である。これは非常に薄いガラス球の内部にＤＴ固体燃料を封入したペレットを用いることによって爆縮速度を速めて燃料中心へ向かうショック波に合せることによって、10^{13}個以上の中性子を発生することに成功したもので、同様の成果はＬＬＮＬにおいても確認されている。

このようなスキームで１００ｋＪ程度の短パルスブルーレーザーによって点火実験が可能であると予測されている。問題はレーザー照射の均一性であって、ガラスの非線形光学効果によって不均一になり勝ちなガラスレーザー出力を、ペレット表面で如何に均一（１％以下）にするかが重要な課題である。均一照射を得るにはレーザーのビーム数が多いほど有利で、３６本以上が理想的とされるが、ビーム数が多いほどシステムが複雑となる。点火に続く段階では実際に利得を産み出し得る事を示す事になるが、そのためには新型の高利得ペレットを設計することが必要となる。

現在波長約１ミクロンの赤外線を発生するガラスレーザーシステムが主とし

て実験に用いられているが、プラズマの吸収率を高めるために、そのままの基本波でなく、第２高調波（0.53ミクロンの緑色光）あるいは第３高調波（0.35ミクロンの青色光）が用いられる。世界の主たる核融合研究用のレーザーシステムは、表１に示すようなもので、特に１００ｋＪ級の基本波出力（１０ビームの合計）を誇る世界最大の ＮＯＶＡ（ＬＬＮＬ）、第２位の３０ｋＪ級システム（１２ビーム）激光ＸⅡ（阪大）が他を圧倒している。その他、均一照射に有利な２４ビーム、出力５ｋＪのシステムとしてロチェスター大学の ＯＭＥＧＡ－Ｘ が注目される。

現状のガラスレーザーの効率はたかだか１％程度で、炉のエネルギー収支を保証し得るほど高くない。将来更に向上する可能性は十分残されているが、ガラスの非線形効果の影響を考えると、核融合用として理想的な新レーザーの開発が望まれる。現状では、波長２４８ｎｍの紫外線を発生するフッ化クリプトンエキシマーレーザー（ＫｒＦレーザー）が最も有望と考えられ、電気通信大学の定量的研究によれば１．５ＭＷ／ｃｍ^{3}以上の高密度電子ビーム励起で１２％の内部効率が保証される。また大容量のレーザー媒質を均一に励起し、高効率・高出力の可能なモジュールも開発されている。アメリカでは、ロスアラモス国立研究所（ＬＡＮＬ）で５ＭＪ級を目指してＫｒＦレーザーシステムを開発中であるが、その１部にターゲット実験の計画もある。

以上のようにレーザー技術はますます発展し、その応用分野も質・量共に充実することが予測される。その中でも原子力産業への応用は、これから大いに進展する見通しがつき始めている重要な領域である。今後の順調な発展のために、レーザー応用技術とレーザー自身の改良研究との両面を強力に推進する必要がある。

高エネルギー加速器：その技術と産業応用

高エネルギー物理学研究所
教授　　菊池　　健

高エネルギー物理学は物質の究極的構造や自然界に存在する基本的な物理法則を解明することを目的とする学問であり、高エネルギー加速器は不可欠の研究手段である。高エネルギー加速器やそれを用いる実験装置はそれ自身が最先端の科学技術の結晶であり、新しい加速器や測定器の建設は必ず技術的な開発をともなうものである。そのような意味で、高エネルギー物理学は過去の歴史においても、つねに新技術の開発を促進してきた。こうした開発の結果が、直ちに産業界の利益につながるわけではないが、長い期間で眺めると商品開発、市場の開拓、技術水準の向上など産業界の利益につながるのである。このような経済効果については、既にヨーロッパ合同原子核研究所（ＣＥＲＮ）の調査報告が提出されており、それによると過去３０年間に、ＣＥＲＮと契約したメーカーは、業種によって差があるものの、平均して契約額の約３倍の利益を挙げたと報告されている。

一方、加速器は元来、原子核や素粒子の研究手段として発明、開発されたものであるが、最近では、広い範囲の研究や応用に利用されている。サイクロトロンはかなり以前から、癌治療、放射性アイソトープ生産などに利用されており、電子リニアックは医学や非破壊検査などに使われている。近年、電子シンクロトロンやストーレジリングが放射光光源として利用されるようになり、現在、世界中で２０台近くの放射光専用加速器が稼働している。

高エネルギー物理学研究所で完成した大型加速器トリスタンにももちいられている。この加速器は電子と陽電子を反対方向に加速し、正面衝突させることによって超高エネルギーの素粒子反応を起こさせるものである。加速器全体は、リニアック（全長４００ｍ、エネルギー２５億電子ボルト）、入射蓄積リング（直径１２０ｍ、エネルギー６０～８０億電子ボルト）、衝突リング（直径９６０ｍエネルギー、３００億電子ボルト）から構成され、衝突リングの中で電子は時計まわりに、陽電子は反時計まわりに加速され、リング上の４ケ所に設けられた実験室で衝突する。実際には、電子と陽電子は小さいかたまりになって加速され、このかたまりは毎秒２０万回ぶつかりあうが、かたまりの中の電子と

陽電子が正面衝突するのは１日に数１０回程度である。電子と陽電子が衝突すると、それらは消滅してエネルギーのかたまりになり、直ちに数１０個の粒子を生成する。これらの粒子の飛跡やエネルギーを一瞬のうちに測定するのが測定器である。これらの加速器や測定器につかわれている新技術のいくつかについて報告する。

高エネルギー研の放射光実験施設（フォトン・ファクトリー＝光工場の意）は放射光専用加速器としては、現在、世界最大のものである。放射光の特色は従来のＸ線源や光源に比べて、波長領域が全域にわたっていること、輝度が１０００倍～１００００倍大きいこと、光の方向が鋭く揃っていることなどであり、その利用範囲は理工学や医学の全分野に及んでいる。放射光加速器は年間約２０００時間が実験に用いられており、採択する研究テーマも約３００件に及んでいる。今年中には、ビームライン１８本が整備されることになっており、そのうち４本は民間企業によるものである。放射光利用は今後ますます高輝度の光源が要求される傾向にあり、今後の加速器はアンジュレーターやウィグラーなどの挿入光源を多用するものになるであろう。それとともに、加速器のビームをより安定に長時間維持することが重要であり、そのためにはいくつかの技術的問題を解決しなければならない。それらの技術的な諸問題についても報告する予定である。

高エネルギー物理のもたらす技術のうちいくつかの例を挙げて説明する。

１．電磁石に用いる磁性材料

陽子シンクロトロンの建設に当たり、高磁場を得るための新しい鉄鋼材料を開発した。これは、炭素の含有量が通常の鋼よりはるかに小さいもので、炉から取りだして圧延をすると、圧延方向の透磁率μが５００以上という高い値が得られる。この材料を用いるとモーターやトランスが小型化されることになる。この材料はすでに市販化されている。

２．超伝導線材や超伝導の電磁石

すでに米国では超伝導シンクロトロンが稼動しているが、ここではトリスタンの実験装置に用いられている薄肉ソレノイドの例を示す。磁場はそれ程高くはないが、直径約３ｍ、長さ５ｍの大きさのものであり、測定器の性質上、薄いことが要求される。

３．リニアックや高周波加速装置の高周波空洞

４．超伝導の高周波空洞

５．大出力の高周波管（クライストロン）

高周波技術に関連して新しい技術が開発された空洞とクライストロンである。また、超伝導空洞についても世界水準のものが作られている。大出力クライストロンは連続出力１ＭＷのものが開発された。

６．真空材料と真空ポンプ

真空容器の製作には従来、ステンレススチールが使われていたが、これに代わってアルミ合金製の容器が開発された。熱伝導度が大きく、電子の加速器にはとくに有用である。

７．大量情報を処理する大型計算機とソフトウェア

８．大型液化器や低温技術

９．検出器用の新材料

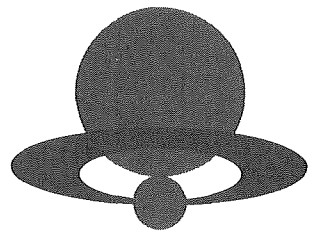
１０．耐放射線材料

１１．精密据付のための測量技術

トリスタンでは磁石の据付の精度は０．１ｍｍ程度であり、磁力線が全円周にわたって平行になるように、磁力線は地球の垂直線とは一致しない。将来の高輝度放射光リングではビームの安定性が必要であり、そのためには気温等の外的条件をも考慮することが必要である。

セッション5

燃料サイクル産業の課題と展望



＜基調講演＞

わが国における原子燃料サイクル事業の役割と課題

東京電力(株)副社長
豊田正敏

＜講　演＞

フランスのウラン濃縮事業の現状と将来展望

フランス原子力庁（ＣＥＡ）副部長
Ｊ．－Ｈ．コーツ

ウラン濃縮市場におけるウレンコの役割

ウレンコ社取締役
Ｊ．Ａ．バーライト

アメリカのウラン濃縮事業の最近の展開

米国エネルギー省（ＤＯＥ）次官補代理
Ｊ．ロングネッカー

再処理 — 競合性ある原子力エネルギーのための戦略

フランス核燃料公社（ＣＯＧＥＭＡ）副社長
Ｊ．－Ｐ．ルジョー

西ドイツにおける再処理の見通し

クラフトベルクウニオン社（KWU）副社長
W．ビュルクレ

イギリス・セラフィールドにおける酸化物燃料再処理

イギリス原子燃料公社（ＢＮＦＬ）副総裁
W．ウィルキンソン

回収ウラン転換産業

コミュレックス社会長
Ｊ．ペリシエタノン

混合酸化物燃料の課題 — 大規模利用へのアプローチ

コモックス社副社長
H．ベイリオ

混合酸化物燃料リサイクルの産業・技術側面

アルケム社社長
W．シュトール

わが国における原子燃料サイクル事業の役割と課題

東京電力株式会社
副　社　長
豊　田　正　敏

1．原子力発電の現状と展望

わが国の原子力発電は、本年中に３５基、２，７８８万ＫＷに達することとなるが、現在すでに、設備利用率７６％という、安定した高稼働を示しており、総発電電力量の３割を超える電力供給を行うものと予想される。

資源の乏しいわが国においては、原子力が、環境への影響も小さく、資源確保の確実性においても、電力供給の安定性においても、化石燃料に比べて優れており、かつ、備蓄、輸送が容易であるという特性を有するので、現時点では、最も優れた電源と考えられる。従って安全性、信頼性の確保に努めつつ、経済性の向上をはかり、今後とも、原子力をエネルギー開発の主軸と位置づける方針の下に、原子力発電量の比率を、２０１０年には５０％程度、２０３０年には６０％程度に高めることを目標としている。

原子力の開発に当たっては、ウラン資源の有効活用の観点から、ＦＢＲの実用化に努力していくが、ＦＢＲ実用化時期の見通しがやや遅れ、軽水炉時代が２１世紀中頃まで継続すると見られるため、当面、軽水炉の高度化をさらに進めることが肝要である。

2．原子燃料サイクル事業の役割と課題

軽水炉による原子力発電が成熟化時代を迎えたことに伴い、その長期安定運転を支えることが、原子燃料サイクル事業の重要な役割となっており、その産業基盤の整備が重要である。

わが国においては、原子燃料サイクルの主要な部分を海外に依存してきたが、エネルギーセキュリティ確保の観点から、海外依存の現状から脱却し、濃縮、再処理等各段階について、原子燃料サイクルの自立化をめざすこととし、当面、青森県六ケ所村の原子燃料サイクル３施設の建設を、積極的に推進している。

この推進に当たっては、発電コストミニマムをめざし、経済性、効率性を高め、国際競

争力を確保することに努めている。

次に各工程ごとに、事業化の進展状況と、具体的な課題について述べることとする。

（1）ウラン精鉱

ウランは、資源的には、世界的に十分な埋蔵量が賦存しているが、長期的な軽水炉需要に対応するため、着実な探鉱開発が継続的に展開されることが必要である。

わが国としては、１９９０年代後半までの所要量は手当ずみであり、新規手当はそれ以降必要となるが、調達に当たっては、セキュリティの観点から、供給源の多角化、および調達方式の多様化を進める考えであり、開発輸入の割合も増加させる方向で考えている。

現在、資源国が行っている、外国資本に対する投資制限や付加価値政策等は、開発輸入を阻害するものなので、その緩和ないし撤廃が望まれる。

（2）濃縮

わが国は、原子燃料サイクルの自立と濃縮役務のバーゲニングパワーを確保する見地から、濃縮役務供給の国産化計画を進めている。本年より２００ｔＳＷＵの原型プラントが運転を開始する。商業工場については、１９９１年運開を目途に、青森県六ケ所村に、１，５００ｔＳＷＵの第一工場を建設することとし、建設準備が進められている。第一工場に続き、第二工場を建設することにより、２０００年代初頭に、国内需要の１／３に見合う、３，０００ｔＳＷＵの供給を国産化する方針である。機種としては自主技術により既に確立した、遠心分離機を採用することとしているが、経済性向上の観点から、遠心分離機の高性能化のため、新素材を採用する遠心分離機の研究開発を進め、実用化の見通しが得られれば、これに切換えることとする。また、次世代技術としてのレーザー濃縮技術は、わが国では現在基礎的段階であるが、国際競争力の保持、テクノロジー・セキュリティー等の観点から、その開発を強化することとし、本年から研究組合を発足させ、技術開発に取組んでいる。１９９０年までに、実験規模（１～５ｔＳＷＵ）の試験を行い、その成果によっては、２０００年代の初め頃には、実用化に持込みたいと考えている。

ウラン濃縮分野は、厳しい国際競争の下にあり、核不拡散の問題もあることから、国際協力の推進には、困難が伴うことが予想されるが、わが国を含めて技術保有国が、開発の効率化のため、協力を進めていくことは、望ましいことであり、今後、開発効

率化のための国際協力を進めていくための具体的方策があれば、講演者から提案されたい。

なお、国産供給分以外については、原子力推進の自主性が阻害されない限り、今後とも、国際的配慮と経済性の観点から、海外調達を進める考えである。

（3）成型加工

わが国の成型加工事業は、国際的に最高品質の供給を行うまでに定着化しているが、いかにコストダウンをはかり、海外との価格差を解消するかが緊急の課題といえよう。

このため、炉心管理をはじめ、燃料設計、製造工程、検査方法、生産体制にいたるまで、メーカーとユーザーが協力し、効率化の方策を追求する必要がある。

（4）再処理

わが国は、ウラン資源を準国産エネルギーとして有効活用する観点から、また、使用済燃料を安全に処理するという観点から、再処理を基本路線としてきている。

現在のウラン価格、再処理費などを前提にすれば、極端なインフレのない限り、ＦＢＲの実用化の時期までは、再処理するよりも貯蔵しておいた方が経済的に有利である。

しかしながら、上記の考え方に加えて、ＦＢＲ実用化に向けて、再処理技術、プルトニウム利用技術、ならびに高レベル廃棄物の適切な処理処分技術を確立するため、適当量の再処理が必要である。

以上の点を考慮すれば、再処理することを基本路線とするが、一部使用済燃料を一時貯蔵するなどのオプションを含めて、柔軟に対処することが望ましい。

このような考え方の下に、青森県六ケ所村に、年８００ｔの民間第一再処理工場を、動燃東海工場での貴重な経験を生かすとともに、仏・英・独の技術協力を得て国内メーカーの自主技術を活用することにより建設する。現在、用地取得を完了し、立地調査を進めるとともに、仏ＳＧＮ社と技術援助契約を締結し、基本設計を開始している。民間第一再処理工場を設計、建設、運転することにより、再処理技術をわが国に定着させることを意図しているので、技術協力を要請している各国が、今後とも、長期的な協力をされるよう期待したい。

国産再処理能力で賄えない使用済燃料の再処理のため、ＢＮＦＬ、ＣＯＧＥＭＡに合計４，６００ｔｕの再処理を委託しているが、今後は、国産再処理能力で賄えない使用済燃料については、原子力発電所での一時貯蔵のための貯蔵容量の増大、民間第

一再処理工場附属の貯蔵プールの拡充、またはドライキャスクによる貯蔵で、対処することを考えているが、一部使用済燃料の海外委託の追加も検討されることとなろう。

再処理については、自主技術を確立し、プルトニウム利用の経済性向上をはかるため、技術開発およびそれによるコストダウンがとりわけ重要である。また、高燃焼度燃料およびＭＯＸ燃料の再処理技術の開発をはかる必要がある。再処理の経済性向上のためには、稼働率の向上が最も重要であり、そのための具体的方策として、機器信頼性の向上、運転・保守技術の高度化、環境安全を配慮した合理的運転停止基準等が、必要と考えられるが、これについて、ＢＮＦＬ、ＣＯＧＥＭＡ、ＫＷＵより、見解を述べられたい。

民間第二再処理工場の建設時期については、一応、２０１０年頃を目途とするが、ウラン価格、再処理費の見通し、今後のプルトニウムの需要動向、使用済燃料貯蔵動向、高燃焼度化の進展状況等を総合勘案し、決定すべきであると考えている。

（5）回収物質のリサイクル

回収プルトニウムは、利用効率が最も高いＦＢＲで利用することが望ましいが、ＦＢＲの実用化時期が先に延びることから、その実用化までの間、ＡＴＲおよび軽水炉において利用することを考えている。プルトニウムリサイクル実施規模は、プルトニウムバランスから見て、１９９０年代の後半に、合計１２基程度の軽水炉において、各炉心の１／３に、ＭＯＸ燃料を装荷することになる見通しである。

このため、軽水炉でのＭＯＸ燃料体の特性の確認、ならびにＭＯＸ燃料の加工および取扱い経験の蓄積を目的として、先ず、ＢＷＲおよびＰＷＲそれぞれ１基に、２～４体のＭＯＸ燃料体を装荷し、経験を積むこととする。その後、更に、ＢＷＲおよびＰＷＲそれぞれ１基に、最終装荷規模約１／４炉心のＭＯＸ燃料体を装荷して、実用規模での経験を蓄積する。これらの経験を経て、１９９０年代後半に、軽水炉での本格利用に進むことを考えている。

このプルサーマルを実施するためには、英仏から日本への回収プルトニウムの輸送が、国際協定にもとづき円滑に行われることが課題である。

ＭＯＸ燃料の成型加工については、動燃が、ＡＴＲ、ＦＢＲ用として、８０ｔの製造実績を持っており、さらに、ＡＴＲ実証炉用として、年４０ｔの能力の工場を建設中である。プルサーマル本格化時期には、年１００ｔＭＯＸの成型加工が必要となるため、国産工場を、民間事業として、建設する方向で検討を進めている。

ＭＯＸ燃料の成型加工コストは、ウラン燃料に比べ相当割高になると予想されるが、軽水炉リサイクルの経済性達成を確保するため、技術開発によりコストダウンをはかることが課題である。この分野で経験の深いアルケム社およびコモックス社から、技術開発および今後のコスト動向について、説明をお聞きしたい。

一方、回収ウランについては、ＭＯＸの母材としての利用、再転換再濃縮、ブレンディング、および当面一時貯蔵の何れかによることが考えられる。

回収ウランの再転換再濃縮については、放射能対策および製品管理上の観点から、転換工場、濃縮工場で、天然ウランフィードと運転系列を別にしなければならないかどうか、また、運転を別系列とすればコスト増につながるか、という問題がある。更に、回収ウランに含まれるウランの同位体元素Ｕ－232 、Ｕ－236 が濃縮されること、特に、Ｕ－236 は中性子吸収体であるので、反応度を補償するため、より高い濃縮度のものが要求されるという問題がある。一方、ブレンディングの場合については、濃縮役務量が相対的に多くなるという問題がある。したがって、これらの問題点について、今後技術的経済的検討を行った上で何れによるか決めることとしたい。

この点について、コミュレックス社、ＢＮＦＬ社、ＤＯＥおよびウレンコ社より技術的経済的見通しと、役務提供の可能性について説明されたい。

3．課題解決の方向性

以上、わが国における原子燃料サイクル事業の現状と課題について述べてきたが、ここで、国際的視野に立って、課題解決への対応について述べてみたい。

（1）技術開発

原子燃料サイクル事業は、その信頼性、経済性を高め、国際競争力のある事業として育成に努める必要がある。この事業は、技術集約的である反面、事業施設の建設機会が限られているため、事業の成熟とコストダウンをはかるためには、技術開発を積極的に進めることが必要である。このため、テクノロジーセキュリティの見地から、自らの技術開発力を高め、継続的に自主技術開発を進めるとともに、可能な限り国際的な技術交流により技術レベルの向上をはかることが望ましい。

（2）経済性の確保

原子燃料サイクルコストが発電単価に占める割合は、他の火力発電等に比べ、相対的

に低いとはいえ、原子力発電の経済性を高めるには、原子燃料サイクルコストの低減が大きく貢献する。

経済性を確保する第一の方策は、技術開発を先行的に実施し、その成果を、プラントの建設運転の効率化に、充分反映させることである。

経済性確保の方策の第二は、的確な需要予測にもとづいた設備投資を行うことにより、過剰投資を回避することである。このため、需給両者による緊密な情報連携が望まれる。

（3）安全およびパブリック・アクセプタンス

昨年のチェルノブイル原子力発電所事故の例に見られるように、原子力事故の影響は、広く国際的な悪影響をもたらすものであり、原子燃料サイクル事業における事故もその例外ではない。したがって、各国の事業者は、安全性の確保及び、環境保全のための放射能放出量低減を最重点として、事業運営に当り、所要の技術開発を進めるべきである。

なお、事業者相互に、安全技術、安全運転管理手法や、放射能放出量低減方策に関する情報交換を行うこともその一助となろう。

（4）政府間の協力

原子燃料サイクル事業の運営に当たっては、核不拡散政策に対する充分な配慮が必要である。このため、現在、核不拡散条約にもとづき、核不拡散政策を実施する枠組みとして設けられているＩＡＥＡによる保障措置体制の機能を充実し、運営を効率化することが重要であり、これに対する各国政府の協力が望まれる。

以　上

ROLES AND TASKS OF NUCLEAR FUEL

CYCLE INDUSTRY IN JAPAN

Masatoshi Toyota

Executive Vice President

The Tokyo Electric Power Co., Inc

1. Current Status and Outlook of Nuclear Power Generation:

This year, our country will have 35 nuclear power plants with a capacity of 27,880 MW. The current plant capacity factor has surpassed 76% which indicates the very stable and high performance of the reactors. With such capacity and capacity factor, nuclear power will supply more than 30% of total generated electricity.

In a country with scarce indigenous resources, we see in nuclear power many advantages such as less influence on environment, more national security in the supply of resources, and stability in the supply of electricity. Nuclear is superior to fossil fuel in all these aspects and furthermore it has the good characteristics of easy transportation and storage, making it the most superior electric power resource at the present. Therefore, we will continue the policy of placing nuclear power in the mainstream of energy development and have set our target to increase the ratio of nuclear power supply to about 50% by the year 2010, and to about 60% by 2030, bearing in mind to continue our efforts for the improvement of the economics of nuclear power, securing in parallel its safety and reliability.

In promoting nuclear power development, we need continued efforts toward the commercialization of a fast breeder reactor with a view to the effective use of uranium resources. However, given the outlook that FBR commercialization will be somewhat delayed and light

water reactors will continue to play major roles until the middle of the 21st century, it is essential to aim at further improvement in light water reactors.

2. Roles and Tasks of Nuclear Fuel Cycle Industry:

As the nuclear power generation by LWRs has reached maturity, the maintenance of its long and stable operation has become an important role for the nuclear fuel cycle industry, and it has become important to establish its industrial basis.

The nuclear fuel cycle of Japan has been depending upon overseas suppliers for major parts, but from the standpoint of attaining national security in energy, we have to free ourselves from dependence on overseas, and are now aiming towards establishing independence in respective steps of the nuclear fuel cycle which includes enrichment and reprocessing. We are now at the stage of promoting the plan to construct three nuclear fuel cycle facilities at Rokkasho-mura, Aomori Prefecture.

In promoting this, the goal of the industry is to attain minimum generation costs while exerting our best efforts toward improving the economics, and efficiency, as well as achieving competitiveness.

Next, let us take a look into the current status of industrialization and specific tasks in respective steps of the nuclear fuel cycle.

(1) Uranium Concentrates:

Although there seems to be sufficient reserves of uranium to meet global demand, it is necessary to continue steady exploration and development activities in order to satisfy the long-term demand for the LWRs.

In Japan, uranium requirements up to the second half of the 1990's have been secured and new commitments will be needed from then. We are looking into diversifying uranium sources and the mode of supply, and are moving in the direction to increase the proportion of our imports from Japanese joint-ventures overseas.

From such aspects, the foreign investment restrictions and upgrading policy in countries with natural resources are desired to be abolished or at least eased since these hinder the activities of joint-ventures overseas.

(2) Enrichment:

For the purpose of creating a domestic nuclear fuel cycle industry and to increase Japan's bargaining power in negotiations with overseas suppliers of enrichment services, plans for establishing domestic supply source of enrichment is under way. A 200tons SWU per year demonstration plant will start partial operation this year.

As for the commercial plants, construction of the first plant with a capacity of 1,500tons SWU per year is to be constructed in Rokkasho-mura, Aomori Prefecture, and preparatory works are on their way for the start of partial operation in 1991. A second plant will be built to succeed the first plant, and Japan will produce 3,000tons SWU per year domestically in the first several years of the 21st century which corresponds to about one-third of domestic SWU demand.

The centrifuges which has been developed through indigenous technology will be used there. From the standpoint of improving the economics, research and development of centrifuges using new materials for betterment of performance is being promoted. And the improved centrifuges will be installed instead of the present ones, once proven to be commercially feasible.
In addition to this, development efforts of the laser enrichment as a next generation technology is being reinforced from the standpoints of maintaining international competitiveness, technology security, etc. although our laser technology is still in its basic stage, and a new organization LASER (Laser Atomic Separation Engineering Research Association)has been formed early this year to deal with its technological development in Japan. We expect that a test of 1 - 5tons SWU scale will be conducted by the year 1990, eventually to proceed to commercialization by the early 2000's depending on the test results.

Although difficulty is expected in establishing international co-operation in the field of uranium enrichment which is facing intense international competition and non-proliferation problems, it is desirable that countries with advanced technologies, Japan included, cooperate to increase efficiency of the development, and I hope to see specific proposals by speakers on how to proceed with international cooperation for enhancing efficiency of development.

Besides the domestically supplied portion, we would like to continue procurement of uranium enrichment services overseas from the viewpoint of economics and taking international relations into consideration as long as such does not interfere with our independence of nuclear power development.

(3) Fabrication:

While the fabrication industry here in Japan has established itself with the capability to supply highest quality products by international standards, Japan has the urgent task of reducing fabrication cost to narrow the gap with the overseas suppliers.

In order to achieve this, the fabricators and the utilities have to cooperate with each other to seek higher efficiency through improvements in core management, fuel design, the fabrication process, inspection methods and production systems.

(4) Reprocessing:

From the standpoints of making efficient use of uranium resources as a quasi-domestic energy source, as well as of disposing spent fuel in a safe manner, the reprocessing option has been the basic policy in our country.

On the basis of the prevailing uranium price, reprocessing charge and so on, it will prove more economical, except in the event of extraordinary inflation, to store our spent fuels until the age of the FBRs rather than to reprocess them.

Nevertheless, it will be necessary to undertake reprocessing on an appropriate scale for the purpose of establishing technological basis for reprocessing, plutonium utilization and sound disposal of HLW towards the commercialization of FBRs, in addition to the aforementioned standpoints.

When we take the above into consideration, it will be desirable to handle this matter in a flexible manner including temporary storage of some portion of our spent fuels while maintaining the reprocessing option as our basic policy.

Based on such a perception, our first commercial reprocessing plant with an annual capacity of 800tons will be constructed in Rokkasho-mura, Aomori Prefecture, utilizing the indigenous technology

of our domestic industry, with the co-operation of France, the United Kingdom and West Germany, as well as incorporating valuable experience gained in PNC's Tokai Plant. The current status is that acquisition of land has been completed and environmental survey is being conducted. The contract for technological assistance has been concluded with SGN, and basic design work has just started. Since our aim lies in establishing reprocessing technology firmly in our country through design, construction and operation of our first commercial reprocessing plant, we would hope to receive long-term cooperation from those countries from whom we are seeking technological cooperation.

We have committed a total of 4,600 MTU of spent fuels to BNFL and COGEMA for reprocessing spent fuel which cannot be catered for by our domestic reprocessing capacity. As for the future, in order to deal with spent fuels which exceed our domestic reprocessing capacity, we are thinking of such measures as increase of storage capacity for the temporary storage at the reactor sites, or storage in storage pools of our first commercial reprocessing plant or dry cask storage, while additional orders to the overseas reprocessors might also be considered.

In order to establish indigenous technology and improve the economics of plutonium utilization, it will be particularly important in the field of reprocessing to promote technological development and cost reduction. Also, it will be necessary to pay

attention to the development of technology for reprocessing high burn-up spent fuel, and also MOX fuel. Improvement in the reprocessing plant's availability factor will be most important in improving economics of reprocessing. For this purpose, such measures as increase of reliability of equipments, advancement of operation/maintenance technology and development of a practical plant operation and shutdown criteria taking environmental safety into consideration, are considered to be necessary. I would like BNFL, COGEMA, and KWU gentlemen to comment on this matter.

As for construction of our second commercial reprocessing plant, while the provisional schedule for start-up is set at around the year 2010, I believe that its construction schedule should be determined with consideration of multiple factors such as forecasts of uranium price and reprocessing cost, future trends in plutonium demand and spent fuel storage method, as well as the advent of high burn-up.

(5) Recycling of Recovered Material:

Although it is desirable to utilize the recovered plutonium in FBRs where highest efficiency can be realized, delay in commercialization of FBRs is foreseen. Therefore, we are considering of utilizing the recovered pulutonium in LWRs and ATRs in the interim period awaiting commercialization of FBRs. Based on the future pulutonium balance, the scale of Pu-recycling will be

to load 12 LWRs with MOX fuel for 1/3 of their respective cores in the late 1990's.

For the purpose of confirming behaviour of MOX fuel in LWRs, and gaining experience pertaining to fabrication and handling of MOX fuel, between 2 to 4 bundles of MOX fuel will be loaded into one each of BWR and PWR at first. After accumulating such experience, one each of BWR and PWR will be loaded with MOX fuel to reach one quarter core eventually, to accumulate experience on a commercial scale. Based on these experiences, we are thinking of proceeding to full-scale use of MOX fuel in LWRs in the late 1990's.

The issue in implementing our Pu-recycling program is smooth transportation of recovered plutonium to Japan from France and the U.K. under international agreements.

As for the fabrication of MOX fuel, PNC has a record of fabricating 80tons so far, and a plant with 40tons per year capacity for a demonstration reactor of ATR is under construction. Since a 100tons per year capacity will be necessary in a era of full-scale Pu-recycling program, construction of a domestic plant by private sector is being considered.

Although the cost of MOX fuel fabrication is expected to be considerably higher than that of conventional uranium fuel, it will be necessary to pursue cost reduction through technological

development in order to maintain the economics of the recycling option in LWRs.

I would like to ask the gentlemen from ALKEM and COMMOX which are the most experienced companies in this field, to comment on the technological development and the future trend of cost.

On the other hand, as for the recovered uranium, we would like to determine between either utilization as matrix material for MOX fuel, reconversion/reenrichment, blending, or interim storage for the time being.

As for reconversion and reenrichment of the recovered uranium, consideration must be given as to whether it would be necessary to prepare separate production lines at conversion and enrichment plants from perspective of radioactivity and quality control of product, and whether such separate lines will result in higher costs. Another problem is that isotopes U-232 and U-236 in recovered uranium will be enriched in the process of reenrichment. In addition, higher enrichment assay will be required for recycling recovered uranium to compensate for decrease in reactivity due to U-236 which is a neutron absorber. On the other hand, in case of using recovered uranium for blending, extra SWU will become necessary when compared with straight reenrichment. We would like to determine the optimum use of recovered uranium upon reviewing the above problems from the technological and economic aspects.

On this subject, I would like to ask COMURHEX, BNFL, DOE and URENCO gentlemen to give a presentation of the technological/ economic outlook and suppliability.

3. Direction of Solving Problems:

I have explained the current status and tasks of the nuclear fuel cycle industry in Japan. Now, I would like to touch on our stance to solve these problems from an international viewpoint.

(1) Technological Development:

It is imperative to improve the reliability and economics of the nuclear fuel cycle industry and to foster them as an internationally competitive business.

This is a technology intensive business and intervals between construction of facilities are considerably long. Accordingly, if we want to materialize cost reduction and reach the stage of sound commercial operations, it becomes more important for us to promote active technological development. For this purpose, it is desirable that we enhance our own technological development capability, and continue efforts in developing our own technology from technology security's point of view, and also improve technology level through international exchange of informations as much as possible.

(2) Realizing Economic Viability:

Although the weight of nuclear fuel cycle cost in nuclear electricity cost is relatively low in comparison to conventional thermal power generation, it will significantly contribute to the improvement of the economics of nuclear power if we can lower nuclear fuel cycle cost.

The first measure for such improvement is to promote technological development in advance, and fully apply the fruits of such development to the efficient construction and operation of plants.

The second measure is to have a precise forecast of demand and undertake investment based on such precise figures avoiding any overinvestment. For this purpose, close communication and coordination between suppliers and consumers are desirable.

(3) Safety and Public Acceptance:

As people have experienced with the Chernobyl accident last year, a nuclear accident brings about a broad adverse impact worldwide. Accidents at nuclear fuel cycle facilities are of no exception. Accordingly, those nuclear fuel cycle enterprises in each country need to put their utmost priority on ensuring safety and minimizing the release of radioactivity, and promote the necessary technological development for this purpose. It will also contribute to this

aim, if those enterprises mutually exchange information on safety technology, safe operation and management procedure and methods for lowering radioactivity release.

(4) Cooperation Among Governments:

In the administration of a nuclear fuel cycle enterprise, due attention should be paid to a nuclear non-proliferation policy. For this purpose, it is important to improve IAEA safeguards scheme which is a framework to implement a nuclear non-proliferation policy under the Nuclear Non-Proliferation Treaty, and to manage the scheme efficiently.

It is hoped that individual governments will offer full cooperation.

20th JAPAN ATOMIC INDUSTRIAL FORUM ANNUAL CONFERENCE

PRESENT STATUS AND FUTURE PROSPECTS REGARDING FRENCH INVOLVEMENT IN URANIUM ENRICHMENT

by
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COMMISSARIAT A L'ENERGIE ATOMIQUE

Chairman, Ladies and gentlemen,

I feel deeply honoured to speak in front of this distinguished assistance. This is the second time I do so. Indeed, I made a first presentation fourteen years ago, in 1973, when I announced the intention of my Country's Government to promote a new commercial uranium enrichment plant. Since then, as most of you probably know, a large gaseous diffusion plant has indeed been built in France by Eurodif, and this plant supplies enrichment services to a large number of utilities including Japanese Electric Power Companies who were among its very first clients. Although I shall certainly not assist to another JAIF meeting in fourteen years from now, I hope that the statements I shall make to day will meet with similar confirmation.

COMPARED MERITS OF ENRICHMENT TECHNIQUES

I have been fortunate enough to visit nearly all the uranium enrichment teams and many of the enrichment facilities of the western world. In other occasions, and although it was sometimes rather a burden than a privilege, I was also involved in comparative assessments of various enrichment techniques. When summing up this experience, I can say that :

- All the enrichment teams I have met are technically outstanding,

- If differences undoubtedly exist in the intrinsic economics of enrichment techniques, it seems that, until now at least, their importance is only of second order. Laser isotope separation is the only technique developed to date which appears capable of procuring a distinctive plus, for both economic and practical reasons such as plant modularity and versatility. Extraction of U_{236} for instance when reenriching reprocessed uranium can only be efficiently achieved by such processes.

- More important perhaps than the intrinsic features of the processes are the general economic assumptions which bear on the resulting costs. These are for instance : the return on investments, the price of energy, that of uranium, plant load factors, royalties, taxes and the comparative rates of currencies. One should notice that during the life time of an enrichment plant, intrinsic factors vary little, whereas external parameters may vary in large proportions and need, therefore, to be followed closely and managed with skill.

- But in the end, even more important than the merits of such or such a technology, the impact of economic backgrounds, or the quality of management, are the incentives which lie behind enrichment activity itself and which foster the efforts of R & D enrichment teams throughout the world. Letting aside military concerns, these incentives are either commercial, strategic (that is related to energy independance), or both.

PRESENT AND FUTURE SITUATION OF ENRICHMENT

Nuclear energy in general is going through a difficult period. Installed nuclear capacity increases only slowly and orders for new reactors are limited to a very small number of countries. This situation cannot continue to last in the long run simply because there is no alternative to nuclear energy. In the meantime however, and apart from a few exceptions such as Japan, France and hopefully the United Kingdom, the present picture should not change deeply until the beginning of the next century unless particular circumstances occured such, for example, as a crisis in oil supplies from the Middle East.

In spite of this passive context, the enrichment market remains quite active. This state of affairs is mainly due to the arrival of Eurodif, a few years ago, as a new major enrichment producer on the world market. This arrival induced strong competition and led a number of consumers to shift from one supplier to the other. It is obvious however that the efforts of productivity made presently by enrichment producers in order to win customers are bound to take place within a slowly increasing envelope shaped by nuclear energy growth and cannot, therefore, open a wider field of application by themselves. In fact, there again, the global picture should not change rapidly and in particular, there is no explicite need in the short or middle term to build new enrichment capacities based on present technologies.

This last remark is enforced by the fact that there is presently an overcapacity of enrichment production in the western world. On the other hand, it only holds inasmuch as the conjunction of financial losses and lack of strategic incentives might not threaten or even banish part of the present capacity. In this respect, and due to its strong commitment to nuclear energy - in fact, the highest that can presently be found in the world - France's nuclear industry and in particular COGEMA is bound to remain a large and reliable supplier of enriched uranium until a new, unavoidable, impulse is given to nuclear energy.

This long term future should be thought over and prepared, in particular by Countries like France and Japan who are in the same strategic situation regarding energy imports. In the particular case of enrichment, the context is not an easy one to handle because the development of laser separation implies heavy investments in high risk technology. The expected attractive economics and operating flexibility of these techniques are not yet accurately known and time will be needed before attaining complete maturity of the technique and full optimization of the corresponding front part of the nuclear fuel cycle.

These last remarks may appear very cautious compared to the usual self confident statements made for commercial purposes in this kind of meeting. However, my declarations should not be misinterpreted : they do not reflect the slightest lack of faith regarding the positive outcome of laser enrichment techniques, but they do not overlook either the efforts lying ahead. The CEA teams are all the more confident in overcoming this challenge that the basic features of laser photoionization have been meticulously investigated and that ample demonstration of engineering ability and management efficiency in industrial achievements has been given in the past.

A CASE FOR COOPERATION ?

When the stakes are high, one can envisage some sort of cooperation in order to share the risks. From time to time indeed, the specialized press mentions some initiatives of that kind but these remain rather allusive. I fear that I shall do little better.

Nevertheless, here are a few remarks concerning possibilities of cooperation :

1) Potential partners should share deep and durable interests in nuclear industry. As a Frenchman, I see two possibilities :

   - The first one would reflect a specific community of interest in nuclear energy such as could be the case between France and Japan in the strategic context mentioned above.

   - the other would respond to a political context and, of course, I am referring here to possibilities within the European Community.

2) Efficient cooperation should be limited to a very small number of partners : preferably two, three at the utmost, and these partners should be similar in size regarding nuclear R & D potential and industrial capacity.

3) Savings in expenditures should lead to share efforts preferably in the field of industrial technology developed in a competitive context.

4) Last but not least, commercial issues should be reviewed prior to the conclusion of any cooperative agreement on R & D.

CONCLUSION

Coopération on new enrichment techniques may not be a requisite. But at least am I entrusted to declare that the CEA Group would not be opposed to enter into practical cooperation on advanced isotope separation with foreign entities if adequate answers to the preceding points could be found.

May I acknowledge, before ending, the help of CEA, COGEMA and EURODIF senior executives in the preparation of this document.

Thank you for your attention.

TWENTIETH JAIF ANNUAL CONFERENCE TOKYO 14 - 16 APRIL 1987

Session 5: Issues and Tasks in the Nuclear Fuel Cycle Industry

URENCO'S CONTRIBUTION TO THE ENRICHMENT MARKET

PAPER BY J A Paleit, Director, Urenco Ltd.

INTRODUCTION

Technical progress and technical advance are an integral part of human culture and civilisation. May I take this opportunity to congratulate Japan on the tremendous achievements that have been made in this country, often unrivalled in the world, since I first stayed in Japan as an exchange student more than 20 years ago. In preparing this paper, I looked into my old study notes; I found two entries that particularly highlight this observation:

- I wrote down that in 1962 Japan had 29 GWe Hydro power stations installed and figured already as one of the most highly electrified industrial countries in the world;

- I further noted at the time that Japan operated only 1 Expressway, the 215 km Nagoya - Kobe Highway, the so-called Meishin-Highway while two others, the 325 km Tokyo-Nagoya-Expressway, the so-called Tomei-Highway, and the 94 km Tokyo-Fujiyoshida Expressway were under construction.

Today, by virtue of long-term planning and vision Japan operates already 33 nuclear reactors with a capacity of 25 GWe, almost the hydroelectric capacity of more than 20 years ago, and a huge network of expressways covering the whole country. The target for nuclear power capacity in the year 2000 is 53 to 62 GWe, which indeed emphasises the "Nuclear Energy Vision of the Electric Utility Industry" in Japan based on a solid "Long-Term Nuclear Strategy towards the 21st Century", as the November 1986 report by the Federation of Electric Power Companies of Japan is so appropriately called.

I also found in my old Japan study notes an etymological explanation of the Japanese word for culture and civilisation: "bun-ka".

Slide 1: Bun-ka

The word "ka" sketches, as you all know, two human figures, one standing on its feet, the other on its head, symbolising change and the potential for change. The word "bun", I was told, can best be translated into English as "without force". Thus "bun-ka" means simply "change without force". This concept is the very essence of culture and civilisation; in this sense every contribution to a peaceful change for a richer, more comfortable and more interesting life is culture and civilisation. Thus, by way of an example, I may submit that both Nihon Doro Kodan, whose student trainee I was in the mid 1960's, and the Japan Electric Utility Industry have, by their planned and visionary implementation of technical progress in the area of road and power station construction respectively, ENRICHED the essential infrastructure of Japanese civilisation.

The key word "enriched" provides me with a good opportunity to explain to you as to how Urenco, the Uranium Centrifuge Enrichment Company sees its role in providing a reliable, competitive and stable source of Uranium Enrichment as a vital step in the Nuclear Fuel Cycle on which Reactor Operators depend.

I propose to focus on the following five main issues which are from Urenco's point of view relevant to the subject of Uranium Enrichment in the context of this conference:

(i) Present status of Urenco.

(ii) Urenco's future development.

(iii) The Western World enrichment supply situation.

(iv) Urenco's policy and contribution to a reliable, stable and competitive world enrichment market.

PRESENT STATUS OF URENCO

When Urenco was founded in 1971 by its British, Dutch and German Shareholders the nuclear future looked very bright indeed. Urenco entered the world enrichment stage with its centrifuge technology as the third contender after the United States and the Soviet Union who were both in the possession of large diffusion capacities resulting from their military programmes. Eurodif, the French controlled consortium, joined

the international enrichment market very soon after with the construction of an updated version of the diffusion plant, with a capacity of 10800 tons SW/a, completed in 1980. Urenco also planned to have enrichment capacity installed in the order of some 10,000 tons/a SW by the early 1980's to meet part of the expected huge world demand. Indeed, in 1971, the concern of nuclear electric power utilities world wide was a threatened shortage of enrichment capacity in the 1980's. For a variety of reasons, well known to you, nuclear power installation plans suffered many set-backs in many countries. Against this increasingly downward trend of world-wide enrichment requirements Urenco was able to adjust its capacity build-up programme in such a way that it matched its delivery commitments secured by firm enrichment contracts with electric utilities. This was possible because of one of the main advantageous features inherent in centrifuge technology: namely, the possibility to construct and operate centrifuge plants in relatively small capacity modules of about 100 tons SW/a, and so to follow very closely the contracted delivery obligations. Thus Urenco was able to avoid expensive speculative investment. Against this background Urenco can now report the following essential achievements which give it a stable and commercially sound foundation:

- Mature Technology

  Urenco has developed centrifuge enrichment to a status of technical and commercial maturity. The main features are its cost saving modular build-up concept; its low electricity consumption of less than 100 kwh per kg/SW, being only about 3% of diffusion plant needs; its high plant availability and low centrifuge failure rates allowing a non-maintenance operation policy; and its still high development

potential allowing further cost reductions in future. Thus Urenco has been able to develop technically and employ commercially the only modern technological alternative to the only other process in use, the older diffusion technology, mainly characterised by its high electricity consumption and the necessity to build large plants in the order of 10,000 tons SW/a; the latter feature has led, to the known extent, to an under-employment of all diffusion plants operated by the other suppliers in the Western World.

- Plant Capacity

Based on the centrifuge technology jointly developed in Britain, The Netherlands and Germany, Urenco has built enrichment plants over the last 16 years on its three sites in Almelo/Netherlands, Capenhurst/England and more recently Gronau/West Germany. The current (1987) capacity totals some 2000 tons SW/a meeting Urenco's 1987 delivery obligations of 2000 tons SW under long-term enrichment contracts. This status demonstrates best the inherent advantages of the centrifuge process. In a radically reduced market relative to the perception of the early 1970's, Urenco is the only enricher who is not suffering from surplus capacity. This has contributed largely to Urenco's competitive position based on sound business principles including the profit motive. Urenco's position has been enhanced by an additional advantage in that the modular build-up concept allows Urenco also to equip its plants on a step-by-step basis with the most advanced Urenco centrifuge technology available at the time.

It is also worth noting that all Urenco plants have been constructed within budget and within schedule; an achievement not only successfully implemented at the sites at Almelo and Capenhurst started already in the early 1970's but also at the green field site of Gronau/Germany in the 1980's. The Gronau plant construction was started in 1981 and commissioned exactly to schedule in August 1985.

- Market Share

Urenco has obtained to date about 10% of the Western World Enrichment Market by concluding long-term contracts with utilities in Britain, Germany, Holland, Brazil, Sweden, Switzerland and the United States of America. These delivery commitments necessitate an expansion of the current capacity of 2000 tons SW/a at the 3 sites to 3000 tons SW/a and upwards in the early 1990's. The value of the total order book exceeds £2.5 billion, being almost US $4 billion at current exchange rates. Most of Urenco's long-term contracts are running well into the 1990's and some have already been extended into the next century.

To date Urenco has delivered to its customers more than 7000 tons SW thus establishing itself as a reliable large scale supplier of these vital services. All plants are fully utilised and deliveries from all three sites are completely integrated into the overall Urenco supply arrangements centrally administered through Urenco Ltd., the central company of the Urenco group, with its offices in Marlow, England.

- International Enrichment Company

Apart from its technical and commercial success, Urenco can also report its achievements as an internationally integrated enrichment company. In its 16 years history the Urenco group has set an example as to how the technology and the personnel as well as the business practices of three independent countries can be integrated in a way that ensures organisationally, commercially and also politically an efficient operation meeting the challenges of a complex and competitive market.

The status of Urenco is exemplified by the following slides:

Slide 2 - Almelo aerial picture

Slide 3 - Capenhurst aerial picture

Slide 4 - Gronau aerial picture

Slide 5 - Cascade Hall picture

Slide 6 - Urenco Enrichment Plant capacities

URENCO'S FUTURE DEVELOPMENT

At first sight the prospect for growth in the enrichment market looks poor. This is partly the result of low growth in nuclear power programmes around the world, but even more so because of the gross over-capacity of enrichment plants available in the United States and France. Nevertheless, Urenco expects its capacity to grow over the next five to ten years, partly on the basis of contracts already signed and

partly on the expectation that new contracts will be concluded because of Urenco's increasing competitiveness resulting from its further exploited development potential and the low operating cost features.

Furthermore, another expected growth area for centrifuge enrichment is in the re-enrichment of recycled uranium. Urenco has concluded successful trials for utilities in Britain, France and Germany on uranium extracted from the spent fuel of Magnox and Light Water Reactors. These trials have demonstrated that technical problems associated with residual traces of fission products and minor uranium isotopes can be satisfactorily solved with only modest cost penalties leading to a commercially attractive re-use of recycled uranium. The modular nature of the plants is particularly suited to the handling of recycled uranium, preventing cross contamination with other customer's natural uranium and enabling the efficient control of minor radiation hazards.

Thus, in the area of recycled uranium, centrifuge enrichment has a significant advantage over diffusion plants. Urenco has proved that the concept of utilising large numbers of machines with relatively modest output, mass produced to a tremendously high standard of reliability on a maintenance free basis with a working life of at least ten years, is a successful technical achievement. On the basis of this technical and commercial maturity Urenco is continuing by further research and development work to reduce specific plant costs, increase output and thus further improve Urenco's competitiveness. To this end there are still areas of the centrifuge technology which can be more fully exploited. Thus Urenco is confident that it will meet the technical and competitive challenges of the 1990's with its proven centrifuge technology.

Urenco's forward investment plan will remain based on centrifuge technology until an economically proven alternative becomes available. Urenco's Shareholders are maintaining R & D efforts on laser enrichment, but are convinced that, with the reliability and cost effectiveness of the centrifuge process with its capability of improvement and with its low technical risk, they have the right technical process at hand now for many years to come. Urenco's centrifuge technology is considered to be more than a match for the laser process at least until the end of the century. However, should laser become commercially feasible Urenco will be in a position, on the basis of its long range strategic research, to adopt the technology either in its own right or in co-operation with others.

The trend in technical improvements can be seen in the following slides:
Slide 7 - Technical development trends - table
Slide 8 - Technical development trends - graph

THE WESTERN WORLD ENRICHMENT SUPPLY SITUATION

The enrichment supply situation in the western world is characterised by an over-capacity of enrichment plants versus real requirements. The total western world capacity of enrichment plants is about 35,000 tons SW/a while the real requirement is probably 25,000 tons SW/a. There is an increasing tendency on the part of the utilities to contract only on the basis of real requirements, thus avoiding future high inventories a policy which also led to a virtual drying up of the secondary market. While competition is particularly strong among the major suppliers, US DOE, Eurodif, and Urenco, an analysis of the major market areas shows that there is a high tendency that the domestic markets of these suppliers are

virtually monopolised by the indigenous enricher. This applies particularly to the United States where the competitive approaches by Urenco and also Cogema have led only to a small degree of diversification away from US DOE, but forced US DOE to offer more competitive terms which are almost geared to keep the competition out. In Europe Cogema/Eurodif and Urenco have succeeded in their respective areas to have a large market share while in the Far East (Japan, Korea and Taiwan) US DOE has remained the predominant supplier with Cogema/Eurodif having made some inroads.

The following diagram illustrates this picture:

Slide 9 - Regional analysis of market shares.

It may be concluded, that, while there is a great deal of competition on the supply side of the Western World Enrichment Market, commercial terms alone are not the predominant factor in the market. Other factors play a major countervailing role, in particular

- the perception of security of supply from "domestic" plants;

- political influences;

- overall country-by-country trading and balance of payment considerations.

URENCO'S POLICY AND CONTRIBUTION TO A RELIABLE, STABLE AND COMPETITIVE WORLD ENRICHMENT MARKET

Urenco's policy and contribution to the stabilisation of the Western World Enrichment Market has been highlighted in this paper and can be summarised by the following key words:

URENCO

- The centrifuge PIONEER
- The first holder of MATURE, MODERN operating technology with DEVELOPMENT POTENTIAL
- The MULTINATIONAL commercial enricher.
- The INNOVATOR of individually tailored supply concepts.
- The enricher of RECYCLED Uranium.

Slide 10: Urenco's Contributions to World Market.

Hence, Urenco has by its commercial, competitive and responsible approach already vastly contributed to the development of a more stable and reliable

enrichment market either directly for its existing customers or indirectly for other utilities. Urenco's build-up programme in three countries without speculative investment on the basis of a mature but still improving technology provides diversification of production and greater assurance of supply. This concept also enables Urenco to meet the different flexibilities and particular needs required by individual customers. The success of this policy is demonstrated by Urenco's deliveries over the last decade already in excess of 7000 tons SW to many customers. In 1987, deliveries will be about 2000 tons SW, growing to at least 3000 tons SW in 1990.

Urenco's ability to solve the problems of re-enriching recycled uranium on the basis of consistently and steadily developed experience gained in well prepared trials is a further feature of this effort. As already practised in Europe, Urenco would like also to invite Japanese utilities to jointly carry out trials with Urenco on recycled uranium in order to establish a common basis for the future of this essential part of the fuel cycle. In Urenco's view recycled uranium is a valuable resource which ought to be utilised on an early timescale.

Urenco has followed with great interest the programme and achievements of Japan in building up its own centrifuge enrichment industry and offers its compliments and best wishes for successful continuation.

Slide 11: Bun-ka

May I finish by saying that Urenco feels well equipped to meet the future tasks and challenges in the enrichment part of the fuel cycle world-wide, in order to further advance the progress of technology as an integral part of "bun-ka", the peaceful change for the benefit of us all. Given the many countervailing factors characterising the World Enrichment Market which have been touched upon in this paper, consistent, patient and continuous work is required by all participants, not only in enrichment but in the nuclear industry at large. In this sense I agree with Shogun Ieyasu Tokugawa who is reported to have said in the 16th century:

"ALL MAN'S LIFE IS LIKE WALKING A LONG DISTANCE WITH A BURDEN ON HIS BACK"

「人の一生は重荷を負うて遠き道を行くがごとし」

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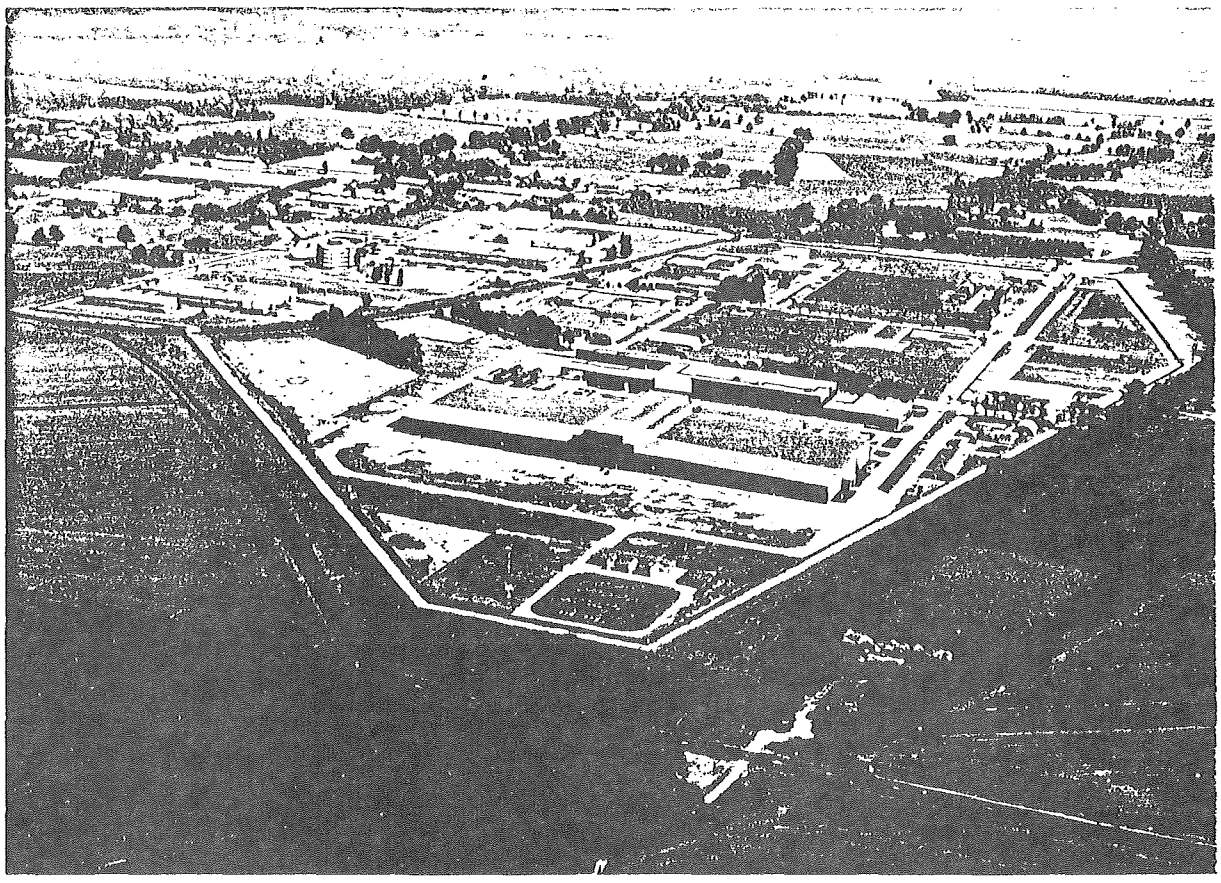
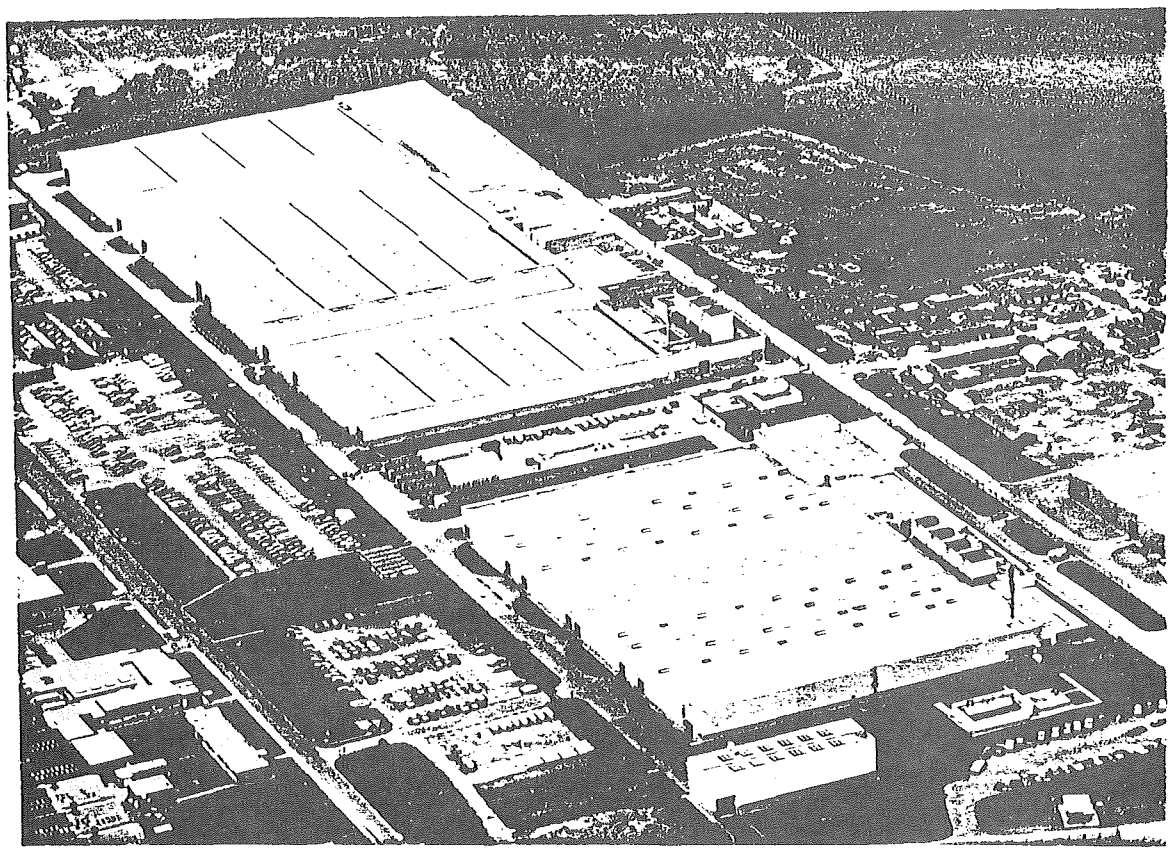
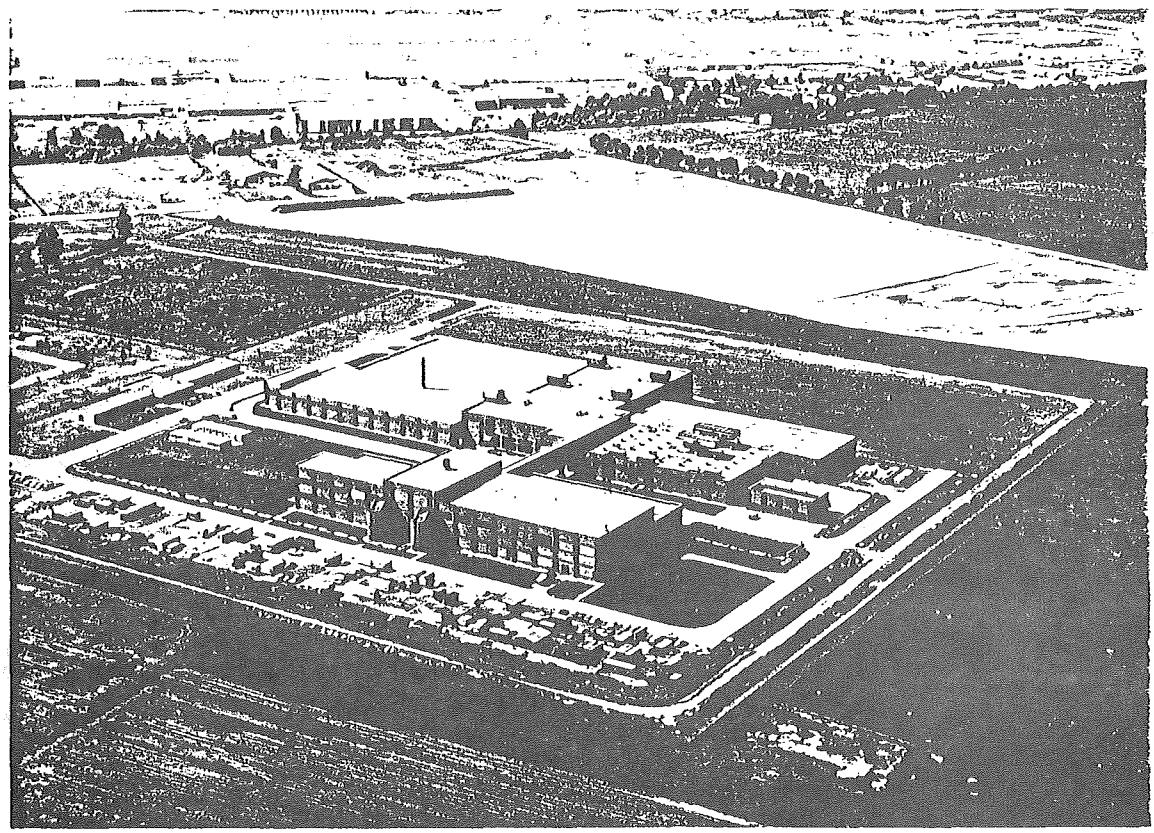
Slide No	Title
1	Bun-ka
2	Almelo, aerial view
3	Capenhurst, aerial view
4	Gronau, aerial view
5	A Urenco Cascade Hall
6	Urenco Enrichment Plants - bar chart
7	Technical Development Trends - table
8	Technical Development Trends - graph
9	Regional Analysis of Market Shares 1990 - pie charts
10	Urenco Contributions to World Market (Japanese text)
11	Bun-ka



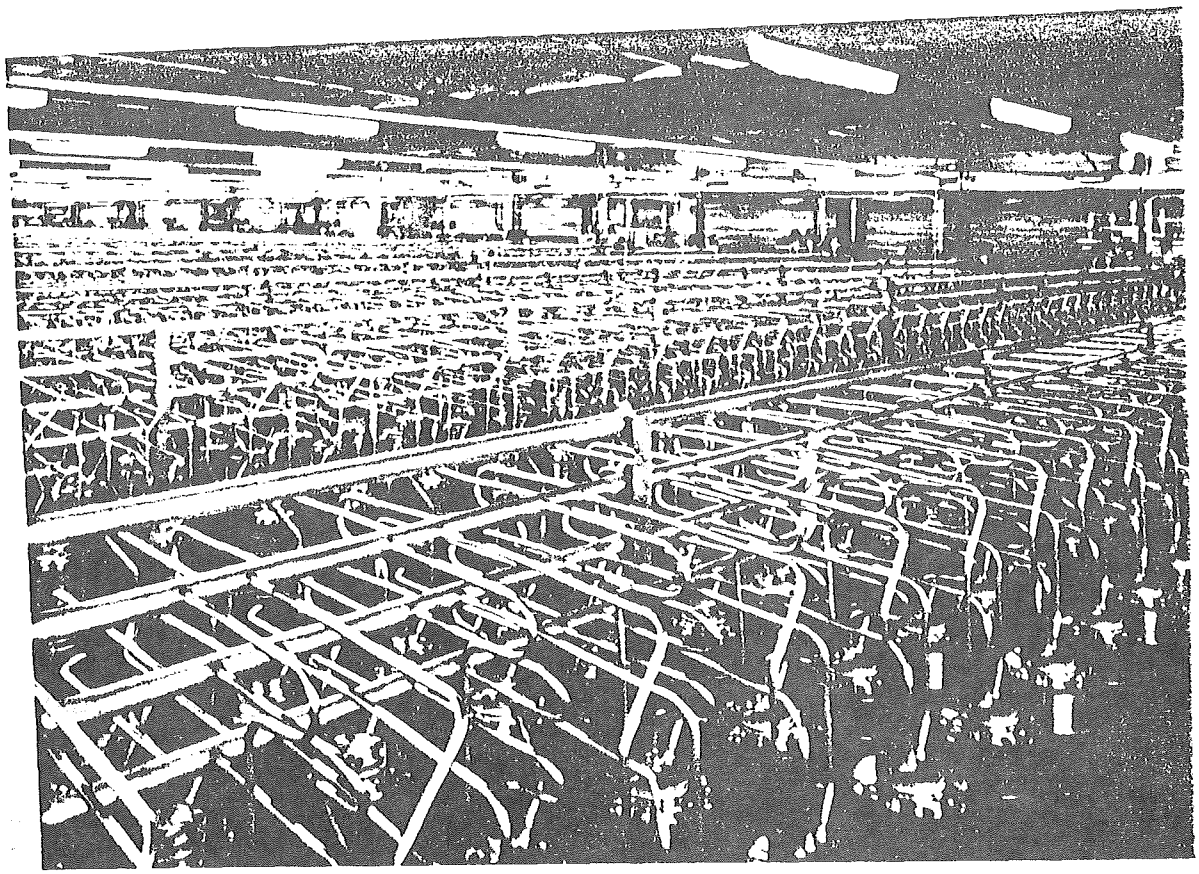
Slide 2 - Almelo aerial picture



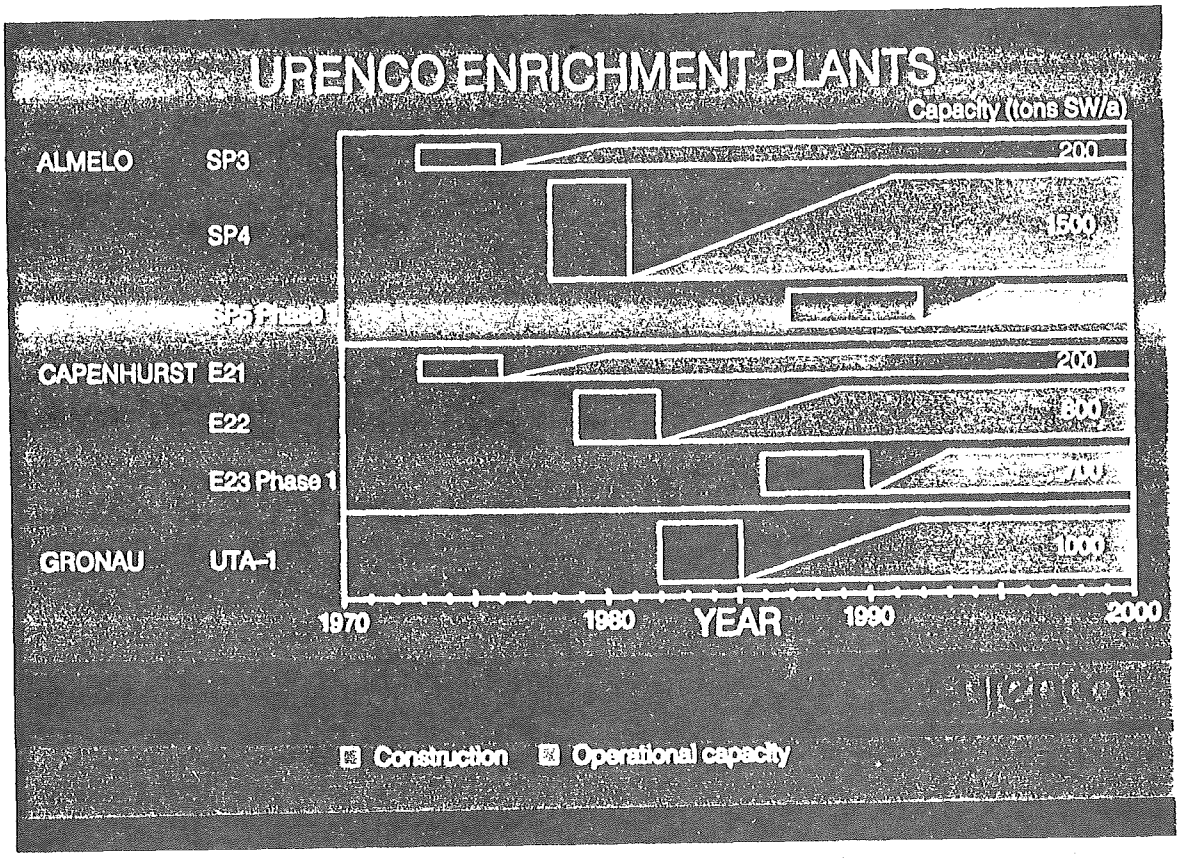
Slide 3 - Capenhurst aerial picture



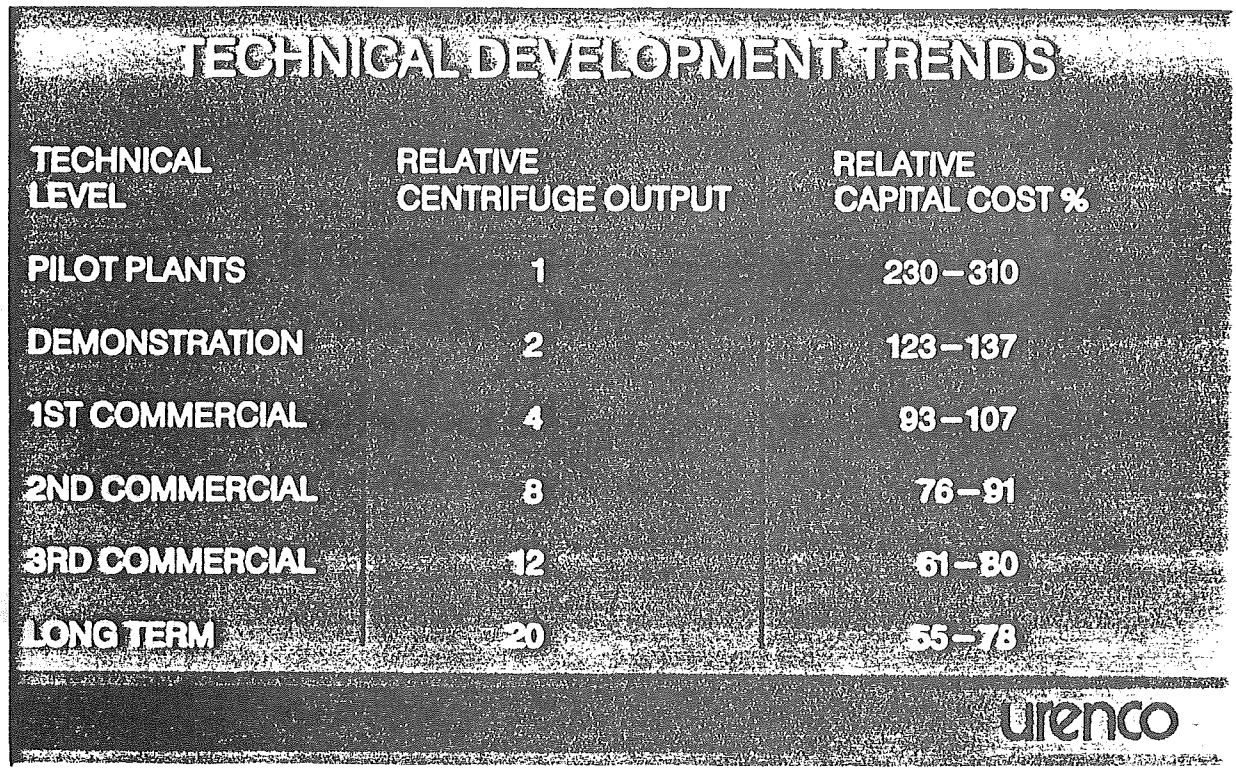
Slide 4 - Gronau aerial picture



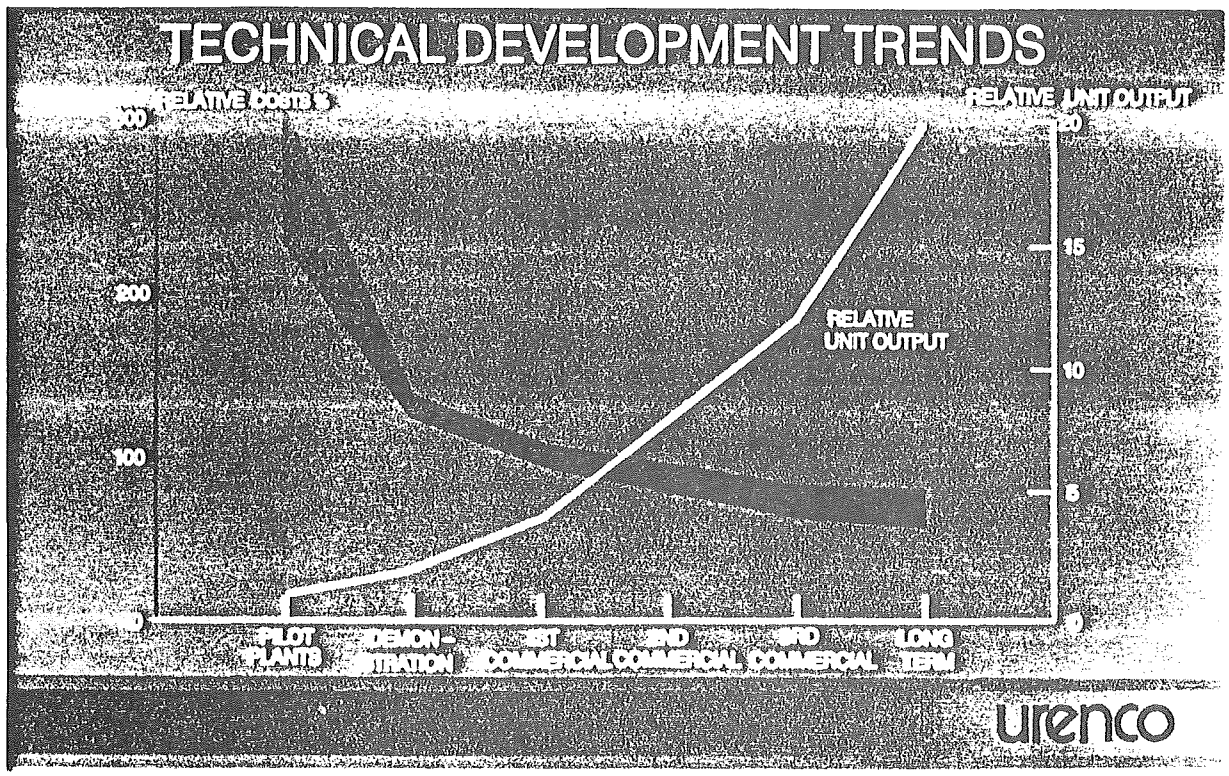
Slide 5 - Cascade Hall picture



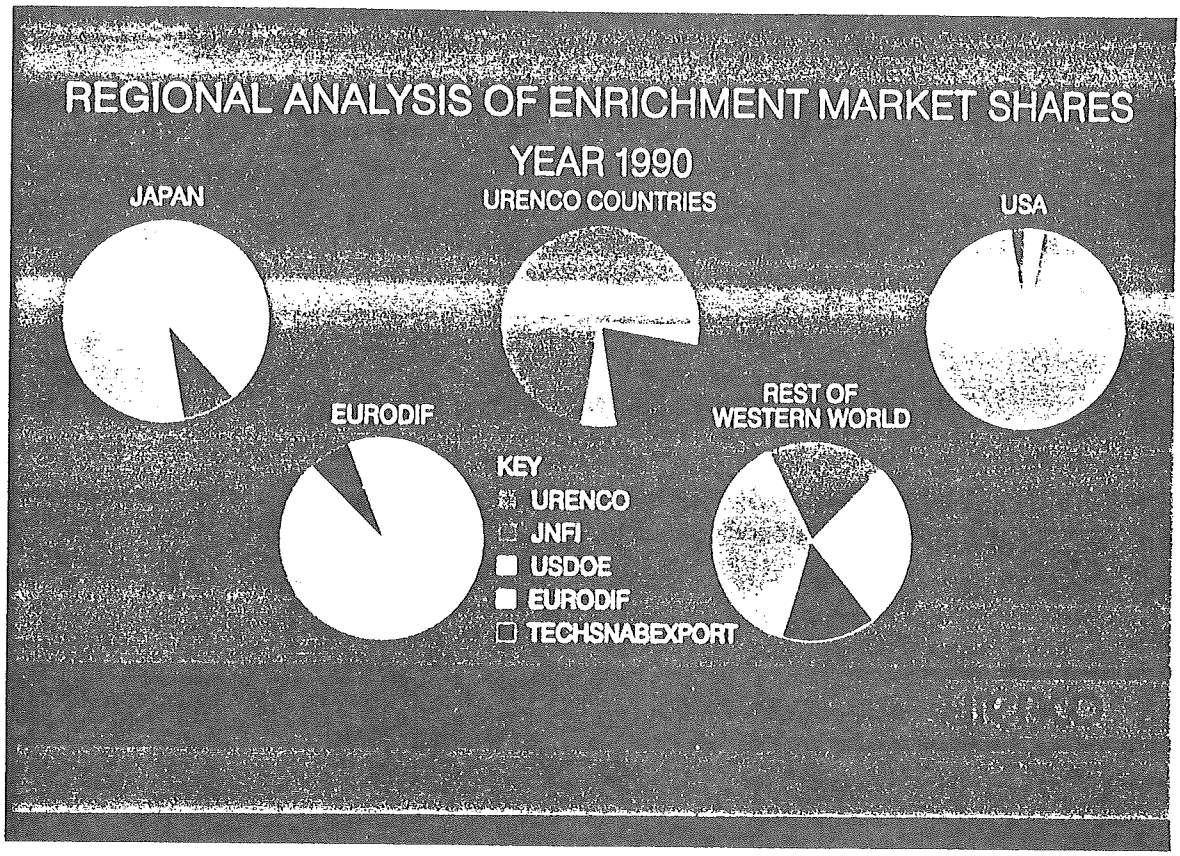
Slide 6 - Urenco Enrichment Plant capacities



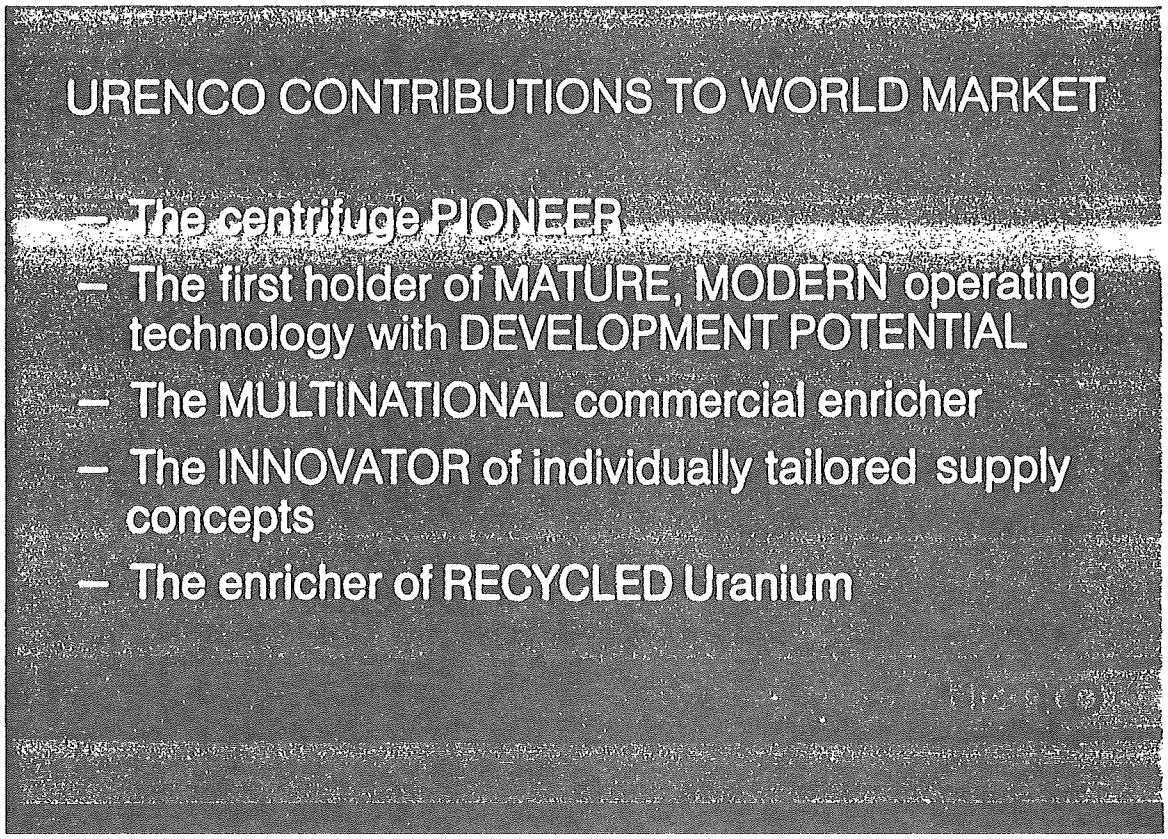
Slide 7 - Technical development trends



Slide 8 - Technical development trends



Slide 9 - Regional analysis of market shares.



Slide 10: Urenco's Contributions to World Market.

JAIF ANNUAL CONFERENCE
TOKYO, JAPAN

RECENT DEVELOPMENTS IN THE UNITED STATES URANIUM ENRICHMENT ENTERPRISE

BY
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U.S. DEPARTMENT OF ENERGY

APRIL 16, 1987

Introduction

I am honored to have the opportunity to participate in the 20th JAIF Annual Conference, and to address this distinguished group. It is always a pleasure to be among my many friends in Japan. We have a great deal of respect for the progress you have made in your nuclear program, including very substantial progress in various areas of the nuclear fuel cycle. Today, I will be discussing U.S. progress in one area of the fuel cycle, that of uranium enrichment.

The United States continues to have a strong commitment to nuclear power. One way to assure that its full potential is realized is through a reliable supply of nuclear fuel at stable or declining prices. To achieve this objective as indicated in Figure 1, the Department of Energy (DOE) is committed to maintaining a healthy and competitive uranium enrichment capability in the United States. We pursue this goal recognizing that the business of nuclear power, like so many others, is international in nature. Thus, we want to maintain a healthy uranium enrichment industry not only for the benefits that accrue to our customers, but also for the benefits to the furtherance of the nuclear option in the free world.

The DOE uranium enrichment enterprise has two major goals. Our near-term goal is to provide reliable, competitive enrichment services to our customers in Japan and throughout the rest of the world. Our long-term goal is to stabilize and maintain U.S. competitiveness by developing and introducing advanced technology, and by restructuring the business to assure that we can be responsive to our customers' needs.

Today, I will be discussing the progress we have made in fulfilling these goals and our plans for the future. First, I will describe how we have implemented significant ways to cut costs to make our gaseous diffusion plants (GDP's) ever more competitive. I will then review the progress we have made with our advanced laser enrichment technology, and finally I will explain the steps we are taking to restructure the U.S. uranium enrichment enterprise.

The GDP's - Competitive Today

The gaseous diffusion process technology for uranium enrichment was developed and a plant built at Oak Ridge, Tennessee, in the 1940's. Using the same technology, the Portsmouth, Ohio and Paducah, Kentucky, GDP's were built in the 1950's. Figure 2 shows the locations of our GDP's. These plants have been reliable workhorses through the years. However, by the early 1980's, the diffusion process was a mature technology, and few thought that significant improvements were possible that could make the technology more competitive. As indicated by Figure 3, our 1982 Annual Report projected gaseous diffusion production costs to be $130/SWU for the year 2000. Based on this projection, many expected the GDP's would be replaced shortly by the centrifuge process, or another advanced technology.

In spite of its technical maturity, the diffusion process is surprisingly competitive today, and we have found significant ways to cut costs to make our GDP's even more competitive for the decade ahead. For example, in 1983, the unit factory cost at the GDP's was over $90 per separative work unit (SWU). As illustrated in Figure 4, by 1986, we had reduced this cost to $68/SWU. This is a dramatic decrease, especially when inflation is taken into account.

A significant portion of the decrease in unit factory cost has been accomplished by shifting most of the production load away from the plant with the most expensive source of power, in effect eliminating the Tennessee Valley Authority (TVA) as a power supplier for the GDP complex, as shown in Figure 5. This shift in production load was completed in 1985 when the Oak Ridge GDP was placed in standby and all remaining production focused at the Paducah and Portsmouth GDP's. Savings have also been achieved by implementing a more efficient mode of operating the two GDP's, and by taking advantage of much lower off-peak power prices by purchasing blocks of unfirm power when funds permitted. Figure 6 indicates our 1987 unit costs for power. At the same time, we have been able to hold the line against inflationary increases, despite increased outlays for environmental requirements, and increased safeguards and security costs. As shown in Figure 7, our GDP operating costs have been held significantly below inflation rates.

Another important method for reducing costs at the GDP's is to improve the operating efficiency by obtaining more separative work from a unit of electric power delivered to the plant. Through continued hard work, our operating team has increased the efficiency at the plants by improving the

separative process, and reducing nonproductive power usage. For example, at the Paducah plant, the efficiency has increased over 3 percent in the last 2 years. This amounts to a cost savings of about $20 million over the last 2 years, and these savings will continue through the life of the plants.

Electric Power Contracts

Electric power for operating the GDP's is now obtained under long-term contracts from two suppliers: Electric Energy, Incorporated (EEI); and the Ohio Valley Electric Corporation (OVEC). Power contracts for the two operating GDP's expire in the late 1980's and early 1990's. In 1985, we initiated power procurement activities to extend these contracts. Negotiations with EEI to supply power to the Paducah GDP were successfully completed in January 1987, and negotiations with OVEC to supply power to the Portsmouth GDP are underway.

A key issue that we hope to resolve this year is the impasse with TVA over the demand charges they've unilaterally established for power not taken. We are not disputing that demand charges are legitimate costs that are due and payable under electricity contracts. Rather, it appears to us that TVA is charging DOE about twice the amount for demand charges that is justified.

We have renewed efforts with TVA to resolve this most serious impasse and recently have initiated discussions with the TVA board for this purpose. We hope that negotiations will be productive, and that we will reach agreement with TVA during 1987.

The DOE power contract with TVA runs through 1994. We have been exercising our 8-year lead time option to cancel power with TVA since 1981. Based on the terms of our contract, by March 1994, our contract demand with TVA will be reduced from the current level of 4,485 megawatts to zero.

The GDP's - Keeping Them Competitive Tomorrow

New power contracts will be designed to help assure that the GDP's will remain competitive well into the future. We are also implementing plans to allow the use of increased amounts of unfirm power to further lower our average factory costs through time. Since unfirm power is usually available on short notice, is subject to interruptions, and is normally available during off-peak hours, such as at night and on weekends, its use at the GDP's requires special operating procedures.

We have been using increasing amounts of unfirm power on an experimental basis at the Portsmouth and Paducah GDP's since 1984, and in 1986 this resulted in a savings of $2.5 million, as illustrated in Figure 8. These savings should grow significantly as we use more unfirm power in the future. Our goal is to obtain 50 percent or more of the Paducah GDP power on an unfirm basis by the early 1990's.

Our operating results, to date, provides confidence that we can utilize large blocks of unfirm power in the future. To increase our use of such power, we will be installing new equipment at the Paducah GDP over the next several years. The new equipment will consist of freezer sublimers and a new power substation. The freezer sublimers will allow us to increase the proportion of unfirm power we can supply to the GDP's, and the upgraded switchyard will give us access to additional sources of low cost power.

These improvements should further reduce our GDP average cost of production to about $60/SWU, thus allowing the GDP's to remain competitive well into the future. We will continue to diligently look for ways to reduce production costs.

Atomic Vapor Laser Isotope Separation (AVLIS) Development

AVLIS has the potential to produce separative work at a unit cost much lower than the diffusion process. As indicated in Figure 9, our projected AVLIS production costs are in the range of $30 to $45 per SWU, including feed processing costs. The distribution of AVLIS production plant costs are shown in Figure 10. DOE's objective is to have the AVLIS technology available for deployment as necessary to retain our competitiveness in the world enrichment market. As you know, other countries, including our colleagues here in Japan, are also developing advanced enrichment technologies. It is our belief that in the decades ahead, AVLIS will be the advanced technology of choice for all nations.

As illustrated by Figure 11, 1986 was a significant year for U.S. AVLIS development. We accumulated 300 hours of operation on the Material Handling Demonstration Module. We also had the initial operation of a full scale uranium vaporizer source for over 50 hours, and vaporized over 5 tons of uranium. The feed source was operated at twice the AVLIS production plant design vaporization rate. 1986 also saw significant developments in the laser components of the AVLIS process. We demonstrated Copper Vapor Laser (CVL) tube lifetimes at 33 percent of AVLIS production plant design requirements. In addition, the CVL system was routinely operated at 50 percent of plant design requirements, and we obtained 500 watts of tunable power from the Laser Demonstration Facility.

A rather significant recent accomplishment has been the series of half-scale integrated enrichment experiments at Livermore, California using the Laser Demonstration Facility and the Mars separator. In February 1987, we completed an integrated enrichment demonstration at one-half scale that was highly successful, during which over one-half ton of uranium was vaporized and processed. Our equipment performed exceptionally well, and all enrichment goals for this demonstration were met or exceeded. These experiments have produced significant quantities of enriched product, and have contributed much towards validation of the AVLIS codes that are used to model the system. Another successful integrated enrichment experiment was recently completed during the week of March 23, 1987. In this run, a significant increase in the enrichment rate was demonstrated. Analysis of the results of these experiments will provide more exact design values for the commercial scale process and will validate more fully the AVLIS process model codes.

Later this year, we plan another long term test in the full-scale Separator Demonstration Facility at full plant operating densities, as shown in Figure 12. If successful, we will vaporize over 7 tons of uranium, and demonstrate the overall operational characteristics of the separator at full scale for over 100 hours in a single experiment.

With our successful testing program to date and the large scale AVLIS equipment we have in operation, the United States should have the technical capability to deploy the AVLIS process when needed to maintain a competitive uranium enrichment capability. It will not be easy and it will not be cheap, so we are continually working to find lower cost and shorter

paths to demonstration and deployment of the technology without compromising quality and reliability.

Utilization of Reprocessed Uranium

I would now like to briefly describe our policy regarding the utilization of reprocessed uranium. The DOE Utility Services Contracts contain our commitment to accept reprocessed uranium as feed from our customers who reprocess fuel. The utilization of re-enriched reprocessed uranium may require changes in the areas of fabrication, conversion, fuel management, as well as enrichment. To meet this need, DOE intends to offer flexibility and multiple options to utilities to permit their best system-wide use of reprocessed uranium. We are now in the process of gaining a better understanding of the particular requirements of each of our customers, in order to tailor the reprocessed uranium enrichment package to their specific needs.

Institutional Restructuring - The Key to Long Term Stability

As I indicated earlier, an important facet of DOE's long term effort is focused on strengthening the uranium enrichment enterprise by a basic restructuring. Figure 13 shows why institutional restructuring is needed. Restructuring DOE's enrichment enterprise should establish an improved infrastructure for providing competitive uranium enrichment services to our customers. We began by revising the guidelines under which we operate.

Revised Criteria

Last year, we developed new Uranium Enrichment Services Criteria. Basically, the criteria describe the terms and conditions under which DOE provides enrichment services. New criteria were an essential first step in restructuring, since we had been operating under criteria that were first established in 1966, and had changed very little since that time. As indicated in Figure 14, our Congress accepted the new criteria with certain provisions in October 1986. These provisions were:

- banning restrictions on uranium imports pending court resolution of this issue;
- reserving for further consideration the issue of the Government's unrecovered cost;
- extending the free variable tails assay option to all customers who qualify, and
- allowing the use of DOE's natural uranium stockpile to reduce costs as long as there is no reduction in customer feed deliveries.

The most important aspect of the new criteria is the flexibility they offer for the future. They will allow us to compete more effectively, to respond better to the unique needs of different market sectors, and to extend our range of customer services. We are currently examining ways to use the flexibility in the criteria for the benefit of our customers.

Obtaining congressional approval of the new criteria was probably our most significant achievement in 1986. This sets the stage, obviously, for the

final step in our competitive strategy, that of changing the basic structure of the uranium enrichment business.

Report to Congress

In response to a Congressional request in the 1987 Continuing Resolution, DOE submitted an Interim Report to Congress on February 17, 1987, addressing what needs to be done to keep the U.S. uranium enrichment enterprise competitive in the future. The report identified several possible restructuring options that we have evaluated including sale or lease of the enterprise, use of a revolving fund or self financing, and formation of a uranium enrichment corporation that could gradually transition to private ownership.

Since the February report, the Department has completed an analysis of the enterprise and provided recommendations for restructuring to the Secretary. The Secretary submitted his recommendations to Congress on March 31, 1987. As indicated in Figure 15, the final report recommended the establishment of a federally-chartered corporation to manage and operate the U.S. uranium enrichment enterprise, with eventual public ownership of the corporation's stock.

Our primary task for 1987 is to obtain enabling legislation that will allow the restructuring process to continue. Introducing and passing legislation is never a simple task, particularly not for restructuring a key element of the nuclear fuel cycle. Nevertheless, the first step in the process is to achieve consensus among the Administration and Congress with input from customers, employees, and other interested parties on the objectives for the enterprise, and then to proceed with the restructuring option that best

allows us to meet those objectives. To complete this process will likely involve multiple steps over several years. We hope that 1987 will be a year of significant progress in this regard.

Summary and Conclusion

In conclusion, the U.S. uranium enrichment business is becoming healthier, financially stronger, and we are focusing our attention on how to improve that competitiveness in the future. Figure 16 indicates that our recovery strategy is working. Costs have been reduced by nearly 50 percent since 1984, as shown in Figure 17. Our gaseous diffusion cost base is down, and progress on developing the even more economical AVLIS technology is going well. We now have new criteria that give us more flexibility to be responsive to customer needs, and we are turning our attention to providing much needed long term stability to the business. The process of change is always agonizing and the end result is uncertain. However, in furtherance of our partnership with our utility customers, and our strong commitment to do our part to provide stability to the nuclear option worldwide, we will continue to pursue our strategy. If we are successful in restructuring the business, the end result will be a highly economical, reliable, stable supply of enrichment services from the United States in the future.

Thank you.

70890032
4/9/87

Figure 1

Uranium Enrichment Enterprise
Goal

Retain a Competitive, Financially Healthy Uranium Enrichment Enterprise Supply Capability in the U.S. for the Long Term

Figure 2

DOE Gaseous Diffusion Plants

Figure 3

1982 SWU Production Cost Projection for the GDP's

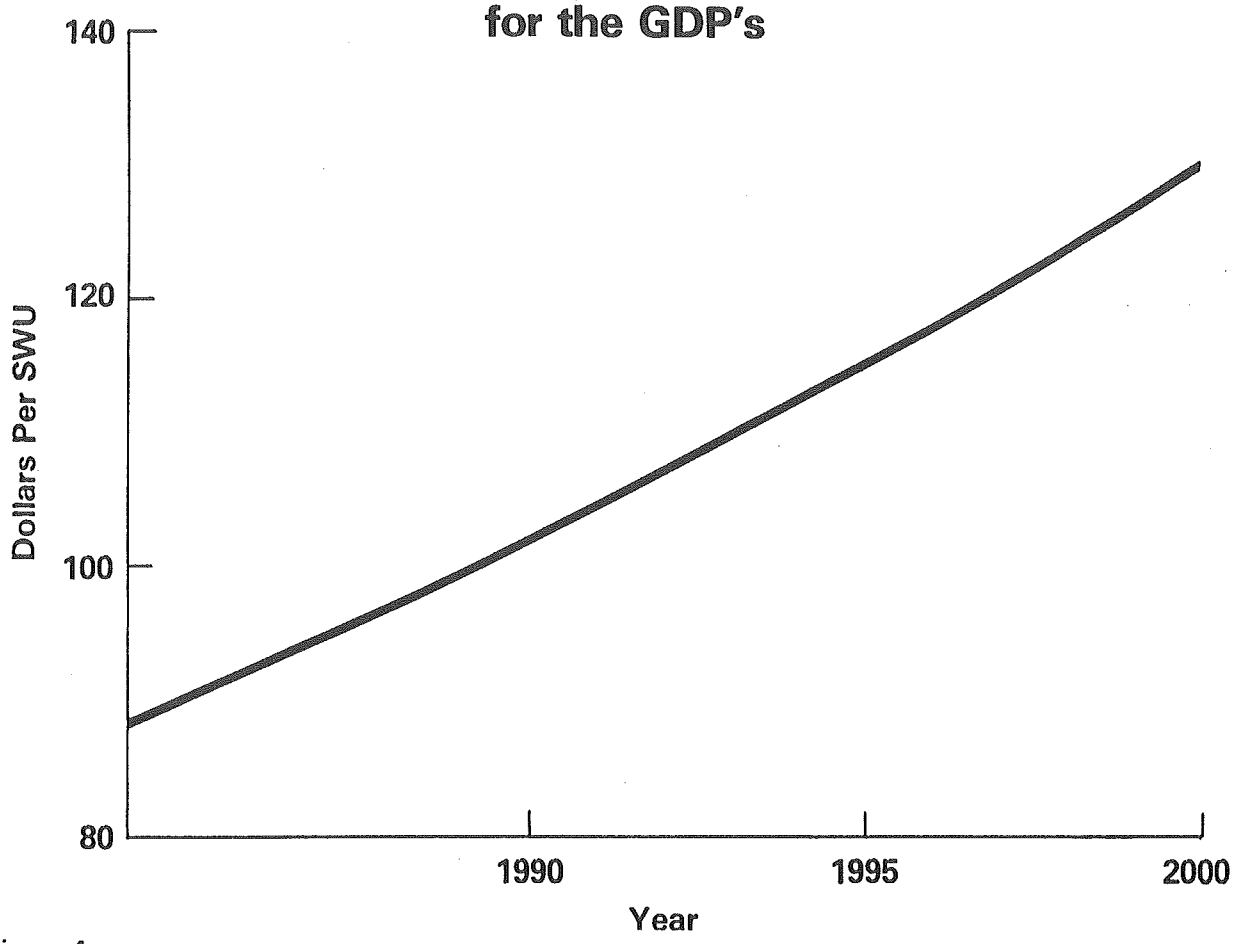


Figure 4

Major Factor in Near-Term Competitiveness — Declining Gaseous Diffusion Production Costs

(Excludes Unused Electrical Demand Charges)

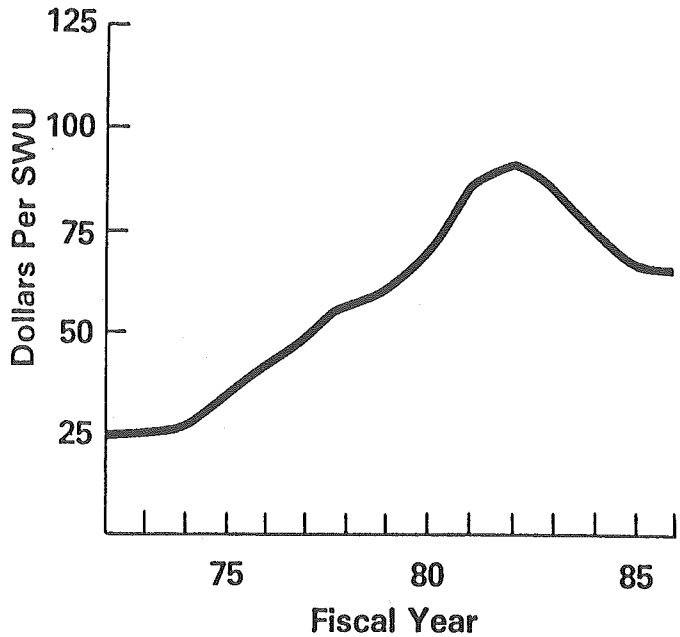


Figure 5

Electric Supply to DOE's Uranium Enrichment Plants

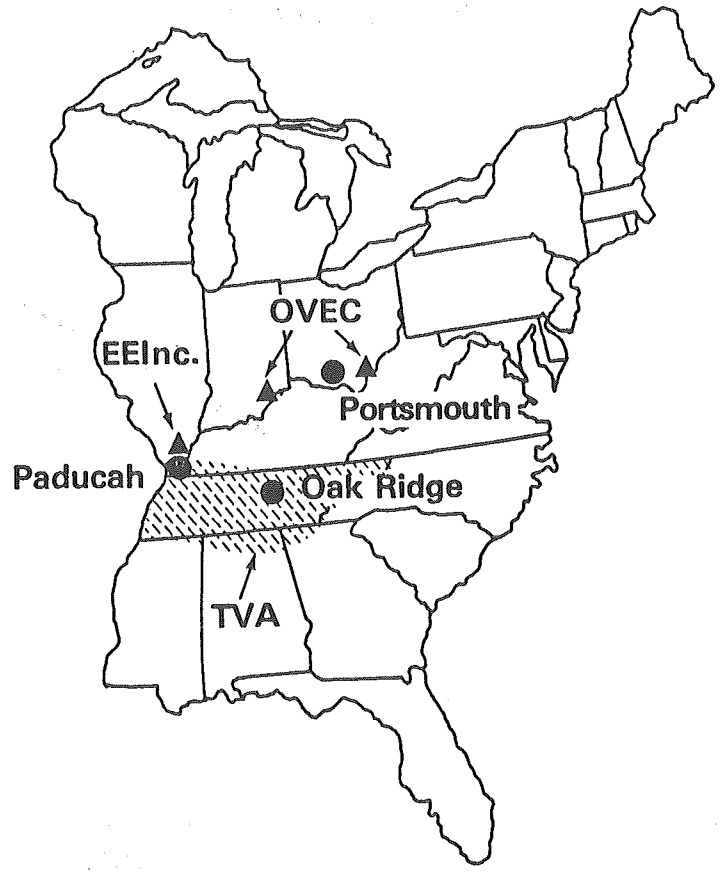


Figure 6

FY 87 Power Unit Costs

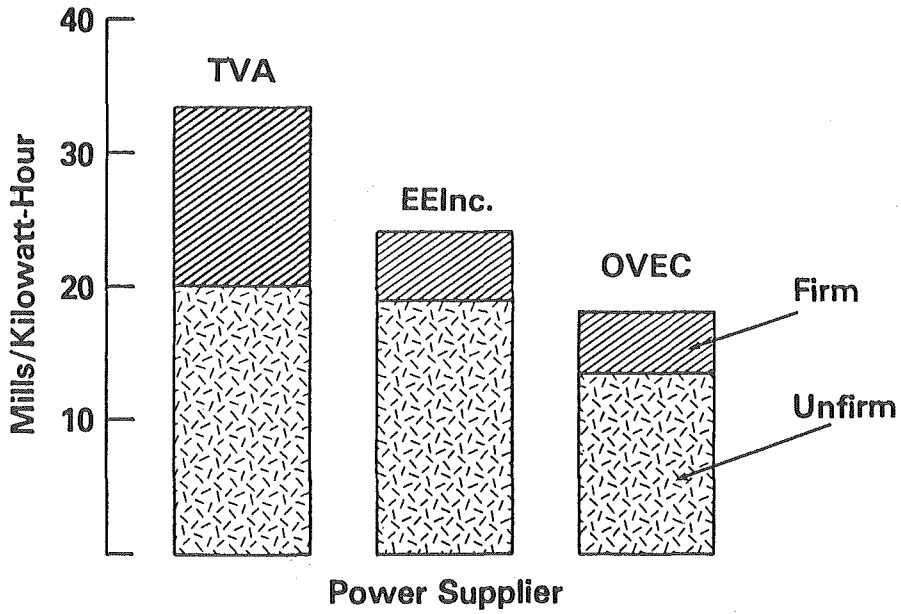


Figure 7

Diffusion Operating Costs Have Been Held Significantly Below Inflation Rates

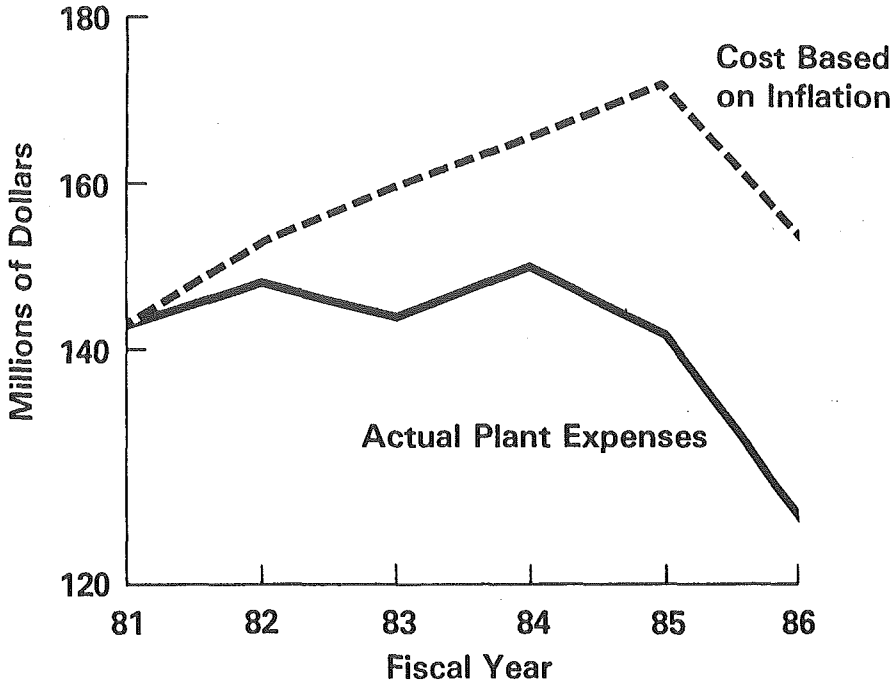


Figure 8

Efforts Continued to Reduce the Cost of Power in FY 86

	Cost Avoidance in Millions
● At Portsmouth	$1.3
● At Paducah	$1.2

Figure 9

The Promise of AVLIS

	Per SWU
• Avg. GDP Production Costs	$65 - $80
• Projected AVLIS Production Costs	$30 - $45
• Projected Range of Cost Savings	$20 - $50

Figure 10

Distribution of AVLIS Production Plant Costs

(11 M SWU/Yr)

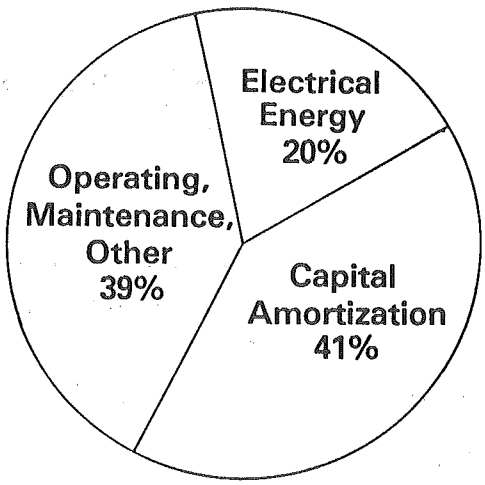


Figure 11

FY 86 AVLIS Accomplishments

- Accumulated 300 Hrs. of Operation on Mat'l Handling Demonstration Module
- Operated Full-Scale Vapor Source >50 Hrs.
- Vaporized > 5 Tonnes of Uranium
- Operated Source at 2 x Plant Design Vaporization Rate
- Demonstrated Copper Vapor Laser (CVL) Tube Lifetime at 33% of Plant Requirement
- Demonstrated CVL Switch Lifetime at 20% of Plant Requirement
- Operated CVL System Routinely at ~50% of Design
- Operated the Laser Demonstration Facility at 500 Watts Tunable Power (Nominally 1/10 of Plant)

Figure 12

Planned FY 87 AVLIS Accomplishments

- Demonstrate Significant Uranium Enrichment at 1/2-Plant Scale
  - Steady State Run Time >10 Hrs.
  - Near Full-Fluence Laser Pulse Illumination
  - Pulse Repetition Rate at 1/6-Plant Rate
  - Enrichment Rate ~500 SWU/Yr
- Separator Demonstration Facility (SDF)
  - Demonstrate Full-Scale Vaporizer Operation for >100 Hrs (12% of Plant Goal)
  - Initiate Activation of Full-Scale Pod Subsystems
- Demonstrate Copper Vapor Laser (CVL) Tube Lifetime at 50% of Plant Requirement
- Demonstrate CVL Switch Lifetime at 50% of Plant Requirement
- Extract 40% More Power From a CVL Chain
- Increase CVL System Output by 50%
- Increase Tunable Power From Laser Demonstration Facility (LDF) by 40%
- Complete Procurement & Initiate Installation of 2nd Corridor of Lasers in the LDF

Figure 13

Institutional Restructuring Is Needed to Provide:

- Stability
- Flexibility
- Reliability
- Credibility
- Accountability

Figure 14

First Major Revision of Criteria in 20 Years Completed in 1986

- 1966: Initial Criteria Established Basis for Contracts, Schedules, Charges, Specifications, etc.
- 1986: Revised Criteria
  - Validate the Utility Services Contracts
  - Do Not Impose Import Restrictions
  - Allow DOE to Price More Competitively
  - Grant Free VTAO to All

Result: Increased Stability, Reliability, Competitiveness

Figure 15

DOE Has Recommended Formation of an Independent Enrichment Corporation

- Clearly Defined Objectives
- More Businesslike, Competitive Approach
- More Flexible Pricing, Contracts
- More Streamlined Budget, Administration & Procurement
- R&D Based on Need
- Industrial-Style Management

Prompt Enactment of Legislation Needed

Figure 16

DOE's Recovery Strategy Is Working

- Normalize Supply & Demand: (Phase I)

  To Stabilize Market

- Streamline Production & R&D Programs: (Phase II)

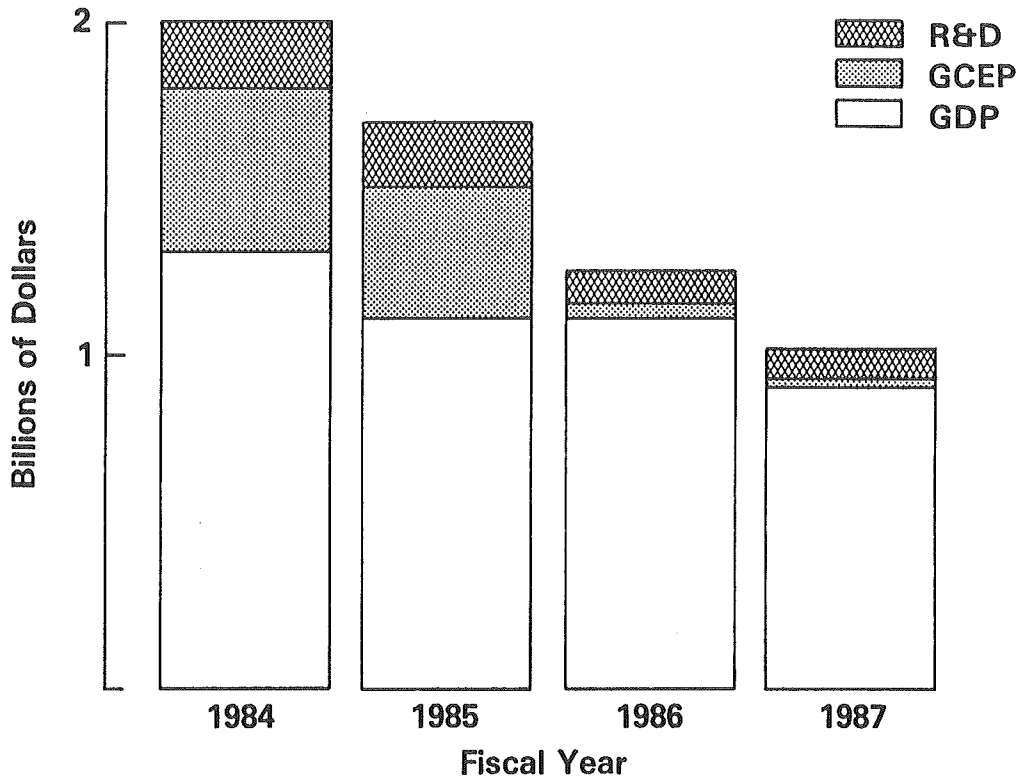
  To Reduce Costs

- Restructure Enterprise: (Phase III)

  To Provide Long-Term Stability

Figure 17

Costs Have Been Reduced by Nearly 50% Since FY 84



20th JAPAN ATOMIC INDUSTRIAL FORUM ANNUAL CONFERENCE

REPROCESSING: THE STRATEGY FOR A COMPETITIVE NUCLEAR ENERGY

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by

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A STRATEGY

Energy is essential to mankind and industrial developments in this field are a real endless story. Each source of energy entailed a progressive sophistication of its related industry: starting with the techniques responding to the most urgent needs, the development then progresses into more subtle processes with the view to save both money and raw material. Recycling of this material is the evidence of efficiency and maturity. In the oil industry, refinery is the first industrial equipment sought by a country exploiting an oil deposit ; a petrochemical plant is really a further step which requires time and more industrial maturity to be successfully achieved. Nuclear energy, in its turn, has its own pace of development and followed a steady time schedule devoted to master progressively the successive industrial steps of the reactor manufacturing and of the fuel cycle industries, in a rational order of priorities.

My country, similarly to Japan, being poor in natural energy resources, is developing an important nuclear energy program and has built up a long term strategy of nuclear fuel development. We will have spent 30 years in France, between 1960 and 1990, to cover the whole cycle on an industrial and commercially competitive scale. We started with mining

raw material, then we enriched it and we have recently achieved the industrial break-through of the back-end activities.
Closing the fuel cycle through the reprocessing and recycling steps is our strategic option because we cannot afford to waste the spent fuels, just back from the reactors and still valuable in fissile materials. Let me quote Ms Dixie Lee Ray, former US-AEC Chairman, at the Tucson recent "Waste Management Conference": "Spent fuel is a resource".

THE REPROCESSING INDUSTRIAL OPERATIONS IN FRANCE

From fundamental research to full-scale industry CEA and COGEMA have spent time and money to reach the present industrial development features by:

- A smooth operation of the reprocessing plant UP2 at La Hague for more than 3 years, in accordance with the design capacity.
- A guaranteed quality of finished products.
- High safety levels.

The back-end "package" services provided by our industry include:

- spent fuel transportation and storage
- reprocessing and waste conditioning
- plutonium and uranium recycling

Spent fuel transportation

More than 1700 transportation casks, i.e. over 5,000 tons of spent fuel have been safely shipped to La Hague from 60 LWR reactors of Europe and Japan.
COGEMA uses dry casks developed by the Transnucleaire group for transporting non-encapsulated spent fuel.
Let us mention the TN 12 cask, in operation since 1980, which contains 12 PWR fuel elements, with a thermal release of 85 KW, corresponding to a discharge burn-up of 35,000 MWd/t and a cooling period ATR of 240

days. This cask can alternately hold 32 BWR fuel elements.
For sea transportation ships have very sophisticated equipments in order to comply with very stringent requirements: an exceptional reliability, the protection of the crew from radiations, specific instrumentations and communication systems.
For ground transportation COGEMA uses preferably rail and road trucks are used only between the customer's reactor and the closest railroad station or seaport terminal.
In term of regulations, France, as practically all other nuclear countries, strictly abides by the rules of IAEA and those of other international organisations: OTI, IATA, which in turn are derived from IAEA regulations.

Spent fuel reception, unloading and storage

Centralized spent fuel storage has been performed in France since 1957 at Marcoule and a large experience of fuel reception and fuel storage has been acquired progressively with all sorts of fuels: gas graphite, LWR, FBR and MTR type fuels.
At the La Hague facility the reception unit has a capacity of 3 casks per day, a storage capacity up to 10,000 tons of LWR fuel, a cask maintenance facility of one to two casks per week. It is designed for the nominal reprocessing capacity of 1,600 tons/year.
In the dry unloading facility (called TO) the casks are set vertically on a trolley and adapted underneath a large handling dry cell with a special contamination-tight coupling device operated from inside the cell.
Such an industrial facility, besides being totally remotely run, presents the advantage of having the cask always free of contamination on its outside. The TO facility started operation in September 1986 ; it truly represents a breakthrough in cask and fuel handling.
The four large storage pools have a total storage capacity of 10,000 tons, the largest pool showing 4,000 tons capacity. These pools are seismic-proof and present several interesting features, including an in-pool heat and ion-exchanger units for added safety and cost savings.

Basket setting and fuel retrieval are remotely monitored. These equipments are designed and supplied by SGN.

Reprocessing

By the end of 1986, the La Hague UP2-400 plant has reprocessed more than 1600 tons of LWR fuel. The facility is presently running smoothly at its nominal 40 tons/month capacity.

In the field of safety results are evaluated by analyzing personnel exposure statistics. The annual average individual dose rate of La Hague personnel decreased from a maximum of 509 mrem in 1975 to 156 mrem in 1986, compared to a maximum allowable dose rate of 5000 mrem.

The specific dose rate, which is the ratio of the collective dose rate to the amount of electricity produced by the reprocessed fuel, decreased also to a level of 0.08 man rem/MWe yean in 1986. The corresponding figure for uranium mining is 0.25 man rem/MWe year and light water reactor operation generates specific doses of at least the same order of magnitude as uranium mining.

Under construction are the facility UP3 scheduled for the beginning of 1989 and the facility UP2 800 which is an extension and modernization of the UP2 400 plant and will be on stream in 1992. The total capacity of La Hague plant will then be 1600 tons/year.

SGN is the architect-engineer for the whole realization, coordinating the work of several other engineering companies.

The financing of UP2 is shared between COGEMA and EDF while UP3 is totally financed by foregin customers, to which this plant is presently dedicated.

These two new plants have integrated in their design the experience of a number of pilot, prototype or industrial reprocessing plants, such as UP1 in Marcoule, Eurochemic in Belgium, Tokai-Mura in Japan, UP2 400 at La Hague. Two major objectives have been sought in their design: safety and reliability. These goals cannot be dissociated, as the high availability factors, keys to low costs, are only achieved through high safety standards.

The safety of operation is obtained by choosing a safe process, safe

procedures, reasonable technical margins and many interlocks and automatisms to prevent manual errors ; but it remains true that safety is basically a question of staff quality.
We consider as essential that the operating company be fully and only responsible for the safety of its facility, since we believe that spreading of responsabilities can only be a source of mistakes. The company shall have to comply with the regulations edicted by the Safety Authorities in the frame of the operation licence issued by these Authorities.
Basically the reliability is obtained by choosing a well-proven technology. It is improved by incorporating results of operating experience. But it is also increased by establishing, at the design stage, the detailed maintenance procedures and by building from start spare production lines whenever necessary. Like safety, reliability is also a matter of staff training and competence.

Waste conditioning

Conditioning the wastes sorted at the outlet of reprocessing facility is a part of the overall back-end strategy.
We consider that well-managed conditoning and disposal increase the safety of the nuclear fuel cycle, compared to long-term storage of unreprocessed fuel elements.
To manage the wastes of a reprocessing plant one must take in account the site caracteristics and comply permanently with the ALARA basic principle. (ALARA : As Low As Reasonably Achievable). This management optimizes several parameters: gaz release, liquid emission, solid wastes production, residual activity, in relation with investment and operating costs.
At La Hague, dissolution offgases, tritium, krypton and iodine are disposed of according to their toxicity. Krypton and tritium are released at a controlled rate to the environment where dilution offers the best safe disposal way. Iodine is trapped in special offgas systems and iodine compounds are embedded in concrete for disposal. The low-level

effluents are concentrated and embedded in bitumen or concrete for disposal.

All the high level effluents are gathered. Accounting for more than 99 % of the total activity handled in the incoming spent fuel elements, they are residues of dissolution and extraction steps and of solvent cleanup. All these compounds are concentrated and incorporated into a borosilicate glass. Extensive research, in France especially, has led to the conclusion that this glass form is highly insoluble in all sorts of natural ground waters and that the glass blocks obtained, properly poured in all welded stainless-steel containers, can be safely disposed of in a man-made underground cavern with appropriate overpack and natural absorbent around each glass package.

The vitrification technology presently installed at La Hague (AVH) is extrapolated from the AVM process developed since 20 years at Marcoule, with extensive R and D conducted by CEA, including tests and fullsize operation of inactive pilot plants.

Six vitrification lines are being installed at La Hague, three for UP3 and three for UP2 800. The latter unit, called R7, will start operation in 1988, the other in 1991.

The glass canisters are let to cool down in concrete engineered storages. At Marcoule, the storage now contains about 1,500 glass canisters which have been elaborated since 1978. At La Hague, the storage will contain 2,500 canisters, i.e. the production of UP3 and UP2 800 from 5 years. Other storage modules can be built. After the 10 to 30 years cooling period, the canisters will be sent to the final repository.

From an environmental point of view, we consider that such system today is safer and more comprehensive that any other industrial waste management system. It has been adopted in particular by BNFL for the Sellafield facility.

As far as final repository is concerned, the governmental agency ANDRA is in charge of such disposals.

RECYCLING

Plutonium recycling

The french experience in plutonium fuels dates back to 1962. The CEA/COGEMA Cadarache fabrication facility supplied fuels for the fast breeder reactors Rapsodie, Phenix and recently Super-Phenix. An extension of this facility for the manufacturing of thermal uranium-plutonium oxydes - the MOX fuels - is currently in the commissionning phase.
COGEMA is associated with BelgoNucléaire (Belgium) in the Commox Company, a joint venture which sells the MOX fuel rods manufactured at Cadarache facility as well as at the Dessel plant owned by BelgoNucléaire. Mr. Bairiot will present in his paper a comprehensive view of this plutonium recycling industry, looking at both technical and economical aspects.
Loading MOX assemblies in a reactor has become a reality in several countries in EUROPE. In France the pressurized-water reactors reloads are currently designed and manufactured by FRAGEMA which incorporates in the bundles the MOX rods supplied by COMMOX. Two nuclear units are to be loaded in 1987 with MOX assemblies and EDF has plans to introduce such fuel material in up to twelve units in the coming years.
To store plutonium in a reactor while it produces energy appears to be the best way to prepare the future, that is the FBR reactor generation. Moreover in terms of safety, the most secure place for plutonium is indeed a reactor core.

Uranium recycling

Recycling the uranium recovered through reprocessing of spent fuels implies reenrichment of this material in order to raise its U235 assay from the residual value around 1 % to the usual 3-4 % range requested by LWRs.
Prior to reenrichment uranyl nitrate produced by the reprocessing plant has to be converted in a more suitable form. Presently, two basic converted products: oxyde and hexafluoride are proposed by a joint venture company, UREP, in which COGEMA and COMURHEX are associated. Both

companies operate complementary facilities and are planning a large new conversion plant consistent with the output of the reprocessing plants in the nineties.

Practically the reprocessed uranium shows a slight content of transuranic and daughter products, the most of it being removed in the conversion step, but still contains noticeable quantities of minor uranium isotopes resulting from the in core irradiation. As far as aerodynamic enrichment processes are concerned it is easy to anticipate that roughly two third of the amount of U236 and almost all the U232 present in the feed flow will be recovered in the enriched product.

While daughter products of the U232 might require special attention in fuel manufacturing facility in case of high content, the main concern is the presence of the neutron absorber U236, which has to be compensated by an over enrichment in U235 to maintain the reactivity of the enriched product. One must know that discussions are still taking place within the ASTM association regarding the maximum U236 content allowable in the enriched product in order to treat it as a natural uranium originated product. A range of .005 to .01 for the U236/U235 ratio is presently considered.

To comply with this limit we can feed the reprocessed uranium in our plant in a proportion of 1.5 % to 3 %. This dilution method is helpful to cope with the limited quantities of recovered uranium available during the few next years.

The other way to manage such reenrichment is campaigning. The Tricastin EURODIF plant can be operated in campaigns of around 1500 tons each. In this case a certain amount of subsequentnatural uranium feed will be affected by the residual decreasing presence of U236 in the cascade ; this amount is several times the quantity of reprocessed uranium introduced at a time in the plant, but the equilibrium rate of 1 kg of REPU received for 1 kg of enriched uranium produced implies a margin sufficient to make sure that the U236 isotope is fully absorbed within the limit of the dedicated campaign.

For the longer term, the AVLIS process will provide a better selectivity by increasing only the U235 content through the enrichment process. The minor isotopes encumbrance will be then drastically reduced, reinforcing the incentive to recycle reprocessed uranium and even raising possible

interest for temporary storage of this material.

COST OUTLOOK

In the last past years several studies on the nuclear fuel cycle economies have been published. It is understandable that, after the large amounts of money invested in nuclear units construction, the electricity producers are looking for all possible savings in the management.
The fuel cycle implies such a number of various services that it is a favored area for optimization and cost reduction policy.
Studies have been devoted to economic comparison of closed fuel cycle (i.e reprocessing and recycling) versus once-through cycle (considering the spent fuel as a waste to be disposed of permanently). A most complete report on this subject was issued in 1985 by OECD/ENEA, using 1984 data and presenting a comprehensive description of the cost calculation method for both closed and open cycles.
Using the same method we recently performed an in-house comparison, feeding the model with our industrial expertise and the most up-to-date actual costs.
A major parameter governing the economic assessment of the closed fuel cycle is obviously the reprocessing cost and its future evolution. COGEMA first achieved a thorough analysis of this important feature and reached the following conclusions:

. The smooth operation of the UP2 400 facility at La Hague is a strong basis for predicting better availability factor than prudently anticipated for the next units.

. The satisfactory progress of UP3 and UP2 800 construction program confirms the full industrial maturity of large scale reprocessing units.

. Subsequent to the amortization period of 10 years of base load operation the UP3 plant will still have substantial capacity available to foreign customers.

. Despite some maintenance and refurbishing expenditures, these circumstances result in a significant reduction of the reprocessing cost by the year 2000.

. The price reduction might reach the 30-40 % range for a long-term contract. Current base-load customers will certainly have priority right to this new conditions.

Now when we take in account this cost evolution, which is all but surprising in the industry, the overall fuel cycle cost appears clearly lower for the reprocessing/recycling option than for the uncertain once-through route.

CONCLUSION

Reprocessing is not an engineer fantasy nor a technocratic obstinacy. It is a real strategic choice for a competitive nuclear energy. This choice has been very demanding in development, investment and management efforts but we have now in France at our disposal the whole set of the proven techniques able to cover all features of this portion of the nuclear fuel cycle.

The review of this various features presented in this paper shows the thorough development devoted to each industrial step and the consistency of the overall strategy. The economic avantage is clearly a result of this industrial achievement.

Beyond the purely economic argument the competitiveness of nuclear energy encompass other important considerations such as safety, security of supply and environment protection which also confirm the positive aspect of reprocessing/recycling route.

Proper conditioning of HLW, MLW, LLW and separation of recyclable material are responsible attitudes towards our future, bearing in mind that it is mandatory to leave an acceptable and manageable solution for the generations of the 21st century, instead of letting them handle our problems.

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PERSPECTIVES OF THE REPROCESSING OF NUCLEAR FUEL IN THE FEDERAL REPUBLIC OF GERMANY

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Introduction

Within a period of 25 years from the first power reactor going on line in Germany, nuclear power has developed into a major factor in electricity production. Today, there are 21 nuclear power stations under operation in the Federal Republic of Germany, sharing almost 35 per cent of electricity production, the same order of magnitude as electricity production from hard coal. Taking into account the three 1300 MW convoy plants presently under construction, nuclear power to date has developed into an indispensable source of energy for electricity.

It was decided not less than thirty years ago, that is four years before the first power reactor went into nuclear operation in Germany, to reprocess the spent fuel from power reactors. However, it was realized at that time that the amount of spent fuel to be expected from the first nuclear power stations in the early days of nuclear power would be too small to sustain commercial operation of a reprocessing plant.

It is to be emphasized that an integrated fuel cycle back-end concept has been developed over the past few years in a joint effort by politicians, public authorities, and the utilities in the Federal Republic of Germany. This concept, described by the term integrated nuclear waste management concept, includes all activities concerned with the reprocessing of spent nuclear fuel, disposal of radioactive waste, and related steps such as transport, interim storage and conditioning.

Spent Fuel Management

All management of spent fuel in the Federal Republic of Germany has to be in accordance with the relevant articles of the Atomic Energy Act. The provisions of this Act call for reprocessing of

spent fuel as long as environmental protection is achievable from a reprocessing plant in accordance with current scientific and engineering practice and is economically justified. On the basis of the Atomic Energy Act, guidelines were issued in 1980 by agreement between the Federal Government and the State Governments to enable the utilities to formulate a strategy for spent fuel management.

In parallel, a programme for the investigation of the potential for direct disposal of spent nuclear fuel had been initiated in 1983. This programme led to the development of a final disposal cask system called POLLUX and the concept of a pilot plant to be built at Gorleben for the conditioning of spent nuclear fuel which, for technical or economic reasons, is not to be reprocessed.

In compliance with the Atomic Energy Act the DWK (Deutsche Gesellschaft für die Wiederaufarbeitung von Kernbrennstoffen) decided to erect a nuclear fuel reprocessing plant in Wackersdorf in the state of Bavaria in the Federal Republic of Germany. With this decision, the DWK took the first step towards closing the nuclear fuel cycle with a plant of industrial size for reprocessing of nuclear fuel. The plant will have a throughput of 350 metric tons of uranium per annum or about 2 metric tons a day.

The decision in favour of the reprocessing plant in Wackersdorf and especially as regards its capacity were based on the expected volumes of spent fuel from all German nuclear power stations. In accordance with the German nuclear power programme, the amount of nuclear fuel expected over the next 30 years ranges from roughly 350 tons heavy metal per year to a quantity of 600 tons heavy metal per year at the close of the century, taking into account an increase of 1.2 per cent per year in the burn-up of nuclear fuel.

Spent fuel management is based on contracts for the reprocessing of nuclear fuel with Companie Générale de Matière Nucléaire (COGEMA) and with the British Nuclear Fuel (BNFL) and also with the Wiederaufarbeitungsanlage Karlsruhe (WAK) in Germany plus the capacity of the national Wiederaufarbeitungsanlage Wackersdorf scheduled to be in operation by 1995.

Thus, all nuclear fuel expected from German nuclear power plants up to the year 2010 will be manageable. There are only a few excess quantities which will be covered by options in the contractual agreements provided both by COGEMA and BNFL. Small amounts of nuclear fuel will be directly stored. These can be taken care of by supplementary contracts with other countries. Compared to the expected growth rates of nuclear power, even under the assumption that the burn-up of nuclear fuel will not increase, the reprocessing capacities available in 1995 will be higher than the expected quantities. Therefore, advance arrangements for waste management, an essential prerequisite for the licensing of nuclear power stations in Germany, are assured.

The reprocessing plant in Wackersdorf

Plant capacity

The plant will have a throughput of 350 metric tons of uranium per annum or about 2 metric tons per day. The spent fuel to be processed is from either PWRs or BWRs and may have a burn-up of an average of about 40.000 MWd per ton. The spent fuel is to be stored for a cooldown period of 7 years before reprocessing. The enrichment is limited to a maximum of 4 per cent U 235 equivalent. A data list provides further data concerning the products and the resulting amounts of radioactive waste.

The layout of the WAW in Wackersdorf

The reprocessing plant in Wackersdorf comprises all process areas necessary for reprocessing of spent fuel and waste management as well as areas envisaged for fuel manufacturing: There is in particular the storage building for spent fuel, the main process building which includes spent fuel reception, extraction of uranium and plutonium, plutonium purification, processing of high and medium active waste including high active fission products, vitrification and uranium purification. Further facilities are envisaged for nuclear fuel fabrication, the management of low-activated waste, and the intermediate storage of material for final disposal.

The FEMO technique for improved maintenance

Within the overall terms of the construction and operation of reprocessing plants, various maintenance principles have been developed with respect to the specific technological peculiarities of reprocessing plants. In principle, one may subdivide the maintenance concepts used in reprocessing plants into three groups: these are direct maintenance, indirect maintenance and remote-controlled replacement and exchange of components.

During the decision making process over the maintenance concept to be chosen for the Wackersdorf reprocessing plant, experience gained from reprocessing plants worldwide was studied. In order to provide a basis for technical judgement with respect to the various maintenance philosophies, the first extraction cycle (HA - HS) was analyzed in such way that the component layout and building layout could be evaluated in detail.

In these studies the building cross-section and thus the maximum cell height and width of the basic concept were fixed. In addition it was found to be advantageous to install all components of the basic process in racks, a principle which has been developed into a specific feature of the reprocessing plant in Wackersdorf.

For both maintenance and exchange of components, installation in racks which can be exchanged as complete modules provides the following advantages:

- first:
  the racks holding the process components may be subjected to all required tests before the hot functioning test, which includes proper functioning, calibration, tightness etc. This commissioning can be performed for subsystems prior to their initial installation and, when necessary, prior to exchange.

- second:
  the combination of several components in one rack means that rack systems reduce the number of high precision assembling and connecting points required compared to individual and separate installation

- third:
  the racks including some of the components may be recycled if they are found to be operable after service and maintenance

- fourth:
  disassembly of the plant or parts thereof with the aid of remote-controlled handling machines following facility shutdown is simplified.

The FEMO technique, that is modular system design for remote handling, incorporates experience gained in other reprocessing plants and also the advantages of various maintenance concepts. The components are arranged in racks which are mainly standardized frames, such arrangement being designated as a module.

In order to facilitate the handling of modules, the cell crane is backed up by a manipulator system having horizontal access from the handling gangway to the process apparatus used for manoevring the operating and maintenance equipment and tools.

Present state of the art is to use electrical servo and power manipulators, but more advanced developments such as robots or computer controlled devices can easily be introduced.

The FEMO technique is thus based on proven systems of today. But is also credited with the developments which have taken place recently in both conventional and nuclear technologies in the areas of remote operation, control, video and signal transmission techniques.

In the Wackersdorf reprocessing plant, the FEMO technique is to be applied in high and medium radioactive process areas. In other areas, where typical mechanical processes take place due to specific operation, the hot cell technique is applied by reason of the experience available. A typical example is the break down of fuel rods. The ancillary devices required for the remote operation of the operating processes in this area is of such design that it can be used directly for maintenance procedures.

The wet chemical process areas of the WAW facility are arranged in two large scale cells of approximately the same size, arranged in parallel. These are known as FEMO cells and are located in the main process building. Within these cells the process equipment is arranged in standard modules with dimensions of approximately 3 times 3 meters and a height of approx. 13 meters on both sides of the longitudinal walls of the FEMO cells.

There is a passageway with a width of approx. 4 meters extending over the entire cell length between the modules. The center passageway is used for movement of the remote-controlled maintenance equipment alongside the cells. The arrangement of the pipes and the process equipment in the modules was chosen such that components which are subject to wear and tear, such as components with an assumed life time of less than five years (example: pumps, valves, measuring equipment), are arranged at the front of each module. These so-called replacement components are either flanged or bolted onto their surrounding equipment and mechanical structures. All other process equipment is welded in place.

This concept of providing maintenance to the plant is suitable to demonstrate that incidents such as failure of a dissolver can be dealt with as a matter of routine. Other components with an expected limited life span can be replaced with the aid of such a remote-controlled procedure in the space of only a few days. This principle has been carefully planned beforehand and is thus a priori licensable thanks to its little to zero radiation exposure of maintenance personnel.

It can be concluded that the FEMO plant design offers quite a few advantages, two of which should be strongly emphasized. First, it certifies the legal demand to minimize the radiation burden on the operating staff while, secondly, it facilitates continuous improvement to operating performance by simply replacing various modules by more developed ones ready tested and commissioned before installed in situ.

Licensing

The nuclear licensing procedure

The Wackersdorf reprocessing plant is subject to the same licensing requirements under the Atomic Energy Act as are nuclear power plants. The body responsible for granting a license to the WAW is the Bavarian Ministry of the Environment, which checks the application and obtains expert opinion. The licensing body may also call in other authorities and institutions to evaluate the application. These are responsible for or specialized in dealing with questions of detail such as control of water consumption and others.

To date, all expert opinions and authorities have confirmed that the conceptual design of the Wackersdorf reprocessing plant is in accordance with the aims of the Atomic Energy Act, which demands emphatically the protection of the population from any potential hazards emanating from a nuclear plant.

In September 1985, DWK was granted the construction permit for the first plant section, which comprises the fuel assembly reception store, the module test facility, the center workshop and security measures such as the perimeter fence and the guard-houses.

Following this first step, the permit for the second stage of construction comprising the central process building is expected for late 1988. The third stage of licensing comprises mainly the buildings for uranium purification and LAW treatment. The fourth stage, finally, covers the remaining buildings of the plant.

The contractor of the plant

The basis of today's knowledge on the reprocessing of nuclear fuel in the Federal Republic of Germany are the results of the development work which was done in conjunction by DWK and Kernforschungszentrum Karlsruhe. The various steps of reprocessing and also the development of components have been carried out in the Wiederaufarbeitungsanlage Karlsruhe (WAK) and in the component test facilities (TEKO), the hot chemical institute at Karlsruhe and in the FEMO test facility in Lade. Valuable experience in the operation of the vitrification process is being gained from operation of the PAMELA plant in Mol in Belgium.

In 1985 a turnkey contract was awarded to a consortium of companies representing the most advanced know-how in nuclear and chemical technology in Germany. KWU is leading the consortium which includes Uhde/Lurgi and Nukem and Kraftanlagen Heidelberg (KAH) for the process engineering and remote handling machines in the relevant processing areas and with Hochtief, Dykerhoff and Widmann and Heitkamp for the civil work.

The Société Générale pour les Techniques Nouvelles (SGN) is being considered as a contractor for specialist work.

In accordance with special contracts within the Consortium, the scope of supply and services is assigned to the individual companies making up the Consortium commissioned to design, to erect and commission the plant.

The companies involved have decided to combine their reprocessing activities - other than for Wackersdorf - under the present consortial structure. The EWW is prepared even for international cooperation within bilateral government agreements.

The time schedule for the Wackersdorf reprocessing plant

The first construction permit authorized the preparation of the plant site including the guard fence and also the erection of the spent fuel assembly receipt and storage building. Whereas site preparation had been largely completed in 1986, the construction of the buildings will start in the spring of 1987.

After issuence of the second part permit in 1988, erection of the main process building is expected to start in 1989, which activities establish the critical time path for overall plant erection. Following this sequence, the plant will be commissioned in 1993 for cold functional testing and in 1995 for the hot functional testing.

Conclusions

Irrespective of the political discussion about nuclear energy in general and the reprocessing of nuclear fuel in particular, the legal basis for the erection of the Wackersdorf reprocessing plant is clear and calls for reprocessing of nuclear fuel.

The Chernobyl disaster, however, created a backstroke for the nuclear power industry in the Western World and in the Federal Republic of Germany in particular, prompting renewed discussion of the question as to whether the employment of nuclear power is morally justified. With great understanding for the irritation caused to the public on the subject of the acceptability of nuclear energy, the further development of nuclear energy will depend on how soon public confidence in the safety of nuclear power can be restored.

The progress of the Wackersdorf plant will depend very much on the political support forthcoming both from the Federal Government in Bonn and from the Bavarian State Government in Munich. With the confirmation recently announced by both governments, there should be no doubt that the plant will be successfully completed in accordance with the time schedule.

Reprocessing of Oxide Fuel at Sellafield

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Introduction

The total capital expenditure required for reprocessing oxide fuels at Sellafield will be about Stg. Pnd. 2,600 million in January 1987 money values. The front end facilities account for about Stg. Pnd. 400 million of the total and include plant for the storage and dismantling of irradiated fuel from the UK Advanced Gas-cooled Reactors as well as the receipt and storage of irradiated LWR fuels from overseas. Whilst the expenditure on the thermal oxide reprocessing plant, (THORP), is the largest single item, at about Stg. Pnd. 1,200 million, the facilities for the treatment of wastes and effluents amount to about Stg. Pnd. 1,000 million.

Some of these waste and effluent treatment plants are shared facilities, in support of both the present reprocessing of fuel from MAGNOX reactors as well as the future reprocessing of oxide fuels when THORP is commissioned. Key items of the total construction programme are as follows:

i. Provision for the maintenance of fuel transport flasks; these are now completed.

ii. Major facilities for the storage and dismantling of AGR fuels; these are now being commissioned.

iii. Shared facilities for waste and effluent treatment; these are now under construction. The Windscale Vitrification Plant (WVP) and its associated store is the first major plant with operation programmed for February 1990. The WVP will have two process lines with a combined throughput which removes the requirement to construct more tanks for the storage of the highly active liquid waste produced by reprocessing operations.

iv. Treatment plants, such as the Enhanced Actinide Removal Plant (EARP), required to further reduce the level of activity (especially alpha) in the low active liquid effluents discharged from the Sellafield site; these plants are programmed for completion before the start of operation of THORP in 1992.

v. The THORP solid waste encapsulation plant; construction is programmed to commence in 1987 for operation in 1992. This plant, known as EP2 will have facilities for the direct encapsulation of leached hulls and centrifuge cake in a cement matrix. Other provisions within EP2 will facilitate the cement encapsulation of materials produced in effluent treatment plants such as EARP.

This paper will present a summary of the main features and construction progress of THORP. Product recycling will also be discussed.

Thermal Oxide Reprocessing Plant

Construction commenced in 1983 on the Receipt and Storage Plant. This was significantly expanded in 1985 when major construction work on the Reprocessing Plant commenced.

Receipt and Storage

Fuel from the UK and Overseas will be received into the THORP Receipt building in wet flasks on either rail or road transporters.

The Receipt building, approximately 70m long, 36m wide and 34m high, contains the Inlet Pond with the Inlet Pond Handler and all the equipment necessary for flask handling, environmental protection and process control. The Inlet Pond is about 10m x 9m in plan and has a maximum depth of 14m to accommodate the handling of LWR flasks. A connecting channel permits transfer of items from the Inlet Pond to the Storage Pond using a Rack Transfer Machine.

The Storage Pond Hall, approximately 100m long, 43m wide and 35m high houses a storage pond and Pond Handling Machine. The storage pond is approximately 72m long, 24m wide and 8m deep and provides for 300 tonnes of AGR dismantled fuel and 1,200 tonnes of LWR fuels. A recirculating cooling water system employing primary and secondary circuits via plate heat exchangers provides a heat rejection capacity of 8MW using induced draft cooling towers.

These facilities are programmed for commissioning in 1987, building and civil construction work is virtually complete. All the major mechanical equipment has been delivered, installation is progressing and testing has commenced.

An additional storage pond is now under construction. This will be the same size as the first pond and is programmed for commissioning in 1989.

Fuel from the AGR reactors will have been dismantled and the separated fuel pins from 3 assemblies placed in special cans for mechanical handling. This process is undertaken in new facilities adjacent to the recent commissioned Fuel Handling Plant. This procedure removes the graphite and stainless steel structural components from AGR fuel assemblies, permitting the fuel pins from 3 assemblies to be stored in the space equivalent to 1 undismantled assembly, thereby improving the utilisation of storage facilities. Transport from the FHP utilises skips which contain up to 20 cans (approximately 2.7 tonnes of uranium) in rectangular flasks having a total weight of about 52 tonnes.

These flasks are lifted from their transporter and are submerged in the inlet pond, the lids are removed and the skips of AGR fuel are transferred to a separate storage container. The containers are then transferred to the storage pond. In the main storage pond the containers will be stacked up to 3 high in predetermined positions.

Fuels from LWRs are contained in Multi Element Bottles (MEBs) and are transported in conventional water filled cylindrical flasks with a total weight of about 100 tonnes. MEBs are sealed cylindrical containers used for both transport and storage at Sellafield. Each MEB can contain up to 17 BWR or 7 PWR fuel assemblies. The average uranium content of an MEB is approximately 2.7 tonnes. Transfer operations in the receipt of fuel are simplified because the MEB is handled as a single item thus avoiding individual handling of fuel assemblies.

Handling procedures for LWR flasks generally follow those for AGR flasks. In the inlet pond the MEBs are removed from the flasks and placed, in pairs, into storage racks. In the main storage pond the racks are placed in predetermined positions.

Reprocessing Plant

The Reprocessing Plant comprises the following main sections:

i. Head End and feed preparation plant;

ii. Solvent Extraction Separation equipment;

iii. Product finishing (both PuO_2 and UO_3);

iv. Medium Active liquid effluent treatment and evaporation;

v. Low active liquid effluent handling facilities:

vi. Centralised services for ventilation and control of serial discharges;

vii. Centralised reagent preparation and distribution.

These facilities are housed within one building approximately 250m long, 150m wide and 50m high. A 120m high ventilation stack is also included.

Construction work commenced in mid 1985. The labour force now totals over 2,000, including about 500 supervisory staff on a two shift work pattern. Where possible special measures have been employed to ensure work necessary prior to the installation of plant and equipment can be completed as required. For example the cell tops have been weather protected to allow stainless steel cladding to commence as early as possible and this strategy has been very successful.

To date about 20,000 tonnes of reinforcement steel has been placed which is 67% of the total and over 80,000m^3 of concrete out of a total of 150,000m^3 ie about 54%.

The first sections of building steelwork have been erected and a further 3,000 tonnes, 20% of the total, has been fabricated and is being stored off-site awaiting erection.

The main biological shielding for the Head End processes is substantially complete up to the 15m high floor level. Work has started on the floor level at 21m and once this floor level is complete the building frame steelwork can be errected. Construction of the biological shielding will then be completed within the building envelope. The 15m floor level was, where possible, weather protected and stainless steel cladding has been progressing in those areas.

The main biological shielding for the chemical processes is complete up to the 11m floor level and construction is continuing on those cells which extend about the 11m level.

Procurement of plant and equipment is progressing. Approximately 1,000 of the required 1,400 vessels have been ordered and early items are now ready for delivery. The installation of plant and equipment will be integrated with the building work and is expected to commence later this year.

Head End

Access to the Head End is through a feed pond which is connected to the main storage ponds by a channel. The feed pond is approximately 37m long and 10m wide and can be segregated into various sections. Whilst the main area of the pond has a working depth of 8m the fuel unloading bay requires a depth of 14m.

Fuels will be transferred from the storage pond to the feed pond by the Rack Transfer Machine. Within the feed pond major mechanical handling will be performed by the Feed Pond Handler. Procedures for opening containers of AGR dismantled fuel or MEBs are carried out by special machines within the feed pond. Containers of AGR dismantled fuel of MEBs follow the same general path; to avoid duplication the treatment of only MEBs is described here.

The first operation performed on MEBs is venting and purging. The water in the MEBs will then be removed, this water might be contaminated with activation products from the fuel cladding and fission products. The lids will then be removed and MEBs transferred to the deep section of the feed pond for fuel removal. Fuel assemblies will then be transported to a monitoring station where fissile content, burn-up and cooling time will be checked. After monitoring the fuel assemblies will be placed on an elevator which lifts them from the feed pond into the shear cave.

The shear machine is hydraulic powered with all the hydraulics located outside the biological shielding. The mechancial assembly (the shear pack) for gripping/compacting and cutting has been designed for remote maintenance and to minimise the retention of fuel assembly debris.

Horizontal location of fuel assemblies in a fixed blade and anvil with a vertical cutting stroke ensures centralised loading of the shear pack. When necessary the shear pack can be disconnected from the system of rams and moved to specially designed locations for remote maintenance.

The material from the shearing operation falls from the shear pack down a containment tube into a basket located in the dissolver. Three such dissolvers are provided. Gadolinium will be used as a soluble neutron poison as a safeguard against potential criticality. Upon completion of shearing 1.7 tonnes of fuel per dissolver batch, the temperature of the acid will be raised to complete the dissolution process. The total cycle of shearing and dissolution takes about 16 hours.

During dissolution volatiles typically, oxides of nitrogen, water vapour and active species (C14 and I129) and inert gases (Kr and Xe) are released in the off-gas system. The major part of the NOx and water vapour are recovered as nitric acid. The residual NOx and the major part of the C14 and I129 are removed from the gas stream by contacting with caustic soda solution in packed columns. The C14 will then be precipitated from the aqueous stream as barium-carbonate and encapsulated in cement. The I129 will be retained in the aqueous stream and discharged to sea. Kr and Xe will be discharged to atmosphere.

After dissolution the fuel assembly debris will be monitored for residual fuel content before being transferred out of the THORP for encapsulation in cement. If necessary the fuel assembly debris could be returned to the dissolvers for further treatment to reduce the residual fuel content.

Batches of dissolver liquor will be fed to one of two suspended solid bowl centrifuges for removal of fission product insolubles and cladding fines. The removed solids will be transferred for encapsulation in cement.

The clarified dissolver liquor is passed forward for accountancy and held in a buffer storage system. The liquor can also be conditioned to ensure optimum performance of the solvent extraction process.

Chemical Separation

Solvent extraction

The solvent extraction plant for THORP uses the Purex flowsheet which has worked well at Sellafield for many years on the MAGNOX programme.

Two factors necessitate changes from the MAGNOX process; viz:

i. the higher plutonium content of high burn-up oxide fuels

ii. the need to reprocess fuels of higher specific activity whilst reducing the quantity of liquid waste to be stored or discharged to the environment.

The first factor has led to the adoption of pulsed columns for all stages of the separation process where significant quantities of plutonium are present. The second factor has resulted in the adoption and development of an essentially 'salt-free' flowsheet. This differs from the MAGNOX flowsheet in which ferrous sulphamate and sodium nitrite are added into the main stream process as reducing and oxidising agents. These salts appear in liquid waste streams and either prevent or severely limit their concentration and subsequent treatment. In the THORP flowsheet these are

replaced respectively by uranous nitrate/hydrazine and oxides of nitrogen as the main plutonium reducing and oxidising agents; hydroxylamine is also used as a reducing agent to improve performance in some sections.

The THORP solvent extraction plant is, therefore, based on an 'early split' Purex process operating in pulsed columns for the first (Highly Active) cycle. Plutonium purification is carried out in pulsed columns and uranium purification in mixer-settlers.

Plutonium Oxide Production

PuO_2 will be produced by the oxalate precipitation process. The precipitate will be filtered on a rotary filter, the cake dried and calcined under argon to convert the oxalate to the dioxide. Plutonium dioxide will be finally packaged in stainless steel containers and transferred to storage.

Uranium finishing

The Thermal Denitration process is used to convert uranyl nitrate to uranium trioxide. From the uranyl nitrate evaporator the concentrated liquor will be fed to four fluidised bed reactors. The reactors have been designed to accommodate a residual U235 enrichment of up to 1.7%. The uranium trioxide powder will be cooled and placed in drums for storage. The drum contents will be monitored for U235 concentration.

Off-gases and vapours from the TND reactors will be cooled and condensed, the resulting liquors being routed to the salt free evaporator for treatment and acid recovery. The residual oxides of nitrogen will be absorbed by alkaline scrubbing and inerts discharged to the environment.

Highly and Medium Active Liquid Waste

HA liquid waste and Salt bearing medium active liquid wastes, from the solvent washing systems, will be transferred out of THORP to existing evaporation facilities on the Sellafield site for further treatment.

Salt free liquid waste will be directed to the THORP Salt Free evaporator for concentration. A double effect evaporator will be used and the vapour overheads from the second effect will be taken as feed to a distillation column for recovery of nitric acid. Concentrate will be transferred to join the HA liquid waste from the first cycle. Thus all fission products and actinides which are present in these streams will eventually be treated as high level liquid waste and will be solidified by vitrification in WVP.

Low Active Liquid Waste

Low active liquid wastes arise from several secondary process operations in the Chemical Separation plants, typically evaporator overheads and liquids used in the decontamination of ventilation extracts. Whilst the environmental impact of these streams is considered to be very low they will be sent to new facilities being designed to minimise discharges to the environment.

Maintenance Policy

A reprocessing facility encompasses a wide range of maintenance requirements ranging from conventional chemical plant in reagent preparation areas to special requirements necessary for both mechanical and chemical plant exposed to contamination by radio active materials.

Maintenance requirements for plant handling active materials are considered at the design stage to ensure that dose uptake to the workforce is minimised. As a matter of policy prime movers, such as electric motors, are located outside the primary biological shielding and equipment placed within active cells is designed to be mechanically robust. For in-cell equipment working stress levels are limited to low values. Extensive testing of components is undertaken to give confidence in the design life of items placed in active environments.

Inspection and surveillance facilities, generally based upon closed circuit television, are provided for all caves and cells. In very special cases, for example where solids deposition might be expected, inspection in vessels is also provided.

This policy results in a plant design in which equipment which might be forseen to require maintenance is located outside the primary biological shielding but placed within engineered enclosures which provide such shielding as necessary. All in-cell equipment is designed to be 'maintenance-free' but provisions are made for direct contact maintenance should that prove to be necessary in extreme cases. The provisions for direct access include extensive facilities

for washing out and decontamination.

Liquor transfer systems which do not require moving parts to be located behind shielding have been developed. Actuators and control systems for these devices are contained in bulges or cabinets which are positioned to limit any back diffusion of activity which may result in contamination. Where it is considered that an item might be vulnerable a duplication policy is adopted to minimise the effect on plant operation.

When equipment is placed within engineered enclosures (bulges) provisions are made to facilitate access. Attention is also given to the provision of subchangeroom requirements to limit the possible spread of contamination. In this respect correct ventilation is important and it is necessary to ensure that ventilation flows are from areas of low activity to the higher activity areas.

There is one significant departure from the above policy in THORP. Specific provisions are being made for the remote maintenance of the fuel shearing system. Whilst the hydraulic power system is positioned outside biological shielding it is considered that direct maintenance of the shearing blades and their support bearings is not practicable within acceptable dose uptake limits. Therefore, the cutting blades and associated bearing mechanisms have been designed into a 'shear pack' so that they can be removed, disassembled, parts replaced and reassembled in a fully remote manner away from the operating position. This work is to be undertaken in a dedicated maintenance facility comprising decontamination equipment to limit

the spread of contamination and three maintenance stations equipped with the necessary special tools.

The policy outlined above has been developed as the result of practical experience gained over a significant period of operating active plants, together with their decontamination, maintenance and refubishment. Such experience includes work at both Sellafield and Dounreay.

The first reprocessing plant at Sellafield was in operation during the 1950's. That plant was subject to decontamination prior to major refubishment in which the fuel handling system dissolvers and highly active solvent extraction were removed, replaced or substantially modified.

The second reprocessing plant at Sellafield came into operation in the early 1960's. Since that time the evaporation plants used to concentrate medium active raffinates have been decontaminated and refurbished. This work has included the complete removal and replacement of the evaporator callandrias.

More recently the dissolver and steam stripping section of the second separation plant has been decontaminated and man access established in preparation for replacement of the dissolver.

At Dounreay the refurbishing of the Fast Reactor Fuel Reprocessing Plant has been completed. That work required the decontamination and removal of both fuel preparation equipment and highly active solvent extration equipment. In addition substantial modifications were made to the

biological shielding. Replacement with new equipment was achieved without significant dose uptake to workers.

Throughput Reliability

The nominal capacity of THORP is 1,200t per annum; this is the capacity that would be achieved in a good year when the overall plant reliability is high. The quantitative prediction of plant capacity involves the combination of the individual item reliabilities, the decoupling effects of buffer storage, and the impact of variations of instantaneous throughput of plant sections. The assessment technique adopted has been Stochastic Modelling.

The THORP Head End and Chemical Separation Plant has been extensively studied using this technique. The initial simple block models with overall reliability and operating parameters based on judgement have been superseded by more detailed assessments of plant sections - for example the Uranium Purification Cycle, Plutonium Purification Cycle and the Highly Active Cycle. To obtain statistically valid results, the computer models were run for extended operating periods.

Availability and reliability data have been derived from assessments or from existing plant experience. These data, and the model operation philosophy, have been the subject of sensitivity analyses to ensure that conclusions drawn from the studies are robust.

Stochastic modelling for THORP concludes that throughputs in a range from about 1,000 to 1,200 tU per annum are achievable within two 150 day campaigns. 1,000t per annum is, therefore, achievable whilst still retaining a margin.

Similar detailed consideration has been given to Pond storage and to the capacity of ancillary plant on which the operation of THORP depends.

This work provides a sound basis for the decision to increase the anticipated capacity of the THORP from 6,000 tU to 7,000 tU during the first ten years of operation.

Product Recycle

The benefits of recycling reprocessed uranium can be obtained via a number of routes. The main options are:

i. Use as a carrier in mixed oxide (MOX) fuel fabrication. Whilst this is a course of action widely favoured, less than 20% of the reprocessed uranium can be utilised this way. The limit is set by the total amount of plutonium available.

ii. Sale of the uranium on the market, presumably to a utility with a definite end use. This happens on a small scale at present and may increase in importance when commercial recycling is established. Moreover the value of the reprocessed uranium will be determined by the usual methods.

iii. Recycle back as fuel, either by:

a. conventional conversion, enrichment and fabrication or by

b. blending with other low enriched stock material.

BNFL believes that the majority of reprocessed uranium will be recycled via the conventional UF_6 conversion and enrichment route. The economic benefits of recycle via this route depend on the uranium quality, the costs of recycle in comparison with normal fuel and the size of the enrichment and virgin uranium cost savings. For typical concentrations in the THORP LWR baseload (which has U235 in the range of 0.9 - 1.0% and U236 concentrations in the range 0.2 - 0.4%) recycle is beneficial compared to uranium prices of $5/lb or less. As this is well below current or expected prices it can be seen that such recycle is providing cost savings broadly equal to the cost of uranium.

To avoid the additional costs of UF_6 conversion and enrichment it might be possible in some circumstances to blend the reprocessed uranium directly with higher concentrations of unirradiated uranium to produce the correct enrichment for fuel. An overall saving results if the loss in separative work caused by the blending operation is less than the additional recycle costs.

The cost of lost separative work per kilogram for a range of concentrations of reprocessed uranium, when blended with 2.5% material to give final blends in the range 1.3 - 2.2% can be assessed. The net avoided cost would be in the range of \$10 - 20/kg, comprising the reprocessed UF_6 conversion cost and the premium for enrichment minus the cost of blending the uranium and any additional fuel fabrication premiums (the total amount of reprocessed uranium will increase because of blending). Typically with 0.9% reprocessed uranium a saving is thus only obtained if the final concentration is below 1.5%. Thus blending as an option will only be economic for small quantities of reprocessed uranium, if at all.

Effects of Timing

The timing of the decision on recycle affects the size of the saving. If a utility can adjust its forward uranium purchase policy readily to accommodate recycle then early savings are possible. Early recycle then provides savings that outweigh any likely benefits of waiting for the possible introduction of laser enrichment, which may avoid some of the extra costs at the fabrication stage because of its greater selectivity. There are also strong technical reasons for recyclying the uranium as promptly as possible, because of the increase in gamma dose rate generated by the ingrowth of the daughters of U232. At typical reprocessed uranium concentrations this effect increases the dose rate by approximately an order of magnitude (relative to unirradiated uranium) after only 1 year's storage. Storage for 10 years increases the dose rate by a further factor of three. This time dependence has a major impact on the operation and scheduling of the recycle plants; the activity of plant waste streams is

increased, additional measures need to be taken to protect plant operators and in extreme cases the capacity of the plant may need to be reduced to allow measures to reduce the dose rate to be implemented. BNFL will shortly be concluding an evaluation of the additional costs resulting from delaying recycle for up to 10 years.

For the majority of reprocessed uranium, the greatest economic benefits will arise if it is recycled promptly via the conventional conversion/enrichment/fabrication routes in appropriate plants. BNFL, together with its associated company URENCO is offering a complete recycle service for the 1990s.

JAPAN AND THE CONVERSION INDUSTRY

Jérôme PELLISSIER-TANON

Chairman and Chief Executive Officer of Comurhex

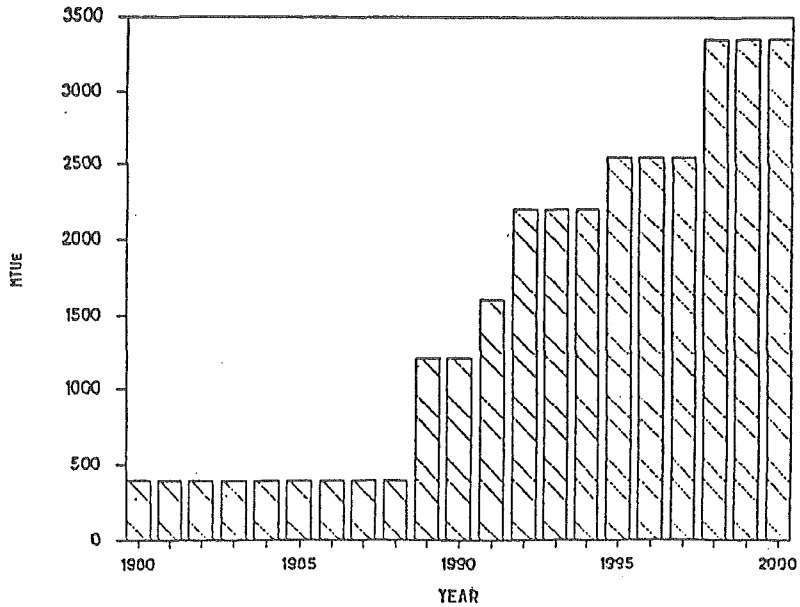
Member of the Board of Urep

1) Although conversion is the least important step of the fuel cycle both naturel U and reprocessed U have to go through it before further processing in the fuel cycle, such as enrichment or fuel fabrication.

2) Reprocessed uranium from LWR is available today from the UP2 400 plant (Cogema-La Hague, France) and the pilot plant of WAK (DWK, FRG). New plants will be put on stream, in particular the UP3 plant (Cogema - La Hague, France) and the Japanese plant of Rokkasho-Mura.

Before the end of the century, reprocessing will make available 3.000 tU/year.

REPROCESSING CAPACITIES



3) Reprocessed Uranium has to be converted to allow further processing in the fuel cycle. Conversion is necessary to produce UF6 needed for enrichment, or oxide for intermediary storage or MOX powder production.

...

4) As of today almost all the Reprocessed Uranium from LWR fuels (1600 tons U) has been converted into UF6 by Comurhex in its unique in the world 350 tons U/year pilot plant, in line with the UP2-400 reprocessing plant at La Hague. Comurhex benefits from more than 10 years of experience in this field. Uranium oxides have also been produced by Cogema in a specific pilot plant called TU2, with a capacity of 400 tons/year.

The marketing of these conversion services is the task of a joint company, Urep, a 50/50 Comurhex Cogema organization.

5) Early in the next decade a new large conversion plant for Reprocessed Uranium will be put on stream, in order to offer sufficient conversion capacity to the utilities having to take care of their reprocessed uranium. This new plant will receive UNH as well as oxides and will produce UF6 and oxides.

6) The techniques of conversion for natural Uranium are derived from traditional chemistry, but have to adapt to the peculiarities of uranium, and have to respond to several in-line production steps :

a) Refining the uranium concentrates to nuclear specifications;
b) Production of intermediate stable product : UF4;
c) Production of a highly sensitive reagent : Fluor;
d) Final fluorination of UF6.

...

Metal is produced from UF4, while oxide is produced from purified uranyle nitrate solutions (phase a).
High safety standards, high guaranteed yields (99,5 %), and several other features such as adaptability to uranium concentrates qualities and transportation organization, make conversion a multi-facet industry, which could be best summarized :
"Advanced chemist dedicated to the nuclear industry".

What is true for standard conversion of naturel uranium concentrates becomes more essential with the break in of Reprocessed Uranium.

7) Since natural uranium conversion is not a very well known segment of the fuel cycle, it is worthwhile to give a brief description of our industry's present status.

There are five converters with large capacities in the western world; their nominal capacities for natural uranium conversion are as follows :

Converter		tons U
Allied Chemical	(USA)	12.700
BNFL	(UK)	9.500
Comurhex	(France)	12.000
Eldorado	(Canada)	9.000
Sequoyah Fuels	(USA)	9.090
Total Werstern World		52.290

...

Total conversion of natural uranium in 1986 has been well below 40.000 tons. Forecasts for the next fifteen years show a slowly growing demand, to reach an average of 45.000 tons per year in the 1990s. There should be no problem for the present producers to cope with the future market demand for the end of this century.

All five producers deliver UF6. Two of them deliver metal also (for the graphite-gaz type reactors), and a third one, oxides (for the Candu reactors).

UF6 is a sensitive product and has to go through more or less extensive storage and transportation before delivery to the enrichment plants. Many years of experience have proven that the present 48 Y cylinders are an extremely reliable and reasonably cheap means of storage and transportation.

The 1984 Mont-Louis wreckage and subsequent rescue operations in the North Sea, have resulted in the complete recovery of UF6 and in the complete loss of all other highly valuable goods on board, such as electronic equipment and computers.

8) A new fast growing market will be conversion of Reprocessed Uranium from LWR fuel, the fluorination of which has been so far industrially demonstrated only by Comurhex.

...

On a chemical view point conversion of Reprocessed Uranium is similar to natural U conversion. In another hand, despite the remarquable performance of the reprocessing, it carries slight amounts of radioactive by-products, partly related to newborn short-lived U232.

Reprocessed Uranium's "impurities" include the following categories :

. Transuranians such as Plutonium, Neptunium, Americium, which are long-lived and are mainly α emitters.

. Fission products, mainly Ruthenium, which are γ emitters.

These two groups of products are found in Reprocessed Uranium in minute quantities, which could not be removed at the reprocessing stage.

. New Uranium Isotopes, including U232 which is short-lived (72 years half life), and U236 which is a neutron absorber. The last one reduces the fuel efficiency and thus requires higher enrichments.

. Filiation products from U232, which are α and γ emitters. Overall, activity of U232 and its filiation products increases over a period of 11 years and slowly decreases afterwards.

...

Impurities levels in Reprocessed Uranium vary greatly from one fuel load to another, depending on initial enrichment level, burnup, cooling time before reprocessing. So does U235, from 0.6 % to 1.2 %.

All together, Reprocessed Uranium as Uranyle nitrate or Uranium oxide bears radioactive characteristics which require some added caution over natural uranium. For example, standards for air purity in operating workshops have to be 1/3 to 1/5 of those for natural uranium.

9) The final step of conversion (i.e. fluorination from UF4 into UF6), has a powerful purification effect on Reprocessed Uranium, since most of the impurities are non-volatile fluorides and will be removed by in-line filters.

As a result, purification factors of 20 to 100 may be achieved, depending on the nature of the impurity.

Of course, U232 cannot be removed. As a consequence, UF6 from Reprocessed Uranium conversion will have very good radioactive characteristics just after it has been produced and will show more radioactivity while it is going through time - due to U232 filiation products build up.

...

For example, after 1 month, the radioactivity level due to U232 decay will be 1/10 of the maximum level (obtained after 11 years of aging). It will be 1/5 after 6 month, 1/3 after 1 year and 1/2 after 2 years. In another hand, recent experiments have shown that filtration techniques may at anytime "clean" UF6 from these newborn filiation products.

Of course, while conversion provides good purification of Reprocessed Uranium, it produces radioactive dusts in small quantities, which can be disposed of as low level waste, after consolidation.

10) Experience acquired from its 350 tons/year present shop and evaluation of various schemes have led Comurhex to consider that fluorination of Reprocessed Uranium into UF6 at industrial scale (800-2.000 t/year) will require the following means :

. A shop specially designed to cope with the remaining problems of radioactive pollution.

. Independent means of liquid and solid waste treatment.

. Production management to avoid the mixing of various grades of Reprocessed Uranium.

Proper engineering and operative choices should lead to safe pollution-free operations at costs compatible with the overall economy of Uranium recycling. Design will have to provide adaptability to expected changes of ASTM standards and future increase of fuel burnup, leading to more active Reprocessed Uranium.

11) Although there is no major secret about conversion, know-how gained through years of operation in our facilities may appear useful to the Japanese industry. Cooperation is still a guarantee of better standards and higher quality. We wish it can develop between industries in this field as it did in other steps of the fuel cycle.

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MOX ISSUES : THE APPROACH TO LARGE SCALE UTILIZATION

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Vice President COMMOX
LWR Fuel Manager BELGONUCLEAIRE

The policy followed by Japan for the development of nuclear power in general, and in particular for the use of Pu generated as a national resource in the nuclear power plants is close to the policy followed by the major European countries.

It is therefore an honor and a privilege for me to present a European point of view on the MOX fuel issues.
The important German contribution to industrial MOX fuel has been outlined by Dr. Stoll. The paper I am going to present will complete the perspective by providing an overview on the approach in the main European countries concerned with MOX fuel and commenting on the contribution of Belgium and France to large scale MOX utilization.

1. Pu arising from reprocessing

The achievements of the reprocessing plants have been presented by various speakers at this session, together with the industrial prospects for the years to come. The successful operation of this reprocessing industry allows to forecast Pu to be produced by the reprocessing plants in the future.

For each of the major countries owning Pu, Fig. 1 gives a prospective view of the cumulated quantities of Pu delivered by the reprocessing plants, respectively by 1990, 1995 and 2000. Fig. 2 presents, for the same countries the cumulated needs for Fast Breeder Reactors (FBRs) and Advanced Thermal Reactors (ATRs).

By deducting from the quantities given in Fig. 1 the needs expressed in Fig. 2, it is possible to evaluate the cumulated excess Pu that will be available for recycling in thermal reactors, usually called Pluthermal in this country ; Fig. 3 represents these quantities. It can be seen that the situation in Japan is similar to the European one, in particular for what concerns the fast increase of available excess Pu.

Part of this Pu is from gas cooled reactors. In the future, the large majority will be from LWRs. Only this type of Pu will be analysed hereafter.

2. Policy of utilization of this available Pu

Whether to reprocess or not is a national policy decision. Such decision is based on various considerations.

For some European countries as for Japan, the Pu generated in their power plants is a major, and sometimes the only, national energy resource. This is probably the leading reason why the concerned countries have taken the decision to reprocess their fuel and use the Pu.

When Pu is or can be obtained in excess over the current FBR and ATR needs, two solutions are possible : either to store this Pu for the future needs of those power plants, or to recycle this Pu as MOX fuel in LWRs. This MOX fuel can then later be reprocessed and serve as a Pu mine to fuel the future fast breeders.

The following considerations are governing the decision in this field :

2.1. ~~The storage~~ Delaying the use of Pu is costly. Beside the storage costs themselves, some countries take into consideration the value of this Pu and therefore the carrying charges of this capital. It is clear that the utilities have advantage to put their capital at work rather than store it with no return.

2.2. The Pu progressively looses part of its fissile content, due to decay of Pu 241 into Am 241, so that the valuable fissile material is lost for recycling, being converted into an inert constituent which moreover adds significantly to the radioactivity of the Pu to be handled.

When too much Am 241 is accumulated, this Pu needs to be purified. The losses in this process are usually evaluated to be equivalent to the losses due to reprocessing.

Fig. 4 presents the amount of fissile Pu which is lost during storage. It depends a little bit on whether this Pu is to be used in LWRs or in fast breeders, due to the different fissile value of the Pu isotopes in each reactor system.

2.3. Due to the build-up of Am 241, Pu becomes more and more radioactive, after it has been produced by the reprocessing plant. It is usually referred to as "the aging" of Pu. As a consequence, Pu must be utilized for fabrication within a definite period after its production by the reprocessing plant. The length of this period depends on the Pu isotopic composition. For typical LWR fuel irradiated to standard discharge burnups, the Pu produced should be utilized within 3 years after reprocessing. Thereafter it must be purified. With the progressively increasing burnup of LWR fuel, this acceptable age of Pu will decrease in the future. Utilizing more automated equipment in the fabrication plant is likely to provide some margin in this field. This will be discussed later in this paper.

2.4. Pu arising from the reprocessing of MOX fuel is nearly as adequate for fuelling FBRs as virgin Pu arising directly from the reprocessing of U fuel. There is therefore no advantage to store neither spent LWR fuel nor reprocessed Pu during a long period of time, for instance 20 years, rather than utilize the Pu immediately in LWRs and utilize the Pu recuperated from this MOX fuel in the future FBRs.

Fig. 5 presents the influence of storage and recycling on the fissile worth of Pu. Six cases are considered in this figure respectively :

first generation Pu : i.e. Pu issued from the reprocessing of LWR U fuel. The first line applies if this Pu is utilized immediately after reprocessing, either in LWRs or in FBRs. The second line applies if it is utilized after 20 years storage in either type of reactor. It should be mentioned that this seond line is equally valid if the spent U fuel is stored during 20 years before reprocessing.

the last line considers second generation Pu which is Pu issued from the reprocessing of MOX fuel irradiated in an LWR.

From this figure, it can be seen that the best policy for the utilization of energy resources is to incorporate first generation Pu into LWRs (fissile worth of 62 %) and to utilize the Pu recuperated from this MOX fuel as a second generation Pu in FBRs where it has a fissile value of 76 %. This is better than the alternative of storing spent U fuel or Pu for 20 years in the hope it will be utilized in future FBRs, because it will then only have a fissile value of 70 % with the danger that, if the FBRs are delayed, it will have to be utilized in LWRs at that time with only a fissile value of 54 %.

2.5. The progressive incorporation of MOX fuel into power plants enables to gain experience in Pu utilization and prepares in a timely manner the 21st century when Pu will be one of the major energy resources.

These five considerations have been the major reasons why the concerned European countries have decided to reutilize Pu and to go ahead in a reprocessing policy at quantities even in excess of the needs of the FBRs.

3. Implementation of large scale MOX utilization

In Europe MOX fuel is incorporated progressively into the nuclear power generating system. This progressivity is implemented differently depending on the local situation.

France benefits from a centralized licensing authority and large series of identical power plants, all PWRs. EDF is therefore in a position to take the decision to load MOX fuel in its PWRs of the 900 MWe class, right away with reloads incorporating 16 MOX assemblies per reload. The number of plants reloaded in this way will increase with time as Pu becomes available from the reprocessing as outlined in Fig. 6.

In Germany, where licensing duties are not performed by one single organization at a national level, the situation is different. The situation is also different because the power plants are diversified. Under these circumstances, the MOX fuel incorporation policy is to progressively increase the proportion of MOX fuel in the successive reloads of each selected power plant.

In the other concerned European countries, the policy of implementation of MOX fuel into the power plants is also adapted to the local situation. In Switzerland e.g., BEZNAU has been loading a successive sequence of four and eight assemblies in BEZNAU II, to achieve at equilibrium a total number of 24 MOX assemblies in the core. After this experience, an accellerated rate of MOX fuel incorporation will be adopted in BEZNAU I based on the experience gained from the sister plant.

In Belgium, the adopted scenario is to incorporate MOX fuel in power plants at a rate depending on the availability of Pu with the constraint that it will be 1/3 of the reload from the first year on, and that the selected plants will continuously be reloaded with that percentage of MOX fuel.

In Europe therefore, the same general principle is always followed : the industrial utilization is started right away, since the experimental or demonstration phases have already been implemented earlier and have proven on a significant international level that MOX fuel is qualified. Indeed, the MOX fuel manufacturing industry in Europe has already 20 to 30 years background on Pu fuel, and more than 10 years industrial experience on MOX fuel. This is illustrated by Fig. 7, giving the expansion of the COMMOX manufacturing plants. Demonstration to various proportions of reactor cores and various types of power plants has also been started very early (Fig. 8) providing adequate data and confidence on the possibility to use MOX fuel on a commercial scale. This Fig. 8 shows only the most significant early experience. In fact, safety evaluation and licensing submittals have already been performed for a total of 32 different power plants or series of power plants without any problem. MOX fuel has been incorporated or is still being incorporated into 25 of those.

The future possibility to expand MOX fuel utilization is even already being demonstrated. For instance (Fig. 9), the BR3 PWR has been reloaded with an increasing proportion of MOX fuel presently up to 70 % of the reload and almost 50 % of the fuel in the core. BR3 MOX fuel has also been irradiated to well above 60,000 MWd/t. So the data base and the experience to utilize it are being updated well in advance of the future needs.

4. Fuel fabrication : Present situation and future plants

4.1. Massive utilization of MOX fuel is only possible because the manufacturing industry has already the experience of processing large quantities of Pu (Fig. 10). Since the situation in Germany has been presented by the previous speaker and the situation in Japan is well-known by the audience, only the situation relating to COMMOX will be outlined hereafter.

4.2. The expertise accumulated in France by handling large quantities of Pu for FBRs and in Belgium where specific experience on MOX fuel has been developed without interruption during 30 years have been the key ingredients in establishing a MOX industry which copes with the expanding needs.

The BELGONUCLEAIRE plant at Dessel has been designed and constructed in the period 1968 - 1972 and is in operation since 1973. It is a multipurpose plant capable of fabricating not only LWR fuels but also FBR fuel. After a first period of ten years operation, it was backfitted to a rated capacity of 35 tons/year which is being progressively implemented and commissioned and will be reached in 1989.

In parallel, at Cadarache, a LWR line with a capacity of 15 tons per year is being added to the CEA FBR plant. The design and construction phases started in 1984, this plant will be commissioned next year and operate at the rated capacity in 1989. It will serve in particular to the local training and qualification in view of the operation of the future MELOX plant.

Great care was taken in adapting the progressive increase of our capacity to the needs of the market because of the consequences of an inadequate utilization of a MOX fabrication plant (Fig. 11). It should be reminded that the cost of MOX fuel lies almost exclusively in the fabrication cost which is a different situation from U fuel where the cost of the fuel is to a major extent related to the enriched U. It is therefore essential to match closely the fabrication capacity with the fabrication demand, to keep MOX fuel at adequate price levels.

Satisfying the predicted needs of the future MOX market implies further development. COGEMA and BELGONUCLEAIRE, the two partners within COMMOX, are already preparing the expansion of their manufacturing capacities. Two important projects are currently being conducted :

- MELOX, a 100 t M per year plant to be built on the COGEMA site of Marcoule (extended) to process the massive quantities of PWR 17 x 17 MOX fuel ~~required by the French programme~~ in the most efficient way. Design has started in 1984 and the decision to order the civil works is to be made by the end of 1987. This facility is expected to be commissioned in 1992 and to reach full capacity in 1995.
- DEMOX : an expansion of the existing BELGONUCLEAIRE plant at Dessel. It is based upon reproducing on a modular basis the existing unit with improvements resulting from the experience in operating this previous unit. The design is formally pursued since 1986. The second module will be commissioned at any time to adjust the total capacity to the needs of the market. Indeed, due to the conception of DEMOX, the new module can reach full capacity five years after the decision to build.

This combination of plants was found appropriate and even essential to fulfil the needs of COMMOX. Indeed, it provides a large throughput facility optimized for PWRs 17 x 17 MOX fuel (our main product) and modular lines which can be brought in operation progressively (so that the total capacity is adequately matched with the market needs) and provide the flexibility to handle various types of PWR and BWR fuels in small lines. This combination provides the lowest possible fabrication ~~price~~ cost for the whole fabrication complex.

4.3. Beside the German and the French-Belgian situation, mention should also be made of the British situation, since Great Britain has also a reprocessing activity and therefore cares for the Pu utilization. BNFL, BELGONUCLEAIRE and COGEMA have reached an agreement relating to MOX fuel. This agreement marks the commencement of a joint R & D programme on MOX fuels and allows BNFL access to COMMOX manufacturing capability for MOX fuel. Consequently, BNFL will act as an agent for MOX fuel to be supplied from present and future joint production facilities. If market demand for MOX fuel grows as currently anticipated, it is expected that a UK MOX plant would be brought into operation in the period 1995-2000.

4.4. As a result of the rational development policy, the economy of MOX fuel utilization is very good. The fabrication cost in the present facility is already satisfactory and will be reduced in the future facilities mainly through the size factor, the planned match of the expanding capacity to the needs and the adequate adaptation of the processes and equipment to each product. In this respect, it should be reminded that the "fabrication" cost covers in fact the manufacturing itself, the fuel rod and assembly hardware, the fuel engineering (design, evaluation, QA, etc.), the transports and the warranties related to all those activities. Of course, only the first item is influenced by the manufacturing facility. Fig. 12 compares the resulting cost of the MOX fuel to the cost of U fuel. From this cost comparison can be deduced the value that the Pu has in the present circumstances and will have in the future. Such value sometimes called the "equivalence value" of Pu is in fact the price that can be assigned to Pu to make MOX fuel competitive with U fuel.

When looking at the Pu value in the present manufacturing context and in the future manufacturing facilities, it is worth asking oneselves whether Pu should not be stored to be fabricated in the future manufacturing plants. The cost related to the storage of this Pu must take into account the storage cost itself, the interest charges on the value of Pu, the price of purification when the radioactivity of the Pu becomes too high (typically around 3 years age) and the loss of fissile Pu due to aging during the storage and to the rejects of the purification operation. Each Pu owner must assess those cost factors in its own perspective. Fig. 13 is an example thereof.

In any case, it would be uneconomical to store Pu for 3 years or more in the expectation that the low fabrication cost will lead to a benefit. In fact the benefit from lower fabrication cost is lost in the costs associated with Pu storage. Practically, since the manufacturing capacity will gradually increase and therefore the fabrication price gradually decrease, it is not justified, on economical grounds, to store Pu for more than 1 or 2 years.

5. Lessons learned

The lessons learned from 30 years experience of which over ten years of industrial experience cannot be conveyed in a few words. Therefore the main head-lines will only be emphasized here :

5.1. Process performance is the largest factor influencing product quality and fabrication cost. Improvements are only effective if they have proven by experience to result in a more reliable fabrication or a better utilization of the capacity.

5.2. Automation is effective in reducing exposure of the operating personnel. It has however limits since it increases the exposure of maintenance and service personnel and ~~can~~ could increase the ~~fabrication cost. Indeed, it can lead to~~ down-times for repairs of the equipment, replacements of parts and especially setting of the toolings for varying products, for instance, if successively BWR and PWR fuels need to be fabricated or fuel for different BWR or PWR reactors.

5.3. The present age limit for LWR Pu (i.e. Pu resulting from the reprocessing of LWR fuel) is 3 years for fabrication with the equipment actually demonstrated. DEMOX and MELOX plants are designed to handle Pu up to 5 years old. Operating experience of those plants will indicate the consequences of the higher radioactivity background. Anyway, the acceptable age of Pu will again be reduced in the long term future with the need to process Pu issued from reprocessing of higher burnup U fuels with a higher intrinsic Pu radioactivity and Pu 241 content.

5.4. MOX fuel can be designed, fabricated and licensed to the same standards as U fuels. Adequate experience in this field has been collected and demonstrated by the incorporation of MOX fuel in many reactors and in various countries.

5.5. MOX-fuelled LWRs can be operated without inconveniences. ~~The only~~ A practically adaptation of the power plants to the MOX fuel utilization is to take adequate measures about arrival of the MOX fuel on the site namely for unloading the transport containers and storing the fresh fuel. No inconvenience has ever been reported during plant operation by any operator even when extensive quantities of MOX have been incorporated.

Finally, the situation can be summarized by saying that the MOX technology is developed at an adequate level for immediate industrial use and that the cost is already attractive with a trend to progressively decrease, ~~not so much with time but~~ with accumulation of experience and adequate planning of the development of the fabrication capacity as the needs progressively evolve.

FIGURE 1

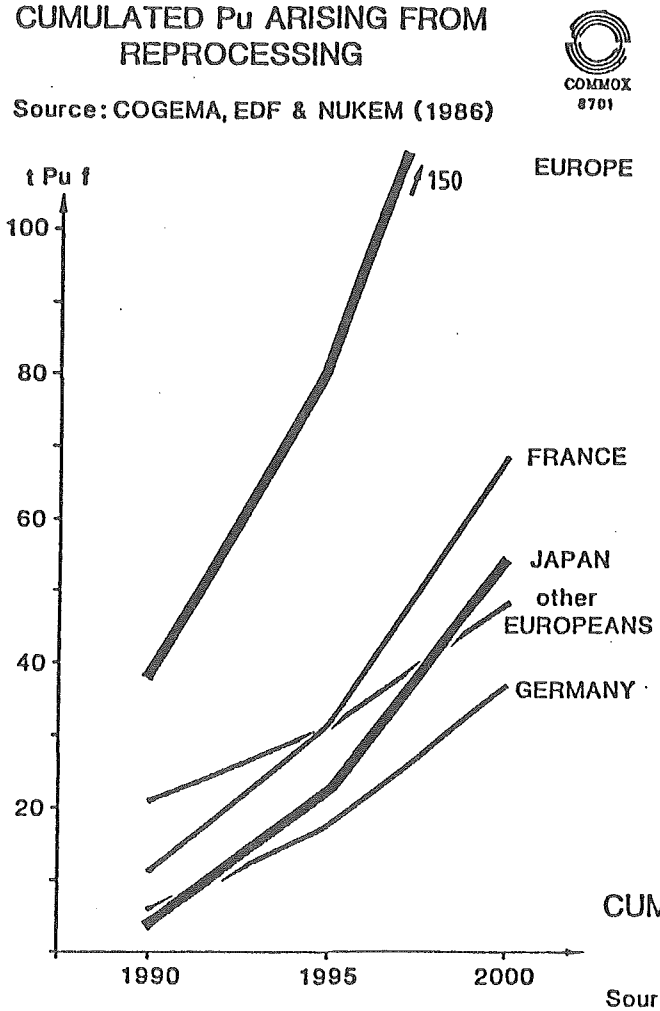


FIGURE 2

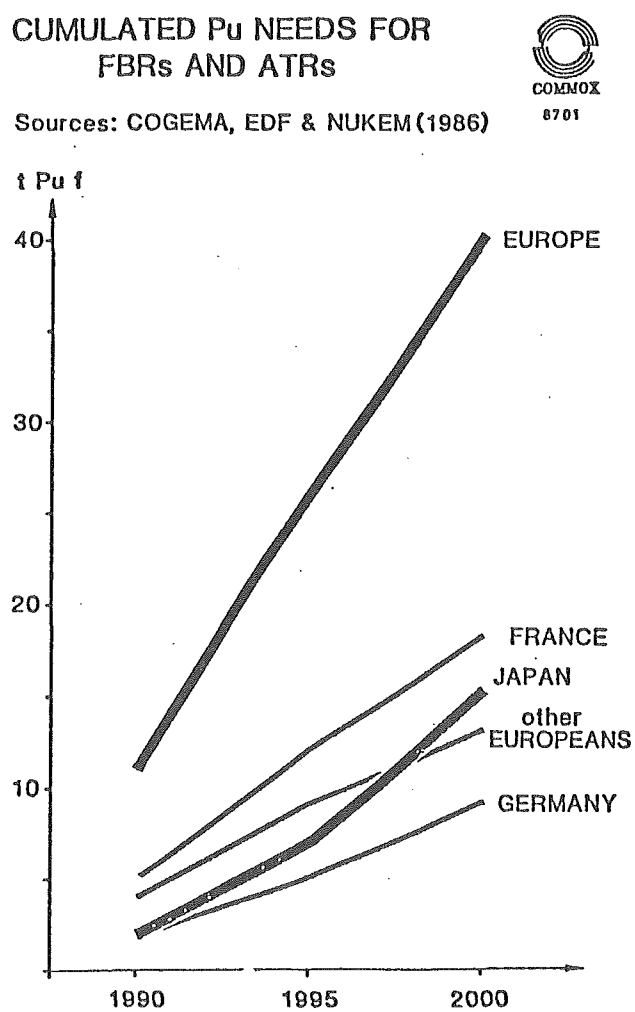


FIGURE 3

CUMULATED EXCESS Pu
(→ MOX fuel)

COMMOX 8701

Sources: COGEMA, EDF & NUKEM (1986).

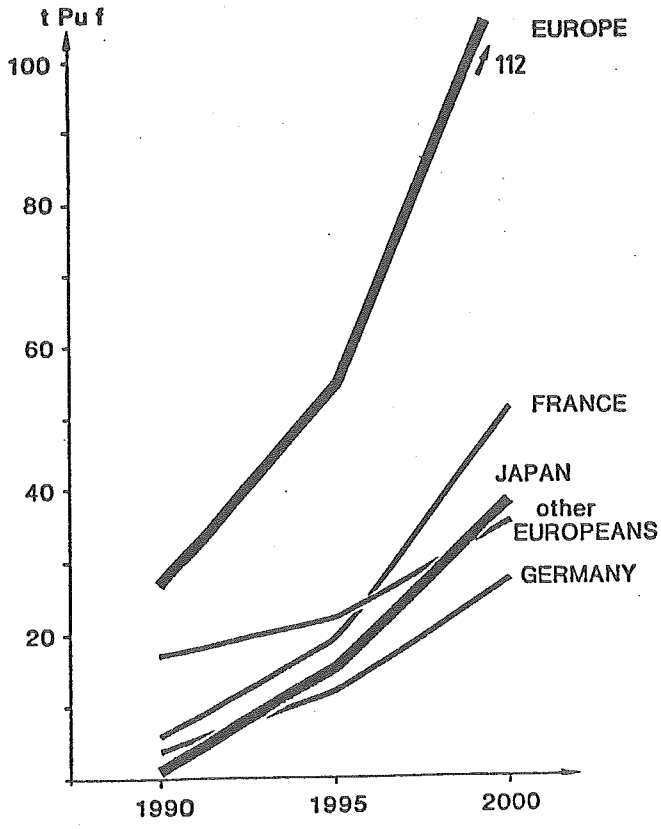


FIGURE 4

8610

LOSS OF FISSILE Pu DURING STORAGE

COMMOX

(expressed in equivalent Pu 239)

• Due to Pu 241→Am 241

Storage period	LWR	FBR
0 yrs	0 %	0 %
10 yrs	9 %	9 %
20 yrs	14 %	14 %
30 yrs	19 %	17 %

• If purification is required 1 to 2 % should be added to those figures

FIGURE 5

BELOO BN NUCLEAIRE 8611

INFLUENCE OF STORAGE AND OF RECYCLING ON THE FISSILE WORTH OF Pu

COMMOX

	Equivalent Pu 9 content in LWRs	in FBRs
1st generation Pu		
after reprocessing	62%	83%
after 20 yrs storage	54%	70%
2d generation Pu	44%	76%

FIGURE 6

MOX FUEL LOADING IN EDF POWER PLANTS

COMMOX 8701

Source : FRAGEMA

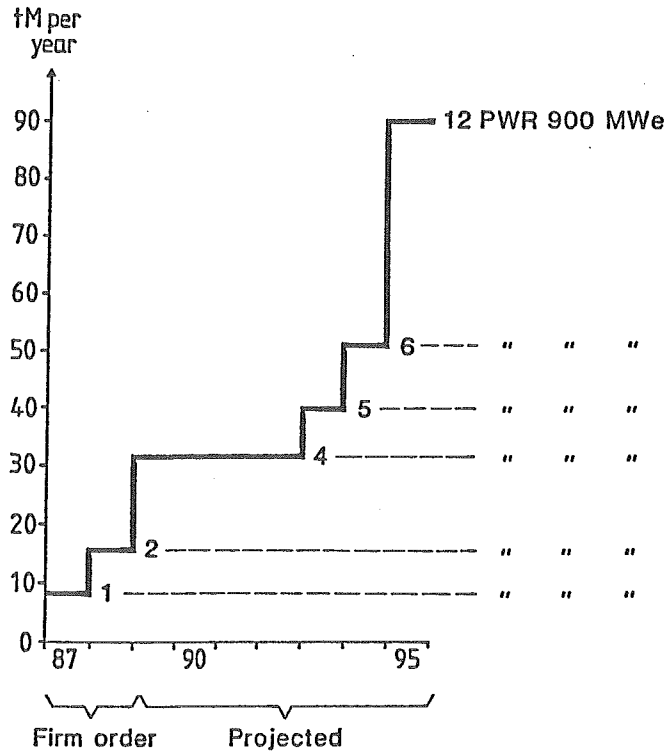


FIGURE 7

FABRICATION FACILITIES

COMMOX
8608

	BE	FR
lab	Mol 58-f	FAR 58-72
pilot plant	Mol 68-74	Cadarache 62-83
commercial plant	Dessel 73-f	Cadarache FBR lines 77-f +LWR line 88-f
f = future	DEMOX	MELOX

FIGURE 8

MOX fuelled power plants

8606

COMMOX

PWR

BR3	1963 →	BN
Saxton	1965-1972	W
KWO	1972 →	KWU-Alkem
CNA	1974-1978	BN-CEA
Trino	1976-1985	W
Beznau 1	1978-1981	W
GKN	1982 →	KWU-Alkem

BWR

VAK	1966-1984	KWU-Alkem
Garigliano	1968-1979	GE-BN
Big Rock Point	1969-1979	GE-ENC
Dresden 1	1970-1977	GUNF-UNC
Dodewaard	1971-1981	GKN-BN
KRB	1974-1983	KWU-Alkem

FIGURE 9.

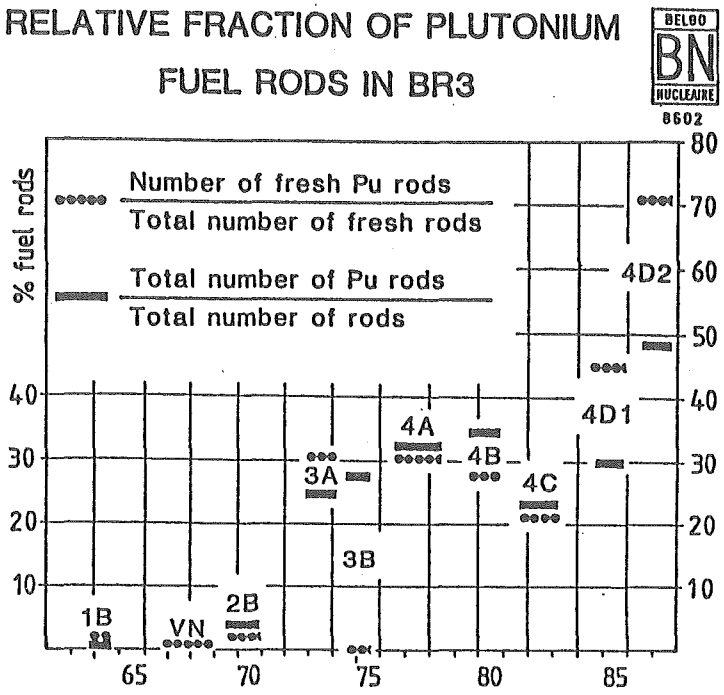


FIGURE 10

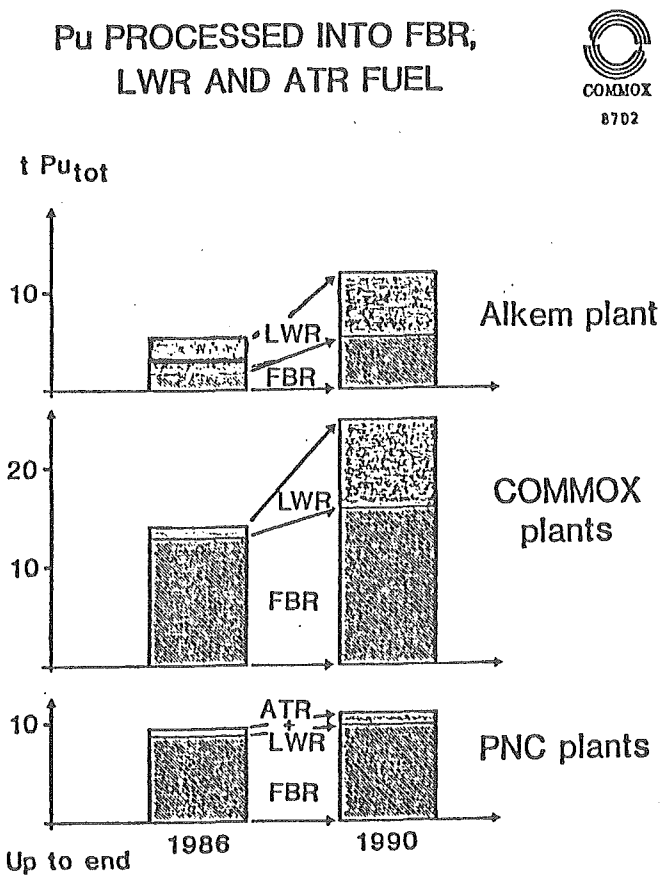
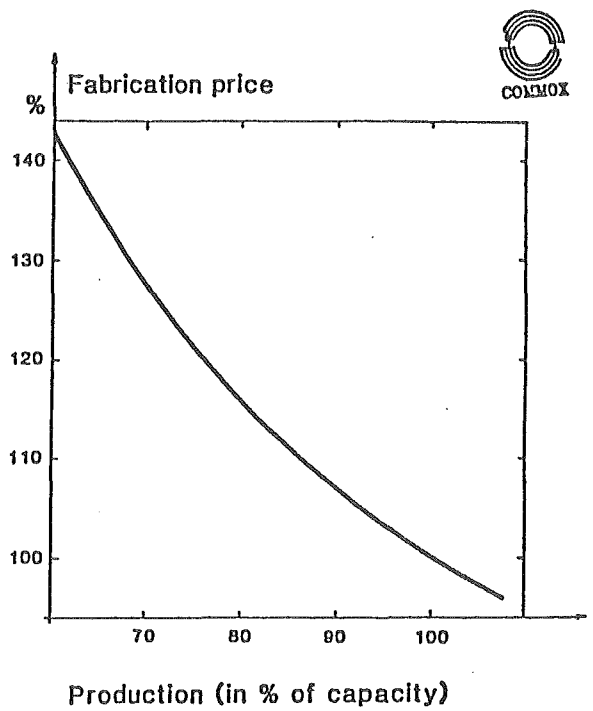


FIGURE 11



CONSEQUENCES OF AN INADEQUATE UTILIZATION OF THE MOX FABRICATION PLANT

FIGURE 12

PWR 900 MWe FUEL COST (USD/kg M)

COMMOX 8703

Item	U fuel 3.4% U5	MOX fuel	
		Present 35 t M/a	DEMOX & MELOX
Nat U	510	-	-
Conversion	40	-	-
SWU	510	-	-
Fabrication	ref.	ref.+1000	ref.+700
Total	ref.+1060	ref.+1000	ref.+700
Difference	basis	-60	-360
Pu value (USD/g Pu f)		2	10

1 USD = 40 BEF = 6.2 FRF

FIGURE 13

EXEMPLATIVE COST RELATED TO Pu STORAGE (USD/g Pu f)

COMMOX 8701

Storage	2 yrs	3yrs		5 yrs
Storage cost	5.4	8		13
Interest charges	1	1.5		2.5
Purification cost	0	0	12	11
Fissile Pu loss	2.2%	3.4%	5%	7%
Real cost	7	10	23	28

Discount rate : 5%/a

INDUSTRIAL AND TECHNOLOGICAL ASPECTS OF MOX-RECYCLE

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Introduction

Nuclear power in Germany must be looked at under the constraints of competing energy sources and under political and acceptance problems as well. After the initial growth rate Germany is likely to increase its nuclear share only by one or two more nuclear power stations until to the turn of the century.

Electric power supply comes from four big and more than 50 small utilities which are privately owned and have their local distribution rights. 19 nuclear power stations with altogether 16 GWe supply most of the baseload, now around and above 1/3 of the electricity consumed.

As there is no nuclear defense program, government restricts itself to formulate legal boundary conditions (atomic law, radiation protection rule, etc.) and to support high risk technology through the Research Ministry (BMFT). Among those were several nuclear power systems, some of them abandoned now, and all major stations in the nuclear fuel cycle. Industry together with government has pursued two advanced reactor concepts, namely the Helium High Temperature Reactor (HTR) and the sodium cooled Fast Breeder Reactor (FBR). With the operability of prototype power stations of both types responsibility for the follow-on power stations now switches to industry.

Arguments for the FBR were its higher efficiency, sodium as a low pressure coolant and its fuel saving potential as Germany has only very limited indigenous uranium resources. Raising costs of SNR-300, limited growth rates in electricity consumption and low uranium prices have delayed interest at the potential customers, who are also influenced by public opposition against the breeder.

As delays for breeder introduction in Germany were visible already in the early 70ies, closing the fuel by recycling U and Pu into existing LWR was accepted as the preferred mode to save energy resources and to establish the fuel cycle during the transition period until to the delayed breeder introduction.

Therefore reprocessing was legally established as the preferred mode to take care of spent fuel. As, however, e. g. the HTR fuel reprocessing technology would not be available for a long time, if ever, for special fuel like this final direct disposal had to be considered as an alternative.

Plutonium-Availability

The German recycle program is based on the quantities of Plutonium which are expected to come from the reprocessing of spent fuel according to existing reprocessing contracts of German utilities with COGEMA, BNFL, the existing

reprocessing plant of WAK in Karlsruhe and the later German reprocessing plant WA 350. The expected quantity will be approximately 30 t of Plutonium fissile up to the year 2000.

Annual Pu availability is shown in figure 1. It is expected that most of this Plutonium will fit into the average isotopic composition (figure 2) of spent light water fuel with less than 40.000 MWd/t burnup. Some of the material towards the end of the period envisaged may have a higher content in critical isotopes like ^{238}Pu. It is also assumed that German Pu-requirements for fast breeder fuel in this period may not exceed 10 % of the Pu-available, so most of it must be recycled into LWR.

Most of the Plutonium will be supplied until to the start-up of Wackersdorf Reprocessing Plant in the form of PuO_2, resulting from oxalate precipitation in the La Hague Reprocessing Plant. This means that this oxide should be fabricated into fuel rods before the ingrowth of Americium creates appreciable higher gamma-doses to the working population. Two years of intermediate storage time for the separated PuO_2 are now considered a maximum after which a very cost effective redissolution and Am-separation seems inavoidable. Only soluble forms of Pu in storage like solid Pu-nitrate could overcome this close coupling between reprocessing and fuel fabrication. Those forms have been developed at ALKEM but they still await their industrial introduction.

Fuel design optimisation

There are continuous improvements in LWR fuel design underway. They result in higher burnups and very low defect rates. MOX fuel here has to follow trends in advancement of UO_2-fuel.

For existing LWR stations neutron physics calculations are taking into account the U-235 content of the matrix material and the (Pu 239 + Pu 241) content of the Plutonium such that

- the reactivity of MOX-fuel-assemblies averaged over the total residence time is roughly equal to that of uranium fuel assemblies
- the local power distribution in MOX-fuel-assemblies is similar to that of uranium fuel assemblies
- the overall power distribution in the core is changed only slightly
- in all respects the safety requirements are fulfilled an inherent safety is ensured.

The neutron physics design methods of KWU (cell burnup calculations by means of FASER, fuel assembly burnup calculations by means of MEDIUM) can be applied analogously and yield an information as reliable as for uranium fuel assemblies.

The methods used at KWU for core design and fuel management (using MEDIUM) are in principle applicable to all types of LWR fuel assembly. The present geometrical description used for the neutron-physics calculations of the pure uranium core can also be used to a great extent for a core containing MOX-fuel-assemblies. This is true for calculation of power distribution as a function of burnup and for the calculation of reactivity coefficients and reactivity worth of the control assembly system also performed on a 2-dimensional basis. The radial or axial istribution is further simplified for 3-dimensional analyses, where necessary.

Comparison of core properties reveals certain differences in boron worth, coolant temperature coefficient and control assembly worth. The reactivity balance is governed by the increased reactivity on coolant temperature reduction and by a different temperature response of the control assembly system worth for a low stuck rod value. Similar effects on the reactivity balance also occur with a transition to higher uranium fuel assembly burnups.

The fission product inventory is practically governed by core burnup only and not by proportion of MOX-fuel-assemblies in the core (apart from insignificant shifts: more tritium and ruthenium less noble gases and halogens than in an uranium core).

The incident analyses to date (main steam line rupture, rod ejection) did not indicate any cladding tube damage. Hypothetical incidents involving fuel rod damage do not differ because of the similarity of the fission product inventory; possible leaching of Plutonium would primarily involve Plutonium bred at the pellet surface the quantities of which are very similar in both uranium and MOX-fuel-assemblies.

Basis for all design work are a large number of irradiations and post irradiation examinations which have so far never shown any major handicap of MOX-fuel against UO_2-fuel. The only minor difference seen so far is a somewhat higher fission gas release of the MOX-fuel-matrix which, however, can be taken care of by the proper gas plenum design.

With increasing burnup goals in future the fissile content has to be increased, this results also in more than two Pu-U-ratios in PWR-fuel elements where mainly the corner rods must be graded to smoothen the flux distribution towards the neighbouring U-fuel.

It is also forseen to introduce watergaps, Gd-containing UO_2-rods and finally also including UO_2-PuO_2-Gd_2O_3-rods into future fuel assemblies. Irradiation test for similar fuel types are already under way, showing that 55.000 MWd/t can be reached in future.

It could also be shown that UO_2-fuel from residual uranium from reprocessing can be fabricated and successfully inserted. This has also been demonstrated for this uranium as a base material for MOX-fuel. By this about 30 % of the residual uranium could be used economically without further reenrichment.

Fabrication development

Fabrication processes for MOX-fuel rods both from PuO_2 and Pu-nitrate are well established now and did not require major changes in process variables over the last 10 years. So most of the improvements are oriented towards a better economy and a reduced exposure risk for operators. Better economy again in most cases means bigger lot sizes and higher throughputs whereas dose reductions are achieved mainly by better shielding and more hands-off-operation of the fabrication lines. As in Germany licensing of Pu-plants is a time consuming and expensive process it was advisable to concentrate up to now on a series of minor improvements against building new and radically different fabrication equipment.

Chemistry of the AUPuC-precipitation and calcination process is now well understood and the only minor disadvantage of this process which results in nitrate-containing filtrates

will be overcome by a decomposition of all salts in a fluidised bed, resulting in water, CO_2 and N_2 as endproducts only. Whatever remains in potentially active liquids is consumed by the waste conditioning process in concrete form.

In ceramic processing OCOM-process in which PuO_2 and UO_2 are undergoing a co-milling process to enhance mixed crystal formation, is now done in a largely hands-off milling equipment.

Pelletizing is getting even more economic by using rotary presses while sintering in Argon-Hydrogen-mixtures gives now a much smaller variation in ceramic properties of the pellets by a more open sintering boat design. Grinding is done partly already in a dry grinder avoiding any complications by water as a moderator and as an impurity. Rod loading and welding were always highly automated, but have further been improved by pressure resistance welding of endplugs which was taken over as a technique from the UO_2-fuel plant and works now successfully with low weld-contamination.

Future developments are oriented towards low temperature sintering of pellets, sintering to size and axial grading of Pu-U-ratios.

Safety and Safeguards aspects

Detailed statistics over the years show that for a given fabrication line radiation dose received by the workers increases only marginally with throughput. However, aged Pu and Pu_{238}-fractions above 2 % do increase gamma- and neutron-dose levels. These developments have to be compensated by more gamma- and neutron-shielding. While gamma-shielding above 3 mm Pb equivalent does not reduce dose levels any more, a neutron dose reduction by a factor of four would require 10 cm of Polyethylene which in most cases reduces manual accessibility through gloves too much. So a new type of glovebox has been developed with double wall and shielded gloveport as well as replaceable round glass windows. At present a working population of 250 people receives with an annual throughput of about 1 to Pu an integrated gamma dose of about 1 SV while the highest dose group mostly in ceramics area of around 10 people accumulate 30 % of this. Continuous measurement of received neutron doses by ALBEDO-belts show that where pure PuO_2 or large amounts of fuel in rod form is handled the neutron to gamma ratio can be well above 1 and shows a clear dependence from the hold-up of Pu in a given area. Anticipating both an increase in the Pu_{238}-fraction and a higher relative biologic effectiveness factor for neutrons in future, more

automation and more neutron shielding will be required. Also new ventilation concepts reducing inhalation potential in case of minor glove leakes are under development.

In the field of safeguards a new facility attachment has been implemented by the IAEA. It defines inspection goals and two annual inventories to be taken. Reduction to one inventory per year is possible by a revised inspection technique where individual fabrication batches are followed by inspectors through the plant.

Economic situation

As the market volume for fast breeder fuel elements is now limited and no special economic Pu-burning reactors exist, the basis for any near future economic operation can only be recycle fuel into LWR. There MOX-fuel must compete with UO_2-fuel. Major cost-fractions of UO_2-fuel are U-procurement, enrichment and fuel element fabrication. As U-procurement and enrichment both together cover more than 80 % of the fuel element costs and both are largely based on US-Dollar prices, any change in the US-Dollar to DM--conversion has major impact on U-fuel costs.

So the equivalence value which MOX-fuel had to meet two years ago was about 140 % from what it is today. It is our experience, that MOX-fuel fabrication has a very high

fraction of fixed cost because up to 80% of the cost are depreciation, safety, safeguards, physical protection, maintenance and salaries of the capacity invariant base crew. This leads to a steep decrement of cost over throughput. As most MOX-fuel fabrication facilities had been heavily underrated over the last decade, now the few facilities still operating near their planned throughput make interesting economic progress.

Utilities in Germany have taken advantage of these facts. In 1982 they concluded agreements with the MOX-fuel manufacturer and among themselves. They agreed to share all Pu coming from reprocessing (at that time WAK and mainly La Hague) and distribute it according to an optimised scheme among all power stations licensed for MOX-recycle which were 3 at that time and are 8 now. They also agreed to share development efforts for uprating the throughput of the existing MOX-fabrication plant to the 40 tons MOX/year level until 1988. They finally agreed to load the plant with MOX-fuel orders at their best possibilities and share initial losses while the plant is underrated. Those losses were expected to be regained from cost decrease from the fully loaded plant afterwards.

Records now in the second before last year show that utilities were about to gain from the contract, if the cost of UO_2-fuel would have stayed at the margin of 1982. As,

however, UO_2-fuel costs have dropped drastically, the amount of money set out for the whole 6 year's program of about 10 million DM/year is about to suffice development and fabrication cost difference needs while the two fabrication lines are likely to reach the design through-put in 1988. This result has been achieved in spite of severe licensing and public acceptance problems which have even culminated in twice overthrowing the local Hessen state government.

Available Experience

As long as the fraction of MOX-fuel elements in a given reactor core does not exceed 30 % this substitution does not change operating or safety parameters more than the usual differences between fresh and spent fuel and therefore have no gross effect. Local flux perturbations are controlled by the proper Pu/U-ratios in the fuel rods and precalculated reload schemes. As there was no single fuel rod defect in the last 60.000 thermal fuel rods, the specified degree of nonuniform Pu distribution and burnup behaviour causes no problems. It has enhanced the confidence both of reactor operators and safety authorities to increase the MOX-fuel loading per reactor gradually starting from one or four fuel elements to eight, finally to sixteen or thirty-two, so that the number of fresh MOX-fuel per cycle is limited.

What altogether has been produced and irradiated can be seen on the attached reference list.

As was reported earlier the initial 20 tons of MOX-fuel fabricated until 1977 did not reach the state of full Pu solubility in nitric acid after irradiation. This made them less acceptable for standard reprocessing procedures. Since the full solubility can be guaranteed for any fuel either made by co-milling (OCOM-process) or by co-precipitation (AUPuC-process) reprocessors have agreed to accept MOX-fuel under the same conditions as UO_2-fuel for their reprocessing plants. They will have to blend MOX-fuel with UO_2-fuel, however, to cope with the higher Pu-content of MOX-fuel in respect to the concentration sensitivity of the Purex--process and the capacity of the Pu-purification tail end of the plant.

This preparedness to accept is also in the best interest of reprocessors because MOX-fuel either bearing the cost burden of higher reprocessing cost or facing the unavailability of a suitable final repository would discourage utilities from further MOX use and would therefore make any further U-fuel reprocessing unattractive.

Outlook into future

In West Germany current fears after the Tschernobyl accident and the perceived weapons proliferation potential have caused major acceptance problems for closing the fuel cycle

through reprocessing and MOX-recycling. This particularly endangered continuation of ALKEM operating license under Hessen state government and its "green" coalition. There are, however, hopes to overcome these problems by correcting actions of the generally pro-nuclear federal government.

MOX-fuel technology, originally developed for fast breeder fuel supply, finds its technical and economical backbone in thermal recycle into existing LWR power stations. As there is ample Pu available and as there are enough power stations licensed for MOX-fuel use and as total cost of MOX-fuel elements lies in the range of UO_2-fuel, no major technical or economic obstacle is in sight. The limiting factor for some years may be fabrication capacity, if licensing of new plants is slowed down further.

The trend goes towards higher Pu-concentrations in MOX-fuel together with Gd-poisoning to reach even higher burnups and to equilibrium reactor loadings with 30% MOX-fuel. It can be expected that more automized and continuously loaded MOX-fuel fabrication lines fabricating more standardized MOX-fuel rods using spent U from reprocessing as base material will allow a positive Pu-value to be payed to the reprocessor.

This should further enhance economic viability of reprocessing over final repositories of fuel elements. It appears also evident that an economic MOX-fuel cycle in LWR provides all elements for a cost reduction in fabricating fast breeder Oxide-fuel.

As it is generally believed that for an extended use of nuclear energy fast breeders are a necessity, economic fast breeder fuel manufacturing in fabrication plants with dual purpose (fast and thermal) fabrication lines may be a valuable contribution for earlier breeder introduction.