THE 21ST JAIF ANNUAL CONFERENCE

第21回原産年次大会

APRIL 13～15, 1988

JAPAN ATOMIC INDUSTRIAL FORUM

日本原子力産業会議

目　次

CONTENTS

LUNCHEON

SESSION 3: CURRENT ADVANCED NUCLEAR TECHNOLOGIES

SESSION 4: NUCLEAR FUEL SUPPLY SYSTEM : PROSPECTS AND ISSUES

SESSION 5: EFFORTS FOR FURTHER ENHANCEMENT OF RELIABILITY OF LWR

第21回原産年次大会総括プログラム

基調テーマ：原子力 ― その評価と選択

	第1日 4月13日（水）	第2日 4月14日（木）	第3日 4月15日（金）
午前	開会セッション (9:30～12:20) 大会準備委員長挨拶 原産会長所信表明 原子力委員長所感 ＜特別講演＞	セッション2 (9:30～12:00) 「アジアにおける原子力協力の展開」 ［パネル討論］	セッション4 (9:30～12:20) 「原子燃料利用体系の展望と課題」 ［講　演］
午後	セッション1 (13:40～18:00) 「エネルギー複合時代と原子力政策」 ［講　演］	午餐会　(12:20 ～14:30) 通商産業大臣所感 ［特別講演］ 於東京プリンスホテル ………………………………… 原子力映画上映 (13:00～14:10) ――― セッション3 (14:45～17:45) 「今日の原子力技術」 ［映像と解説］	セッション5 (13:40～17:20) 「軽水炉信頼性向上への努力」 ［パネル討論］
	レセプション (18:30～20:00) 於東京プリンスホテル		

４月１３日（水）

開会セッション (9:30〜12:20)

議長：武　田　　　豊　　新日本製鐵㈱会長

大会準備委員長挨拶

那　須　　　翔　　東京電力㈱社長

原産会長所信表明

圓城寺　次　郎　　日本原子力産業会議会長代行

原子力委員長所感

伊　藤　宗一郎　　原子力委員会委員長，科学技術庁長官

＜特別講演＞

議長：松　永　亀三郎　　中部電力㈱社長

「中長期的にみた国際エネルギー戦略」

Ｈ．スティーグ　　ＯＥＣＤ国際エネルギー機関（ＩＥＡ）事務局長

「２１世紀のエネルギーシステム ── 原子力の役割」

Ｗ．ヘーフェレ　　西ドイツ・ユーリッヒ原子力研究所長

「世界のエネルギー問題と日本の進路」

生　田　豊　朗　　日本エネルギー経済研究所理事長

セッション１：エネルギー複合時代と原子力政策 (13:40〜18:00)

議長：伊　原　義　徳　　日本原子力研究所理事長

「西ドイツにおける原子力開発ならびに安全政策」

Ｋ．テプファー　　西ドイツ連邦環境自然保護原子炉安全大臣

「原子力発電ー２１世紀のエネルギー挑戦への解決方策」

Ｊ.-Ｐ．カプロン　　フランス原子力庁（ＣＥＡ）長官

「中国の原子力開発の展望」

陳　　肇　博　　中国原子力工業省次官

「日本のエネルギー政策と原子力開発のあり方」

大　島　恵　一　　東京大学名誉教授

議長：玉　川　敏　雄　　東北電力㈱会長

「ブルガリアにおける原子力開発の現状と将来計画」

Ｎ．トドリエフ　　ブルガリア国務大臣・エネルギー産業公社理事長

「米国における原子力発電 ── 輸入石油代替としての役割」

Ｈ．Ｂ．フィンガー　　米国エネルギー啓発協議会（ＵＳＣＥＡ）理事長

「原発問題 ── その政治的・社会的意味」

大　谷　　　健　　ジャーナリスト

レセプション (18 : 30〜20 : 00)

於：東京プリンスホテル２階「鳳凰の間」

４月１４日（木）

セッション２：アジアにおける原子力協力の展開 (9:30〜12:00)

議長：　村　田　　浩　　　　　日本原子力産業会議副会長

「アジアにおける原子力地域協力の展開」
　　ﾉﾗﾑﾘｲ･ﾋﾞﾝ･ﾑｽﾘﾑ　　　国際原子力機関（ＩＡＥＡ）事務局次長

「アジアにおける原子力協力の展望」
　　中　江　要　介　　　　原子力委員会委員

＜パネル討論＞

パネリスト

ﾉﾗﾑﾘｲ･ﾋﾞﾝ･ﾑｽﾘﾑ	国際原子力機関（ＩＡＥＡ）事務局次長
劉　雪　紅	中国原子力工業省外事局副局長
Ｄ．アヒムサ	インドネシア原子力庁長官
韓　弼　淳	韓国エネルギー研究所長
Ｑ．Ｏ．ナバロ	フィリピン原子力研究所長
井　田　勝　久	科学技術庁長官官房審議官
武　田　康	海外電力調査会専務理事

午餐会 (12:20〜14:30)　於：東京プリンスホテル２階「鳳凰の間」

通商産業大臣所感
　　田　村　　元　　　　通商産業大臣

特別講演　「東西文明の接点」
　　会　田　雄　次　　　　京都大学名誉教授

原子力映画上映 (13:00〜14:10)　於：東京郵便貯金ホール

- ２１世紀のエネルギーめざして
- 大いなる北の大地で一原燃サイクル建設へのあゆみ
- 新しい原子力発電一軽水炉改良技術確証試験

セッション３：今日の原子力技術 (14:45〜17:45)

議長：　青　井　舒　一　　　　㈱東芝社長

「西ドイツの乾式キャスク貯蔵開発の経緯と現状」
　　Ｗ．ストラスブルク　　西ドイツ核燃料再処理会社（ＤＷＫ）専務取締役

「カナダにおける使用済燃料処分の概念」
　　Ｗ．Ｔ．ハンコックス　　カナダ原子力公社（ＡＥＣＬ）副社長

「フランスのウラン濃縮技術開発の現状」
　　Ｐ．レニー　　　　フランス原子力庁（ＣＥＡ）ウラン濃縮研究・物理化学部長

「日本のウラン濃縮技術」
　　高　島　洋　一　　　　東京工業大学名誉教授

議長：　岸　本　泰　延　　　　昭和電工㈱会長

「高速増殖炉の革新技術」
　　澤　井　　定　　　　動力炉・核燃料開発事業団理事

「核融合実験炉への道」
　　苫米地　顕　　　　日本原子力研究所特別研究員

「先端技術と放射線利用」
　　田　畑　米　穂　　　　東京大学教授

４月１５日（金）

セッション４「原子燃料利用体系の展望と課題 (9:30〜12:20)

議長：　永　野　　健　　　三菱金属㈱社長

「原子燃料利用体系の展望 ── ２１世紀へ向けて」
林　　政　義　　　動力炉・核燃料開発事業団理事長

「燃料サイクルの総合的経済評価と将来展望」
Ｊ．Ｃ．ゲ　　　コジェマ社（フランス核燃料公社）
市場・事業開発部長

「原子燃料サイクル戦略と課題」
飯　田　孝　三　　　関西電力㈱副社長

「燃料サイクル技術の評価と見通し」
Ｗ．Ｌ．ウィルキンソン　英国原子燃料公社（ＢＮＦＬ）副総裁

「原子燃料新時代へ向けて」
岸　田　純之助　　　（財）日本総合研究所会長

総括コメント：
Ｈ．Ｋ．シェーパー　　ＯＥＣＤ原子力機関（ＮＥＡ）事務局長

セッション５：軽水炉信頼性向上への努力　(13:40〜17:20)

共同議長：　岡　部　　實　　　日本原子力発電㈱社長
〃　：　Ｒ．　カール　　　フランス電力庁（ＥＤＦ）副総裁

＜パネル討論＞
パネリスト
Ｌ．Ｍ．ワローニン　　ソ連原子力発電省第一次官

Ｂ．Ｖ．ジョージ　　英国中央電力庁（ＣＥＧＢ）理事

Ｈ．Ｊ．シェンク　　西ﾄﾞｲﾂ　・ﾌｨﾘｯﾌﾟｽﾌﾞﾙｸ 原子力発電会社取締役

Ｓ．ハーベル　　チェコスロバキア原子力委員会委員長

Ｋ．Ｃ．ロジャース　　米国原子力規制委員会（ＮＲＣ）委員

金　　東　柱　　韓国電力公社専務取締役

池　亀　　亮　　東京電力㈱常務取締役

コメント：
柴　田　俊　一　　京都大学名誉教授

21ST JAIF ANNUAL CONFERENCE

PROGRAM

WEDNESDAY, APRIL 13

9:30 am — 12:20 pm
OPENING SESSION

Chairman:	
Yutaka Takeda	Representative Director and Chairman Nippon Steel Corporation
Remarks by Chairman of Program Committee	
Shoh Nasu	President Tokyo Electric Power Co., Inc.
JAIF Chairman's Address	
Jiro Enjoji	Acting Chairman Japan Atomic Industrial Forum
Remarks by Chairman of Atomic Energy Commission	
Soichiro Ito	Chairman, Atomic Energy Commission Minister of State for Science and Technology

SPECIAL LECTURES

Chairman:	
Kamesaburo Matsunaga	President and Director Chubu Electric Power Co., Inc.
Mid and Long Term World Energy Strategy	
Helga Steeg	Executive Director OECD International Energy Agency
Energy Systems in the 21st Century and the Significant Role of Nuclear Energy	
Wolf Häfele	Director General Jülich Nuclear Research Center Federal Republic of Germany
World Energy Problems and Japan's Future Course	
Toyoaki Ikuta	President Institute of Energy Economics, Japan

1:40 pm — 6:00 pm

SESSION 1: THE ENERGY COMPLEX AGE AND NUCLEAR POWER POLICY

Chairman:

Yoshinori Ihara	President Japan Atomic Energy Research Institute

The Development of Nuclear Energy and Safety Policies in the Federal Republic of Germany

Klaus Töpfer	Federal Minister for the Environment, Naure Conservation and Reactor Safety Federal Republic of Germany

Nuclear Electricity, the Answer to the Energy Challenges of the Century to Come

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

Prospects for Nuclear Power Development in China

Zhao-Bo Chen	Vice Minister Ministry of Nuclear Industry China

Nuclear Energy Development in Japanese Energy Policy

Keichi Oshima	Professor Emeritus University of Tokyo

Chairman:

Toshio Tamakawa	Representative Director and Chairman Tohoku Electric Power Co., Inc.

Nuclear Energy Industry in Bulgaria — Present State and Its Development

Nikola Todoriev	Minister Chairman, Energy Industry Association Bulgaria

Nuclear Power in the United States: Providing Electricity to Replace Imported Oil

Harold B. Finger	President and Chief Executive Officer U. S. Council for Energy Awareness

Nuclear Power Issues — Political and Social Implications

Ken Ohtani	Journalist

6:30 pm — 8:00 pm

JAIF Chairman's Reception

Room "HO-O"
TOKYO PRINCE HOTEL

THURSDAY, APRIL 14

9:30 am — 12:00 noon

SESSION 2: FOR COOPERATION AMONG ASIAN COUNTRIES IN UTILIZATION OF NUCLEAR ENERGY (Panel Discussion)

Chairman:

Hiroshi Murata	Vice Chairman Japan Atomic Industrial Forum

Keynote Address:

"Development of Regional Nuclear Co-operation in Asia"

Noramly bin Muslim	Deputy Director General Head, Department of Technical Co-operation International Atomic Energy Agency

"Overview of Nuclear Cooperation in Asia"

Yosuke Nakae	Commissioner Atomic Energy Commission

Panelists:

Noramly bin Muslim	Deputy Director-General International Atomic Energy Agency
Xue-Hong Liu	Deputy Director General Bureau of Foreign Affairs Ministry of Nuclear Industry China
Djali Ahimusa	Director General Badan Tenaga Atom Nasional Indonesia
Pil-Soon Han	President Korea Advanced Energy Research Institute
Quirino O. Navarro	Director Philippine Nuclear Research Institute
Katsuhisa Ida	Deputy Director-General Science and Technology Agency
Ko Takeda	Executive Managing Director Japan Electric Power Information Center, Inc.

12:20 pm — 2:30 pm
LUNCHEON

Room "HO-O"
TOKYO PRINCE HOTEL

Remarks: Hajime Tamura
Minister for International Trade and Industry

Special Lecture: "Interface of Eastern and Western Civilization"
Yuji Aida
Professor Emeritus
Kyoto University

1:00 pm — 2:10 pm
FILMS

CONFERENCE HALL
Most recent films on nuclear power development will be shown

2:45 pm — 5:45 pm
SESSION 3: CURRENT ADVANCED NUCLEAR TECHNOLOGIES

Chairman:
Joichi Aoi — President and Chief Executive Officer, Toshiba Corporation

History and Actual Status of Dry Cask Storage Development in West Germany
Wolfgang Straßburg — Member of the Executive Board, Deutsche Gesellschaft für Wiederaufarbeitung von Kernbrennstoffen mbH (DWK)

The Canadian Concept for Used Nuclear Fuel Disposal
William T. Hancox — Vice-President, Waste Management, Atomic Energy of Canada Limited Research Company

Present Status of the Development of Uranium Enrichment Technology in France
Paul Rigny — Directeur, Division d'Etudes de Séparation Isotopique et de Chemie Physique, Commissariat à l'Energie Atomique, France

Technologies for Uranium Enrichment in Japan
Yoichi Takashima — Professor Emeritus, Tokyo Institute of Technology

Chairman:

Yasunobu Kishimoto	Chairman Showa Denko K. K.

Technological Development of Fast Breeder Reactors

Sadamu Sawai	Executive Director Power Reactor and Nuclear Fuel Development Corporation

Waty to Fusion Experimental Reactor

Ken Tomabechi	Special Researcher Japan Atomic Energy Research Institute

High Technologies and Radiation Application

Yoneho Tabata	Professor University of Tokyo

FRIDAY, APRIL 15

9:30 am — 12:20 pm
SESSION 4: NUCLEAR FUEL SUPPLY SYSTEM: PROSPECTS AND ISSUES

Chairman:
Takeshi Nagano — President, Mitsubishi Metal Corporation

Perspective toward 21st Century on Nuclear Fuel Utilization
Masayoshi Hayashi — President, Power Reactor and Nuclear Fuel Development Corporation

A Comprehensive Economic Assessment of the Fuel Cycle, with a Prospective View
Jean-Claude Guais — General Manager, Marketing & Business Development, COGEMA, France

Nuclear Fuel Cycle Strategy andTasks
Kozo Iida — Executive Vice-President and Director, Kansai Electric Power Co., Inc.

An Assessment of the Prospects for Fuel Cycle Technologies
William L. Wilkinson — Deputy Chief Executive, British Nuclear Fuels plc

Moving toward New Era of Nuclear Fuels
Junnosuke Kishida — Honorary Chairman, Japan Research Institute

General Comments:
Howard K. Shapar — Director General, OECD Nuclear Energy Agency

1:40 pm — 5:20 pm

SESSION 5: EFFORTS FOR FURTHER ENHANCEMENT OF RELIABILITY OF LWR (Panel Discussion)

Co-Chairman:

Minoru Okabe	President Japan Atomic Power Company

Co-Chairman:

Rémy Carle	Directeur Général Adjoint Electricité de France

Panelists:

Leonid M. Voronin	Deputy Minister Ministry of Nuclear Power U.S.S.R.
Brian V. George	Director of PWR Central Electricity Generating Board United Kingdom
Herbert J. Schenk	Member of the Board Philippsburg Nuclear Power Company Federal Republic of Germany
Stanislav Havel	Chairman Czechoslovak Atomic Energy Commission
Kenneth C. Rogers	Commissioner U.S. Nuclear Regulatory Commission
Dong-Joo Kim	Director and Vice President Korea Electric Power Corporation
Ryo Ikegame	Managing Director and General Manager Nuclear Power Administration Tokyo Electric Power Co., Inc.

Comments:

Toshikazu Shibata	Professor Emeritus Kyoto University

開会セッション

大会準備委員長挨拶
東京電力㈱社長
那　須　　翔

原産会長所信表明
㈳日本原子力産業会議会長代行
圓城寺　次　郎

原子力委員長所感
原子力委員会委員長，科学技術庁長官
伊　藤　宗一郎

<特別講演>
中長期的にみた国際エネルギー戦略
ＯＥＣＤ国際エネルギー機関（ＩＥＡ）事務局長
Ｈ．スティーグ

21世紀のエネルギーシステム —— 原子力の役割
西ドイツ・ユーリッヒ原子力研究所長
Ｗ．ヘーフェレ

世界のエネルギー問題と日本の進路
日本エネルギー経済研究所理事長
生　田　豊　朗

大会準備委員長挨拶

東京電力株式会社
社長　那須　翔

ご臨席の皆様、第２１回原産年次大会の開催にあたり、大会準備委員会を代表してご挨拶を申し上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。

本日は、国内から伊藤宗一郎国務大臣・原子力委員会委員長、また海外からはスティーグＯＥＣＤ国際エネルギー機関事務局長、シェーパーＯＥＣＤ原子力機関事務局長、ノラムリイ国際原子力機関事務局次長、テプファー西ドイツ連邦環境自然保護原子炉安全大臣、カプロン・フランス原子力庁長官、ワローニン・ソ連原子力発電省第一次官、陳肇博中国原子力工業省次官、トドリエフ・ブルガリア国務大臣をはじめとする国際機関・各国政府代表、ならびに国内外の多くの権威者の皆様のご参加を得まして、本年次大会をここに開催する運びとなりましたことをこの上なく光栄に存じます。

ここにあらためて、本年次大会における議長、スピーカーをご快諾戴きました大会関係者各位に厚くお礼を申し上げますとともに、本年次大会に参加された国内ならびに、はるばる海外から参加された皆様に、深甚なる感謝の意を表する次第であります。また、原産前会長の有澤先生が本年次大会の開催を前にして急逝なされましたことは残念の極みでございますが、私ども関係者といたしましては

この大会を成功させ、その成果を原子力の発展に反映させていくことが有澤先生の長年にわたって注がれた原子力平和利用への情熱に報いることになるものと信じます。

ご高承のとおり、わが国の原子力発電による電力供給量は１９８７年には全発電量の３０％を超えました。また、世界の原子力発電は１９８７年末にはその規模も４００基・３億ＫＷにまで拡大し、国際経済社会に大いに貢献しておりますが、その果たすべき役割は今後さらに増大していくものと予想されております。このようにわが国を含めた先進諸国が原子力発電開発を推進し、化石エネルギー資源の節約をはかり、国際エネルギー情勢の安定化を目指していくことは今や国際的な要請であり、責務ともなっております。そのような状況の中で、原子力につきましては、安全の確保を大前提に、将来のニーズに見合った技術の開発、平和利用の拡大、国際的な協力を積極的に推進することなどへの努力が一層必要となってきております。

翻って、一昨年のソ連のチェルノブイリ事故や近年の石油需給の緩和傾向等の影響により、一部の国々ではこのところ原子力開発計画に低迷もしくは減速の傾向が見られるなど、原子力をとりまく動静にはきわめて厳しいものがあります。わが国におきましても、とくに昨年後半以来これまでにみられなかった新しい形の原子力批判運動が展開されつつあり、この流れは今や一般市民の原子力に対する信頼をも揺るがそうとしております。この意味において、私たちは原子力への国民的合意の確立という重要な分野においても、新た

な局面に立たされているといえましょう。

私ども準備委員会といたしましては、このような現時点における諸情勢を踏まえつつ、エネルギー問題をグローバルかつ長期的な視点からあらためて捉え、経済社会、産業技術、環境および資源などの各側面から、原子力開発の意義と役割を総合的に評価することが重要であるとの認識に立って、第２１回原産年次大会の基調テーマを「原子力 ― その評価と選択」と定めた次第であります。

本年次大会は、この開会セッションに引き続き、３日間にわたる５つのセッションのもとに、原子力開発を今後推進していく上で直面する諸問題とその対応について、議論を行うことにしております。

開会セッション後半の特別講演およびセッション１「エネルギー複合時代と原子力政策」では、国際機関をはじめ、西ドイツ、フランス、中国、ブルガリア、アメリカそして日本の代表から、エネルギー供給における原子力の役割とそれぞれの国の原子力政策について、見解を伺います。

石油危機以降、先進諸国はより低廉で供給安定性のあるエネルギー確保のために努力を払ってまいりましたが、その結果、２１世紀にはエネルギー供給源の多様化が進むと同時に、各エネルギー間の競合が一層激しくなると予想されております。そのような中で、原子力は主力電源としての役割を果たすことが期待されておりますが、その期待に応えうるか否かは、わが国はもとより本大会に参加されている皆様のこれからの努力にかかっているといえましょう。

本セッションの各代表からは、世界のエネルギー問題の分析と見通しに立って、エネルギー・セキュリティのための国際戦略、各国の原子力政策等が表明され、エネルギー供給における原子力の役割が明らかにされると同時に、パブリックアクセプタンス問題を含めて、原子力開発を今後進めていく上での貴重な示唆が与えられるでありましょう。

次に、２日目のセッション２「アジアにおける原子力協力の展開」では、国際原子力機関、中国、インドネシア、韓国、フィリピンそして日本の各代表が参加して討論を行います。

最近、原子力分野の国際協力の必要性がとみに高まってきておりますが、これにつきましては先進国間の国際協力のみならず、開発途上国協力の重要性がわが国の新原子力開発利用長期計画においても再確認されております。とくに、わが国にとりましては、アジア地域の原子力平和利用とその技術的向上を通して同地域の発展に寄与していくとともに、安全確保についても積極的に協力していくことが重要であると考えます。

現在、アジア地域諸国は原子力開発利用のための研究技術基盤の整備等、さまざまな共通課題を抱えておりますだけに、本セッションでは、同地域における協力をより効果的に行うため、この地域の原子力開発のニーズと課題とを明らかにし、具体的な地域協力の進め方について十分な意見交換が行われるものと期待されます。

同日午後のセッション３「今日の原子力技術」では、原子力と関

連先端技術との組み合わせによる新しい展開が、映像と解説とによって紹介されます。

原子力は技術エネルギーであり、それ自体が一大先端技術であります。そして、原子力の研究開発を推進することによって、エネルギー供給により大きな役割を果たすと同時に、それによって大きな技術革新や他の科学技術への波及効果も期待されております。

本セッションでは、研究開発段階、実用化段階にある原子力技術の中で、ウラン濃縮、乾式キャスク貯蔵、使用済燃料処分、高速増殖炉、核融合および放射線利用の分野の技術を中心に、内外の発表者からそれぞれの最新の技術とその広範な活用が紹介されるでありましょう。

続いて、3日目午前のセッション4「原子燃料利用体系の展望と課題」では、内外の権威者、専門家が発表とコメントを行います。

原子力発電の燃料には主としてウランが使われておりますが、今後、原子力エネルギーを長期にわたって有効に活用していくためには、プルトニウムの利用が不可欠であります。そのためには、原子燃料利用体系の全体の展望にもとづいた燃料サイクルを早い時期に確立する必要があり、それに関連する研究開発や、内外環境の整備を今のうちから進めておくことが重要であります。また、それらを効率的に進めていく上での国際的な役割分担についても積極的に考慮する必要があります。

本セッションでは、燃料サイクル確立の意義、その総合経済性ならびに技術評価、高レベル放射性廃棄物処分、プルトニウム利用へ向けての環境整備等の問題を中心に、原子燃料利用体系を構築する

ためのさまざまな見解の表明や提言が行われるでありましょう。

最後のセッション５「軽水炉信頼性向上への努力」では、日仏の共同議長のもとに８か国のパネリストによって議論が展開されます。

軽水炉時代は当初予想したよりも長期化すると考えられておりますが、２１世紀には各エネルギー間の競合が非常に激しくなることが予想されております。このため、軽水炉が他の電力源に対して今後とも優位性を維持し、主力電源としてふさわしい役割を果たしていくためには、安全性、運転性、経済性等を含めた総合的な信頼性の一層の向上への努力が必要でありますし、また、そのような努力が原子力に対する国民の理解と合意を高めることにもつながると言えましょう。

本セッションでは、軽水炉開発を積極的に展開している国々から責任ある立場の方々にお集まりいただき、軽水炉の長期利用にとって最も重要な信頼性向上のための技術開発や国際協力の進め方と枠組などについて、相互に幅広い意見交換が行われるものと思います。なお、本セッションでは、その議論と原子力に対する最近の世論動向を踏まえ、今後の原子力開発のあり方についてコメントが述べられます。

以上、本大会の概要とねらいにつきまして概略をご説明いたしましたが、３日間にわたる本年次大会を通して、示唆に富む意見の表明と活発な議論が展開され、それらの発表や論議がこれからの世界の原子力開発と国際協調に役に立ち、来るべき２１世紀における人

類の明るい将来の保証につながることを念願し、私の挨拶にかえさせていただきます。

以上

第二十一回原産年次大会
原産会長所信表明

日本原子力産業会議
会長代行　圓城寺　次郎

第二十一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。

わが国の原子力発電は、一九八七年には全発電電力量の三一．七％を占め、最大の電源となりました。現在稼働中の原子力発電設備は、三六基、二八〇〇万KWと世界第四位の規模でありますが、しかし全発電電力量に占める原子力の割合でみるとフランス、ベルギー、韓国等に次いで十位、さらに人口一人当たりの原子力発電電力量もスウェーデンの五分の一、フランスの三分の一と世界十位にすぎません。つまりわが国の原子力発電利用はそれほど抜きん出ているわけではありません。

国内にエネルギー資源がほとんどない日本として、また、石油危機以降、輸入石油への依存度の低減がエネルギーを大量に消費する先進諸国の義務とされているとき、わが国の一次エネルギーにおける輸入石油への依存度は、第一次石油危機の昭和四八年度の七八％から現在五六％へと確かに減少しているとはいえ、依然としてその半分以上を輸入石油に頼っている現状であります。とくに中東地域への依存度はほとんど減っていないのが実態であります。

その一方で、最近、日本が原子力開発利用の先進国の仲間入りをしたと評価されていますのは、稼動中の原子力発電所がここ数年きわめて高い安定性、信頼性をもって運転されていること、またそれを裏付ける高い製造

技術に加え、燃料の利用技術－濃縮、加工、再処理、および廃棄物の各分野－について、それぞれ緩急、達成度はさまざまであっても、とにもかくにも確立した基本路線の上を進んでいることによるのではないでしょうか。さらに、史上最大のチェルノブイリ事故のあとも、原子力発電の必要性について、最近まで国民の理解が安定していたことにもよるのではないでしょうか。

しかしながら、経済成長とエネルギー需要の鈍化およびチェルノブイリ事故の影響から、いくつかの国にみられる原子力開発の停滞といった厳しい状況は、わが国にも少なからぬ影響を与えております。

とくに、昨年暮れから原子力に対する反対運動に新たな側面が出てきました。このことは、世界の中でも原子力開発が着実に進展していると自負していたわたし達原子力関係者に、社会的信頼基盤がまだまだ不十分であること痛感させるものでありました。それに今回の反対の動きは、既成の組織の枠をこえ、一般市民への反原発気運を拡大しようとする動きとみられるのであります。折しも今年一月に発表された総理府による原子力世論調査結果では、原子力発電の必要性を認める人が六〇％近い一方で、「原子力発電について何か不安（心配）に思うことがありますか」という問いに対し、不安に思うと答えた人が八六％と過去最高の数値を示しております。このことが今回の反原発の動きに一つの背景を与えているといえましょう。チェルノブイリ事故以降、輸入食品の放射能汚染問題から、日常の食生活に鋭敏な主婦層の間に起きた不安感、警戒心、これに最近のいくつかのトラブルと出力調整運転試験についての説明不足に乗じて、あたかもチェルノブイリ級の事故がすぐ起きるかのように国民に誤解させようとす

る動きがあるのであります。

今我々に問われているものは何でしょうか。それは、人間がこの巨大な技術を理性的にマネージ（管理）できるかどうかということであり、これを疑わせようとする恣意的な動きに科学的に対処することであるといえましょう。

その意味で、わたし達自身反省しなければならないと思いますのは、最近、原子力発電所でのトラブルがやや目立っていることであります。いずれも安全性に直接かかわるものではないとはいえ、このようなことは厳しく戒めなければなりません。

原子力で唯一の問題ともいえますのは放射能の管理の問題ですが、技術集約エネルギーとしての原子力は、技術とそれを取扱う人間の努力によって、安全性を確保できるものであります。わが国では、原子力開発の当初から、いわゆる環境影響や安全性に最大限の注意を払って進めてきました。わたし達原子力関係者は、原子力発電の導入初期に生じたトラブルに対処して、メーカー、電力会社、政府を含めて一丸となって取り組み、現在はそれらを克服し、原子力発電は高いパフォーマンスを示すまでになり、産業的・技術的に定着するまでに至りました。最初に触れましたようにわが国の原子力発電実績が高く評価されるようになりましたのも、こうした努力の成果といえましょう。

なお、このなかでも特に注目されている一つに、人間にとっては“血液”の管理ともいえる水化学技術がありますが、これは被ばく低減、廃棄物発生量低減に加えて信頼性向上を支える上で、大きく貢献しております。来週一九日から、原産主催で「原子力発電プラント水化学に関する国

際会議―運転経験と高度管理技術」を開催いたしますのも、こうしたすぐれた日本の技術に対する世界の関心にこたえるためであります。

ところで、このようなわたし達の努力も、多くの一般市民からみると、理解されにくい、かけ離れた形での安全管理であったのではないでしょうか。今後は、それがどう国民の目に映るかも考える姿勢が必要なのではないでしょうか。原子力発電が社会に"定着"し、これからも大きな役割を果たそうとしているときに、社会的な理解と信頼を得ることは不可欠であります。これまで注いできた原子力発電開発に匹敵する努力を国民の理解活動に向け、社会的に一層の定着をめざしていかなければならないと思います。国民が原子力発電について正しい情報をもち、科学的に判断できるよう、また、それを扱う関係者の信頼を高めるようにしていかねばならないと思います。そうすることによって真の原子力時代が花開くのではないでしょうか。

人類の英知により生み出したこの技術エネルギーとしての原子力は、人類共通の知的、技術的財産として、その恩恵は出来るだけ多くの国が享受すべきものと考えております。

原子力平和利用は、いわば「核」という原罪を生れながらにして背負っており、現実にこの世界に核兵器が存在しタテ・ヨコの核拡散の恐れがある現状では、まず原子力平和利用の円滑な推進と核不拡散体制の両立は必要不可欠な条件となっております。昨年十一月に署名された新日米原子力協力協定は、日米両国政府がこのような共通の認識のもとに、五年間にわたって協議した結果、合意したものであり、我々はこれが近く発効するこ

とを確信しております。

わが国は、唯一の被爆国として原子力基本法にもとづき、平和利用に限って原子力開発利用を進めており、核不拡散条約（ＮＰＴ）に加入するなど、核不拡散を担保する健全な国際的な枠組の維持、強化のために積極的に協力してきておりますが、このような努力が国際的にも理解され、信頼されることが重要であります。今後ともわが国は率先して、一層合理的な枠組作りに努力していく所存であります。

本年五月末から第三回国連軍縮特別総会が開かれますが、六年前の第二回特別総会に際して、原産はメッセージを送り、日本の原子力産業の立場から、核兵器の速やかなる廃絶を訴えるとともに、その象徴として国際的監視のもとに核兵器の一部を解体し、その核物質を平和利用のストックパイルとして提供することを提言いたしました。

昨年暮れ、米ソ間で中距離核戦力（ＩＮＦ）全廃条約が調印されましたが、核削減さらに核全廃というこの歴史的な流れが一層前進することを願ってやみません。ブリックスＩＡＥＡ事務局長もその可能性を示唆していましたように、核軍縮による核物質を平和目的のための利用について、具体的かつ真剣に検討していく時期に来たといえましょう。「剣は鋤に、槍は鎌とされ」てはじめて三五年前のアイゼンハワー大統領の“アトムズ・フォア・ピース”の精神を生かすことができるのです。

さて、最後にこれまで十数年にわたり原産会長として日本の原子力平和利用を指導してこられた故有澤廣巳会長が、数多くの人々から惜しまれながらさる三月七日に逝去されましたが、わが国の原子力開発に対する故有

澤会長の死の直前までの悲願は、燃料サイクル、とりわけ再処理、高レベル廃棄物処理処分を含むバックエンド部分の確立でありました。

ウラン資源といえども有限なものであり、いずれ人類は必ずプルトニウム燃料サイクルに依存しなければならない時代が来ます。しかもプルトニウムの平和利用に習熟するには時間がかかります。いま日本が、自らが無資源国であるということを動機として、世界に先駆けて、この課題にチャレンジすることに、我々としても大きな歴史的責任を感じております。また、国際的にもそう理解してほしいと思います。

わが国がこれから建設しようとする再処理施設は、そのための要となるものですが、十～二十年に一回しか建設されない大規模施設です。これが成功するかどうかは、安全性、信頼性、保修性の観点から、それをいかに総合的、合理的に作っていくか、いかにマネージし、産業的にも社会的にも信頼できるものに築き上げていくかが、いま問われていると申せましょう。

わが国では、この春に本州と北海道を結ぶ青函トンネル、および本州と四国を結ぶ本四架橋（瀬戸大橋）の二つの大プロジェクトが完成しました。これらは日本列島をつなぐ大経済・交通動脈ですが、われわれ原子力関係者が取り組んでいる燃料サイクル施設は、二十一世紀にむけてのわが国の準国産エネルギー確保の「かけ橋」になるものと考えております。

以上、わたしは、最近の原子力を取り巻く動向からみて、原子力発電の安全性、平和利用（核不拡散）およびバックエンドの確立が重要であり、加えて、それらに対する信頼構築、すなわち国民的にも国際的にも信頼される形でこれに取り組んでいくことが肝要であることについて述べまし

た。

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、那須準備委員長、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「原子力－その評価と選択」について、有益な示唆が得られますよう祈念いたしますとともに、各国の権威の方々から二十一世紀の原子力への展望と期待を聞かせていただけることを希望して、私の所信を終らせていただきます。

以　上

JAIF CHAIRMAN'S ADDRESS

Jiro Enjoji

Acting Chairman

Japan Atomic Industrial Forum

21st JAIF Annual Conference

April 13, 1988

I am honored to have the opportunity to address you at the opening of the 21st JAIF Annual Conference.

Nuclear power, accounting for 31.7% of Japan's total electricity generated in 1987, has become the nation's largest source of electric power. With 36 nuclear power plants, totaling 28 million KW, Japan now has the fourth largest nuclear capacity in the world. But, when nuclear power is seen as a percentage of total generated electricity, Japan is in tenth place after France, Belgium, Korea and so forth. Japan's nuclear generated electricity per head of population is one-fifth of that of Sweden and one-third of that of France -- or, in this respect, we are tenth on the world list. In other words, Japan in no way stands out in the matter of nuclear power development.

We have little energy resources to fall back on in Japan, and any industrialized nation consuming large amounts of energy has been in duty bound, since the oil crisis, to reduce its dependency on imported oil. Imported oil as a percentage of primary energy in Japan has certainly dropped from 78% in fiscal 1973, the year of the first oil crisis, to 56% now, but the fact remains that we depend on imported oil for more than half of our primary energy supplies. Our dependence on the Middle East, in particular, has not actually diminished.

Recently, however, Japan is considered to have joined the circle of advanced nations in the development of nuclear energy, because the Japanese nuclear power plants have been in remarkably safe and reliable operation for the past several years. I might say it is also because of the high quality of the manufacturing techniques that have brought out the nuclear plants, as well as that of the techniques for the use of nuclear fuel -- in all aspects of enrichment, fabrication, reprocessing and waste -- which, though each in varying degrees of progress, achievement and success, are somehow on course toward the basic objectives established for them. Another reason is, perhaps, that the Japanese people's understanding of the necessity for nuclear power has remained almost unperturbed even under the influence of the Chernobyl accident, the greatest on record.

However, slow economic growth, a dull demand for energy and the impact of the Chernobyl accident combine to make it difficult for some countries to recover from their stagnancy in the development of nuclear energy.

In Japan, a new phase has been brought in the movement against nuclear power since late last year. It has brought us -- all interests involved in the development of nuclear energy which we believe is on a world level of progress -- the keen realization that our foundations are not yet solid enough to win social confidence. Besides, anti-nuclear moves have now been made in a departure from the usual practice of agitation by established organizations, because they are apparently designed to arouse an anti-nuclear feeling among the general public.

Incidentally I may add that Prime Minister's Office samplings of public opinion on nuclear energy, released in January this year, show that while nearly 60% recognize the necessity for nuclear power, 86% say "yes" to the question: "Do you ever have some misgivings (apprehensions) about nuclear power?" This is the highest figure on record, and it provides a favorable climate for anti-nuclear moves. Since the Chernobyl accident aroused the fear that imported foodstuffs might be contaminated by radioactivity, uneasiness and wariness have come upon the housewives who are sensitive to their everyday eating habits. In addition, reports of some recent troubles and insufficient explanations of a planned power modulation operation test have been taken advantage of to lead the people into believing wrongly that a Chernobyl-class accident could happen anytime.

What is the question we face under these circumstances? Perhaps the point is that doubts are being cast on man's ability to keep this big technology under reasonable management.

Perhaps the only major problem about nuclear power is the management of radioactivity. But nuclear power is a technology-intensive form of energy whose safety can be secured by technique and through the efforts of the people who handle it. From the beginning of nuclear development in Japan, we have taken every possible care about its environmental effects and its safety. All the troubles that arose in the early stages of nuclear power generation have now been overcome through the joint efforts of manufacturers, electric utilities, government authorities and all others involved in nuclear power. The high performance of nuclear power has made it come to stay as an industry and as a technology. It is a result of these efforts which has earned Japan a high reputation, as I said earlier, for its performance in nuclear generation.

One of the most significant achievements in this respect is the technique of water chemistry which controls what may be likened to man's "blood." It contributes largely toward minimizing exposure doses, reducing the production of waste and making for the improvement of reliability (a better availability factor). World interest in this and other advanced Japanese techniques will be given some satisfaction next week, April 19, when the 1988 JAIF International Conference on Water Chemistry in Nuclear Power Plants -- Operational Experience and New Technologies for Management is held.

For all our efforts, however, I suspect that we have been exercising safety control in a way hard for many of the people at large to understand and out of their reach. At a time when nuclear power is "coming to stay" in society and is about to play a great role, it is indispensable to assure social understanding and confidence for it.

I think no less efforts than we have paid to the development of nuclear power should be devoted to the promotion of public understanding, with a view to obtaining much more social acceptance. That is how we can ensure that the nuclear age prevails in the true sense of the word. Efforts should be made to let the people have the correct and scientific information needed for them to exercise judgment in matters of nuclear power and eventually to place confidence in those who are involved in its handling.

Does anyone object to my suggestion that our efforts toward safety have been limited, as often as not, to the level of self-complacency within the nuclear community? Does anyone doubt the desirability of our being anxious to know how the people look at us. The question before us is how to regain the people's confidence in those who are involved in nuclear development.

In this connection, we are in need of soul searching on the recent events that led to trouble in a number of nuclear power plants. Although none of them involved a safety risk, we are cautioned against anything like that.

Nuclear power is a technological form of energy which has been produced through the exercise of man's brains and which, as an intellectual and technological property common to all mankind, ought to benefit as many countries as possible.

Nuclear energy cannot be put to peaceful use without carrying with it the original sin of "being nuclear weapons ." In fact, the presence of nuclear weapons threatens the world with their vertical and horizontal proliferation, and so the necessity exists to ensure that the promotion of peaceful uses of nuclear energy is facilitated in a way compatible with the nuclear non-proliferation regime. A new agreement on nuclear cooperation was signed between Japan and the United States in November last year as a result of five years of consultations carried on by the governments of the two countries on their common understanding of such cooperation. I am convinced this will come into force soon.

Japan, the only country to have been atom-bombed in the world, has been guided by its Atomic Energy Basic Law to promote the development and utilization of nuclear energy only for purposes of peaceful use. Acceding to the Nuclear Non-Proliferation Treaty (NPT), Japan has actively cooperated in maintaining and strengthening a sound international framework for the security of nuclear non-proliferation. It is important that these efforts should gain international understanding and confidence. We are prepared to continue to take the initiative in efforts to give more reasonable dimensions to the framework.

In connection with the Third Special Session of the United Nations General Assembly Devoted to Disarmament opening at the end of May this year, it should be recalled that a JAIF message to the Second Special Session six years ago appealed, proceeding from the position of the Japanese nuclear industry, for early elimination of nuclear weapons and, in a symbolic move to this end, proposed dismantling part of the nuclear weapons under international supervision and removing nuclear material from them for presentation as a stockpile for peaceful use.

Toward the end of last year, the United States and the Soviet Union signed a treaty for the total elimination of intermediate-range nuclear forces (INF). It is our sincere hope that there will be further steps forward in this historic process of nuclear weapons from reduction to total elimination. As has been suggested by Dr. H. Blix, director general of the International Atomic Energy Agency, the time is for a concrete and serious study of peaceful uses for the surplus of nuclear material from nuclear disarmament. Only when there occurs the change "from sword to spade, from spear to sickle" can we put life into the "Atoms for Peace" spirit of President Eisenhower 35 years ago.

Finally, let me remind you that the death of JAIF Chairman Hiromi Arisawa on March 7 came as a great loss to the large number of people who have been under his guidance for the peaceful uses of nuclear energy in Japan for more than 10 years. It was the late Chairman Arisawa's cherished desire to his last moment that the development of nuclear energy in Japan should be complete with the establishment of a fuel cycle, notably the back end which includes provision for reprocessing and the management and disposal of high level wastes.

Uranium resources are limited and the day will come when mankind has to rely on a Pu fuel cycle. And it will take time before skill is acquired in the peaceful utilization of plutonium. This is challenge for Japan and we feel we are historically reponsible for ensuring that this country, being not blessed with natural resources, is motivated to take it up. So we wish for an international understanding for this challenge.

The key to it is the reprocessing plant which we are going to build now, and which is a large-scale installation to be built only once in 10 to 20 years. Success in this project depends on how comprehensively and reasonably we can build it with assurances of safety, reliability and maintenability and how well we can manage it as an industrially and socially reliable business.

In the spring of this year, two big projects have been completed -- one is an undersea tunnel (Seikan Tunnel) connecting Honshu with Hokkaido, and the other is a bridge (Seto Ohashi) across the sea between Honshu and Shikoku. Just as these are the arteries of business and traffic that link the Japanese islands together, so the fuel cycle facilities we are working on for the development of nuclear energy are to become a "bridge" leading us to the 21st century when a semi-Japanese-produced form of energy will be made available.

The above is my comment on three considerations of management and operation which I took up in the light of recent developments in the nuclear industry -- namely, nuclear safety, peaceful uses (nuclear non-proliferation) and the back end. The importance of management and operation in regard to these requirements, notably the importance of the need to build up public confidence for them or operate them in ways that win national and international confidence, is what I wanted to emphasize.

In the last place, I wish to express my heartfelt gratitude to those who have arrived from within and outside Japan to speak up in this conference, to the chairman of the Program Committee and to the chairmen of all sessions. I close my address with hoping that useful suggestions will be given on the basic theme of this conference, "Nuclear Power: Assessment for World Energy Option," and that Japanese and foreign authorities will tell us how they view and what they expect from nuclear energy in the 21st century.

伊藤原子力委員長所感

第21回日本原子力産業会議年次大会
昭和63年 4月13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21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たえません。

圓城寺会長代行、那須大会準備委員長を始め、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とこの場に会する事ができ、喜ばしく思う次第であります。先日惜しまれつつも他界されました有澤会長がこの場

に出席されておられましたら、ここまで大きく成長した日本原子力産業会議に、また、日本の原子力業界そのものに、さぞかし深い感慨を持たれたことと推察致します。ここで、改めて心から哀悼の意を表する次第であります。

さて、我が国の原子力開発利用は原子力委員会の策定する「原子力開発利用長期計画」に基づいて着実に推進されてきており、今や原子力発電は国民生活及び産業活動に必要不可欠なエネルギー源として定着しております。御高承のとおり、原子力委員会は、我が国の原子力開発利用が３０年という節目を迎えていることから、これまでの開発路線を総点検し、新しい時代環境に適応した原子力開発利用のあり方と目指すべ

き方向を明らかにするため、昨年 6月に新しい「原子力開発利用長期計画」を策定しました。本長期計画においては、今後2000年までの原子力開発利用推進の基本的な目標として以下の３つの基本方針を掲げております。

第１に、原子力を我が国のエネルギー供給構造の脆弱性の克服に貢献する基軸エネルギーとして位置付け、その開発を推進することであります。具体的には、現在、総発電電力量の約３０％を賄うに至っている原子力発電を２０００年において、約４０％の割合まで高め、発電設備容量として約５，３５０万キロワットの目標まで着実に増加させることとしております。このため、

①軽水炉主流時代の長期化に対応すべく、

原子力発電の信頼性、経済性等をさらに向上させるための軽水炉技術の高度化

②チェルノブイル原子力発電所事故の教訓を踏まえた安全性のより一層の向上

③高速増殖炉原型炉「もんじゅ」の建設等新型動力炉の開発

④青森県における核燃料サイクル三施設の建設計画の推進をはじめとする核燃料サイクルの確立

等を推進して参ります。これにより、我が国におけるエネルギーの安定確保が図られるのみならず、石油需要の減退、大気汚染物質の軽減等につながることから、グローバルなエネルギー問題の解決に大きく貢献することが期待されます。

第２の柱は、創造的・革新的領域の研究開発を推進することであります。具体的には、

①核融合、高温工学試験研究等の技術革新の牽引車としての役割を果たす先導的プロジェクトを推進する

②原子力技術の高度化・多様化に対応することを可能にするため、各種の原子力分野のプロジェクトの共通基盤となる基盤技術として、

ⅰ)原子力用材料

ⅱ)原子力用人工知能

ⅲ)原子力用レーザー

ⅳ)放射線リスク評価・低減化

の４課題について、技術開発を推進する

等、積極的に取り組んで参る所存であります。このため、例えば、昨年9月に臨界プラズマ条件の目標領域に到達した日本原子力研究所の臨界プラズマ試験装置(JT－60)の高性能化を図るとともに、高い固有の安全性等の優れた特性を有する高温ガス炉の技術を確立するため、高温工学試験研究炉の実施設計等を推進することとしております。

第3に、原子力先進国として我が国の国際的責務を果たすとともに、原子力分野における我が国の国際貢献への要請に応えるべく、核不拡散との両立を図りつつ、主体的・能動的国際対応を展開して参ります。特に、開発途上国との研究交流を拡充するとともに、外国人研究者の受入れのための

適切な国内環境の整備等を積極的に推進して参る所存であります。

ところで、この三本目の柱に関連して、我が国の原子力開発利用史上、永年の懸案事項であった2つの国際的な案件につき、今国会において御審議いただいております。

1つは新しい日米原子力協力協定であります。

昭和52年当時、日米間で東海再処理工場の運転をめぐり、現行日米原子力協定に基づく米国の事前同意を得るための交渉が行われておりましたが、カーター政権が打ち出した核不拡散政策を背景に交渉が難航したことがありました。

このような経緯を受け、昭和56年 5月の鈴木総理とレーガン大統領との日米首脳会

談において「日米間の再処理に関する問題について早急かつ恒久的な解決を図る」との合意を得、さらに昭和57年 6月には中川科学技術庁長官が訪米し、早急に日米間で協議を開始することで両国間の合意を得るに至ったのであります。

爾来、5年余りにわたる精力的な協議の結果、昨年11月 4日に新日米原子力協定の署名がなされ、11月 9日には米国議会に、本年 3月11日には日本の国会にそれぞれ提出されました。

新協定は現行協定に代わり、日米間の原子力協力のための新しい枠組を構築するものであり、種々の特色を備えております。

まず、使用済燃料の再処理、核燃料物質の第三国移転等についてですが、従来は、

個別のケースごとに米国の事前同意が必要であり、それ故に交渉が難航したことがあったのですが、新協定においてはあらかじめ一定の条件を定め、その枠内であれば一括承認するいわゆる包括事前同意方式を導入しております。これにより、民間再処理工場の建設・運転及び高速増殖炉等におけるプルトニウムの利用を、十分な予見性をもって円滑に推進することが可能になると考えられます。

また、本協定は、米国核不拡散法の規制要件を完全に満たすものとなっており、このような新協定が日米両国間で締結されることは、世界の核不拡散体制の確立に大きく貢献するものと期待されます。

本協定に関する米国議会における審議状

況ですが、活発な議論がこれまで展開され、去る 3月21日に上院本会議において協定不承認決議案が否決されたところであり、4月末には承認される見込みと聞いております。

さて、本国会でただ今ご審議いただいておりますもう一つの重要案件は、「核物質の防護に関する条約」への加入及びこれに関連した原子炉等規制法の一部改正であります。

我が国は、これまで、官民をあげて原子力の開発利用を推進してきた結果、今や核燃料サイクル事業の本格化の時代を迎えようとしております。

これに伴い、原子力施設における核物質取扱量等の増加が予想されており、我が国の基軸エネルギーである原子力の研究、開

発及び利用を今後とも円滑に推進していくためには、適切な核物質の防護措置を講じていくことが極めて重要となっております。

一方、国際的にみても、核物質の防護は、原子力活動を行う上での基本的要件として認識されており、昨年2月に発効した「核物質の防護に関する条約」に早急に加入し、そのために必要な体制整備を行うことは、原子力先進国としての我が国が果たさなければならない国際的責務でもあります。

我が国においては、関係者の尽力により、昭和56年に原子力委員会が決定した核物質の防護に関する報告書の内容を踏まえ、既に国際水準を満たす核物質防護措置が講じられておりますが、「核物質の防護に関する条約」への加入に際し、核物質防護に取

り組む我が国の決意を内外に明らかにし、さらに、万全の核物質の防護のための体制整備を行うことが重要であります。このため、次に挙げる3点を骨子とする原子炉等規制法の一部改正案を本国会に提出、御審議いただいております。

まず第1に、原子力施設において核物質の防護のための区域の設定をはじめとする核物質の防護のために必要な措置を原子力事業者が講ずる際の基準の明確化等であります。

第2に、核物質の輸送を行う者に対し、核物質の防護措置の義務付けを明確化するとともに、原子力事業者に対して輸送に先立って全行程にわたり、輸送に関する責任の明確化を図り、内閣総理大臣の確認を受

けなければならないものとする等、所要の規定の整備を行うこととしています。

第3に、「核物質の防護に関する条約」が処罰を求めている核物質を用いた犯罪に関し、所要の罰則規定の整備を図ることとしております。

以上申し上げましたとおり、私といたしましても両案件の今国会での審議が円滑に行われ、早急に承認が得られますよう最大限の努力を払って参る所存でございます。

最後に原子力開発を取り巻く国民世論について一言申し上げたいと思います。

最近の我が国経済は国民一人当たりの所得が世界最高水準に達するなど好調そのものに推移しております。特にこの経済活動基盤となるエネルギー需給については、こ

こ当面は緩和基調で推移することが予想されています。

これも、原子力を始めとする石油代替エネルギー開発を推進し、石油の消費を抑制してきたからであります。

このように大きな成果を収めてきた我が国のエネルギー政策は、例えば、ソ連チェルノブイル原子力発電所事故後の昨年夏に実施された総理府の世論調査でも、引き続き原子力発電の開発を進めていくべきとする人が着実に増加し、57%に達するなど、国民の支持を受けて進められているところであります。

しかし、一方で、このような現状に対して反対の立場をとる人も一部にはあり、本年2月に四国電力伊方発電所で行われた出

力調整運転試験が、あたかもソ連の事故の引き金となった実験と同じものであるという風評が流されたことにより、さらに反原子力運動が広まりました。

もとより、原子力開発を進めるに当たっては慎重の上にも慎重を期し、国民の理解と協力の下に行うことが大前提であります。したがって、我々原子力開発に取り組んでいる者は常に原子力に対する様々な考え方に謙虚に耳を傾けていかなければならないことは申すまでもありません。

しかしながら、我が国の経済活動を無視して原子力を全部止めさせるというような意見や、科学的論拠に基づかずに原子力を危険なものとする意見に対しては、正しい理解を得るよう十分な説明を行うことが不

可欠であります。

２１世紀に向け我が国が現在の豊かな生活を維持していくためには、エネルギーの安定確保が不可欠です。そしてそのためには、我が国の置かれた状況からして、原子力をエネルギー安定供給の基軸となるエネルギーとしてその開発を進めていかなければならないことは明らかであります。

したがって、我々原子力開発に携わる者は、原子力に反対する意見に対し、信念を持って、粘り強く説明し続けていくという気持ちを持たなければなりません。ここに御出席の関係者にも一層の努力を強く期待するとともに、国際的な場においてもパブリック・アクセプタンスのあり方についての検討を行うよう提唱したいと思います。

以上、最近の私の所感を御披露致しましたが、本日から3日間、「原子力ーその評価と選択」という基調テーマのもとで、内外の多数の有識者・専門家の方々の間で忌たんのない活発な意見交換が行なわれ、貴重な提言がなされ、本大会が盛況のうちに成功を収められんことを心から祈念いたしまして、私の挨拶を終わらせていただきます。

MID AND LONG TERM WORLD ENERGY STRATEGY

Address by Helga Steeg
Executive Director, International Energy Agency

Good morning, Ladies and Gentlemen. It is my pleasure to address your annual conference this morning -- especially since the conference is 21 years old today. In Europe we have a tradition that when a child reaches 21 years old, the family gathers around to celebrate. I believe you do the same for a 20th birthday here in Japan. We tell each other stories about how our young friend has grown up. We look back with pride and pleasure at the child's achievements over the past years. But a 21st birthday party really celebrates the future much more than the past; it looks forward to the young person's full blossoming into maturity and to his or her contribution to society at large. So, we may be allowed to hope, it is with nuclear power. We can with pride celebrate the achievements of the past. There have been, certainly, some difficult moments especially in recent years -- the adolescence, if you like, of nuclear power -- but we should look forward today much more than we look backwards.

Nuclear power in 1988 is supplying about 23 percent of OECD countries' electricity, which compares with less than two percent in the late 1960s when your first annual conference was held. In Japan, where nuclear power production was still at the experimental stage in the 1960s, I understand that about 28 percent of your electric power now comes from nuclear sources. This places Japan well in the mainstream of countries which use nuclear power, although in some countries the proportion is considerably higher. Nuclear power has developed from being a technology with wonderful potential, into a fuel which accounts for a significant portion of commercial electricity supply. This is an important achievement. In looking forward to the future, we may hope and expect today that there is room for nuclear power to make an even larger contribution to energy supply and to society at large.

The role of nuclear power has to be seen in the national perspective of energy policies in each of our member countries in the IEA. It must also be seen, however, in the wider world energy context. I want to address you today on these wider energy themes. I shall start therefore by describing the current world energy situation. I shall follow by outlining how IEA members see the necessary strategies for electricity and for energy security in today's changed world. Finally I shall say a few words about the particular circumstances of Japan's energy policies in the international context.

The World Energy Scene Today

From the point of view of the International Energy Agency, and from Japan's point of view, the energy situation in general is much improved compared with a decade ago. This improvement can be categorized in two ways. There is an improvement in the structure of energy use; and there is an improvement in the flexibility with which energy is used. In 1973 and still in 1979, the IEA countries depended for one half or more than one half of all primary energy requirements on a single fuel -- oil. The political and economic events of those years showed that this was an unacceptable degree of dependence. Since then, the structure has changed. Energy is now used more efficiently, and other fuels make a much higher proportionate contribution. Solid fuels, natural gas and primary electricity between them account in a much more balanced way for nearly three-fifths of IEA primary energy.

Nevertheless, we recognize that oil is still the dominant fuel and will continue to be so, both in our countries and in the increasingly important developing economies. The rate of growth of oil demand in developing countries continues to be faster than it is in the developed world, so that developing countries are becoming more important both in terms of the world's oil supply and demand balance, and in policy terms. The price of oil continues to be a key economic variable. The volume of oil traded and consumed in the world is so large that changes in its price have measurable macroeconomic effects. Economic growth is influenced by the price of oil through movements in the terms of trade, and inflation rates are directly affected by the contribution of oil prices to the general level of industrial input prices. In 1985 and 1986, there were important benefits to the world economy as a whole from lower inflation and from the subsequent reductions in interest rates although the pass-through of lower prices varied from country to country. At the same time, however, much attention focussed on sectoral difficulties which were caused by lower oil prices. As well as these macroeconomic effects, the oil price has an important microeconomic impact in the energy industry. As long as oil is the dominant fuel, its price remains a key variable -- some may say the key variable -- for the economics of other forms of energy. In particular, the evolution of its price will be an important factor for investment decisions in all energy sectors. It seem likely that there will be in the future more uncertainty, and more fluctuations, in the price of oil as there are with the prices of other commodities. There is no doubt that this complicates life and decision-making both for consumers and producers as they learn to live with fluctuating prices.

There are risks in both directions with the oil price. On the one hand, even though the supply of oil is more diversified than it used to be, supply is still concentrated in the Middle East. If production of oil in the mature geological provinces of the United States continues to decline, and stabilizes in the North Sea and elsewhere in the OECD world, then we are likely to see a further increase in this concentration. The Middle East remains an area where political conflict implies risk for commercial activity -- and oil supply and prices remain vulnerable to that risk. On the other hand, many fundamental factors continue to exert downward pressure on the price of oil.

The imbalance between ample supply and slack winter demand has caused a lot of downward price pressure in recent months. There has been a perception that the market is not likely to tighten in the near term. Many industry participants say, and I think we would agree with them, that recent price developments have simply been the normal kind of volatility which we can expect for 1988 and for future years as well. When I speak of fundamental factors which create downward pressure on the price of oil, I am not only talking of short-term events which we all read about in the newspapers -- the level of stocks, production quotas, and so forth. I am talking also of the underlying factors -- costs, fiscal conditions and technological progress. Marginal exploration and development costs in the most geologically-favoured regions are of the order of less than one dollar per barrel. Marginal operating costs even in climatically hostile and difficult areas such as the North Sea or Alaska are at most a few dollars a barrel. Governments everywhere in the developing as in the developed world, are tending to relax their fiscal regimes for oil exploration and development. Technology is bringing down the cost of enhanced oil recovery, and even bringing down to approachable levels the cost of developing oil sands and heavy oils. The abundant reserves of these so-called "unconventional" oils would transform the life-time prospects for fossil fuels. Restructuring is going on in the oil industry, with acquisition of downstream assets by producing countries complementing the purchase of oil reserves outside IEA countries by Western and Japanese companies. Producers of all fossil fuels are now taking these sorts of factors into account in their planning and expenditure. Producers, in short, are learning to live with lower prices.

You in the nuclear industry, and your competitors in the coal and gas industries also, will have to take decisions whose consequences will be judged in the light of the way that many of these factors in the oil world turn out. Consumers of energy also make choices among fuels which to some extent lock them in the short or medium term. But consumers are increasingly providing themselves with the flexibility to use many different fuels. Electric power utilities, heavy industry, district heating plants and the owners of commercial buildings have invested and will continue to invest in the ability to switch between fuels for economic or security reasons. Furthermore, many consumers who in the 1970s had little choice now face wider opportunities through expanded trade. I can mention power utilities in countries like Denmark, Italy or the Netherlands, where access to imported coal has widened the range of fuel choice and enabled them to increase capacity securely through diversity. Or consider the petrochemical companies for whom the growth in LPG trade has widened the scope of supply competitive with naphtha. Look even at the householder, who more and more frequently has the choice of oil or gas or electricity for his home heating as trade and technological change have opened up new possibilities of competitive supply. This trend towards more flexibility at the consumers' end will continue as trade is further encouraged by the removal of distorting price practices, diminishing government intervention and other institutional barriers.

This is the environment in which energy industries operate today. We see the surplus capacity in oil production translated into day-by-day pressure on oil prices, which is often reported as the continuing struggle by OPEC ministers to balance their national interests against the "need" to manage the price. But this story which attracts the newspapers' attention is only one element in the whole picture. In the late 1980s we have a transformed energy scene, and its hallmarks are more intense competition, more flexible use and supply, and more opportunities opened by the progress of trade and technology. The energy industry and energy policy makers in government need to consider how best to design their strategies in this kind of a world.

For the electricity sector and for the nuclear industry in particular, some things can be fairly clear. Not all countries will want to have a nuclear option if they have other resources and other strategies available to them. But some countries are import-dependent in nearly all forms of energy. These countries will rightly enable their consumers to benefit from the advantages of free and open trade in those energy commodities where this is possible. They will be prudent also to develop nuclear power in the electricity sector as actively as possible, since this is then effectively an indigenous fuel resource. Major countries who fall into this category include France, Germany and Japan. I would note also, that even countries well-endowed with energy resources such as Britain and Canada do not wish to neglect the opportunities that nuclear power offers. The British Government has reaffirmed that it will go ahead with a new phase in the expansion of nuclear power, by constructing a series of PWR-type reactors, starting with Sizewell. Moreover, after electricity has been privatized, the British intend to establish a legal requirement that a certain proportion of their electricity shall be generated by nuclear power. If the British take this attitude, with their oil, their gas, and their coal, how much more do others need to ensure an important place for nuclear power in their energy policies. In my own country, Germany, yes, there is discussion about the future role of nuclear power. The Government for its part remains fully committed to its further development. And, we all know from experience, opposition parties may take an apparently clear stand while in opposition; but when they come to power, they sometimes find they must adjust their stand in line with their new responsibilities and in line with reality.

Ministers also emphasised of course that continued high safety standards are an essential part of any strategy for nuclear power. Continued research and development work for the back-end of the fuel cycle is also vital. I am convinced that it is technically possible to solve problems of waste disposal. The Nuclear Energy Agency of the OECD has just completed a survey of research activities into high-level waste disposal, including those involving practical on-site feasibility tests. The survey shows that the overwhelming majority of governments with signficant nuclear industries share this assessment. It is important to encourage international cooperation in these activities to maximise the advantages to be gained from technical progress.

Energy and Security

In the IEA, we are particularly concerned with energy security. I believe that there should be three parts to an international strategy for energy security.

The first aspect must be a constant readiness to cope with an emergency in energy supply. We indeed hope that we will never need to activate the IEA's emergency oil sharing system, nor to put in motion our countries' coordinated early response measures. These measures are, however, in place and ready to operate should there be an interruption in the normal flow of oil in a way which threatens economic damage to IEA countries. We take very seriously our obligation to stand ready for this. Our member countries also take their obligations seriously. Japan's commitment to a high and rising level of emergency stocks is a very important contribution not only to Japan's own energy security but also to the security of her partners and allies. This year the IEA is conducting two tests of the emergency preparedness of our member countries and of the oil companies who would cooperate should circumstances require it. These circumstances would involve the physical disruption of oil supplies. Stocks of oil would be an essential part of meeting such a disruption. It is not good enough to argue that increased prices would guarantee adequate supply--in the short-term circumstances of a physical interruption, our member countries would certainly require plentiful and readily available stocks of oil. The IEA, therefore encourages those of its member countries who are in a position to do so to increase their level of stocks and to ensure that they would be available quickly when needed. I would certainly applaude the Japanese proposal to increase the level of Government-owned oil to fifty million kiloliters by the mid. 1990's. I think the most important thing will be to translate this proposal into action, so as to reduce the vulnerability of Japan's energy situation as well as to enhance international solidarity.

The second aspect of international energy security must be the continued promotion of structural change through diversification of resources and improvements in energy efficiency. This does not mean that governments need to step in to interfere with normal market mechanisms by indefinitely subsidizing this or that form of energy or uneconomic conservation activities. What it does mean is that governments and industry should play their part in the promotion of technological development, the dissemination of information to help consumers understand what the market signals are (especially in the area of energy efficiency), and, most important, the maintenance of all options for diversified development of energy sources. This latter point is especially important in the electric power sector. At the most recent meeting of IEA Ministers in May 1987, it was agreed that:

> "A significant limitation of any ... options, in particular of coal or nuclear, for the IEA as a whole would increase demand for other energy sources and thus the costs of achieving energy security... Each IEA country will have to decide on the mix of fuels used in generating stations best suited to its particular circumstances. All will, however, seek to achieve a mix which takes into account considerations of energy security, environment, safety and the possible effects of their decisions on other countries."

It is clear that those countries who have important nuclear power programmes will therefore need to continue to support development of nuclear power to continue to improve their structural security and the security of the group as a whole by this means.

But structural change on its own will not be enough. I have hinted already in what I have said about flexibility in energy supply, use and trade that I think this is an important element in today's energy world. Indeed I think it is also a vital aspect of energy security. In Japan's "Energy Vision for the 21st Century", the comment was made:

"Competition between different forms of energy ... enlarges the range of energy selection, and contributes to assuring security by increasing flexibility in the energy supply. Progress in energy competition is indispensable to the healthy development of future energy industries... In order to assure maximum benefit from this competition it will be most important to provide conditions, adapted to each situation, that facilitate technological development and utilization of its results."

Flexibility, competition, and the free flow of information are vital to the dissemination of new technology. Technological innovation makes an invaluable contribution to improved efficiency in the use of energy, and so must be regarded as an essential part of strategy for energy security. There are a great number of energy technologies which hold immediate promise, and the IEA actively promotes the development, sharing and dissemination of these technologies. We do this through methods such as our "implementing agreements" on research projects and various schemes such as our Energy Technology Data Exchange or the newly-lauched CADDET centre. We also actively promote cooperation in research into other new technologies which offer great promise for more distant horizons, such as fusion power. We must not ignore these distant horizons by having our minds too full of present-day problems. It is encouraging for me that the Japanese atomic industry community participates actively in many aspects of this work.

Japan's energy policy in an international context

It is true that changes in one part of the energy world have immediate implications for other parts, and there must be increased flexibility to accommodate this. Let me give you a simple example of this here in Japan. Through the 1970s, the heavy industry made major adjustments in fuel use, and there was strong growth of both nuclear power and LNG in electricity. These two developments substantially reduced the demand for heavy fuel oil. At the same time, the oil refining industry, isolated from international competition but without the financial resources to invest in upgrading capacity, was unable to convert fuel oil into lighter products to the extent required by the domestic market. Under these circumstances, as a result of consumer pressure it became impossible to maintain the prohibition a heavy fuel oil imports. This gives an example of how without flexibility in policy and in the supply and use of energy, irresistible pressures build up because of changes elsewhere in the system. The evenutal process of adjustment may become more painful. In 1985 at a meeting of IEA Ministers, and subsequently in recommendations to the Minister of International Trade and Industry from the Petroleum Council, the direction was set for further liberalization of Japan's oil product markets. This should have the effect of reducing future distortions and the difficulties which can arise as a result. Japan's petroleum refining industry is now moving to a less government-guided mode of operation, with more autonomous management and more able to respond to world market conditions. It has come in this sector to be recognized that the legislation of the early 1960s governing the operation of the refining industry was not flexible enough to cope with the energy world of the 1980s or 1990s, where Japan's domestic needs are different and where Japan has a changing role on the international stage.

The coal sector provides another example of this important point. One of the major developments of the next few years is likely to be the progressive dismantling of barriers to trade in coal. This will mainly affect European members of the IEA where traditionally a high degree of self-sufficiency has been maintained at high cost, and where there are important regional and social aspects to coal production. But it also affects Japan, where costs are also high and where many of the traditional attitudes and social concerns are the same. Reducing energy costs and widening energy opportunities are vital to the twin objectives of promoting economic welfare in a broadly-based way and to reinforcing energy security. Enhancing competition and trade in coal is no exception to this principle. It is encouraging to see the direction set by Japan's Eighth Coal Plan in this regard. Adjustment is taking place here in Japan, and it is important for you to know that the same difficult process is taking place in other countries as well. The IEA provides a forum in which different countries can obtain assurance on matters like this -- where collective needs can be pursued either collectively or, if individually, then on a simultaneous basis.

I have mentioned two areas -- oil refining and coal -- where the particular circumstances of Japan's energy policies have an important international dimension. Both of these are linked to the important aspect of flexibility, which is itself a vital part of energy security. I would like to come finally to Japan's electricity industry and particularly to nuclear power, in this context.

The nuclear industry and the electricity industry will increasingly have to take risks and decisions in an environment of uncertainty. We now see that the oil market, as we have seen for many years with other commodity markets, is not subject over the long-term, to predictable market management. Within individual countries government reassurance about the precise role of each type of fuel may be less readily available. National and international strategy for energy security cannot be one-dimensional. We cannot say "we should do this, and then we shall have done enough." We cannot say simply that "energy will be secure if only x percent of our electricity comes from such and such a fuel source." We cannot predict the future, and we do not know where the next "crisis" in its broadest sense will come from, and our strategic planning should recognize this.

What will be the new momentum for change in the energy world in the next ten years? In the next century? Will it be concern about "global warming", the so-called "greenhouse" effect? Will it be other environmental concerns on an international scale? Will it be enormous social change driven by the march of technology into a post-industrial world? Or will it be a huge demand for energy in a rapidly industrialising third world? Will it again be caused by political problems in the Middle East? We do not know the answers to these questions. The new momentum of change may come from any one of them, from a combination of several, or even from something unforeseen and unthinkable today. Let us pause for a moment and consider the environmental question -- or rather the range of environmental questions -- which we face when making energy choices. Japanese energy policies were powerfully influenced by environmental factors in the 1970s, and much progress has been made in, for example, controlling emissions from stationary sources as a result of major investments in the application of technology and carefully monitored regulation. Similar questions are being taken up, and similar progress is being made, in many other countries today. But there are still great areas of uncertainty -- in the scientific sense as well as for policy-makers. We do not know exactly where we stand in relation to the greenhouse effect, for example. More and more research is being done, but conclusions are difficult, and as yet we do not know even how long it is likely to be before we can come to sensible conclusions about whether action needs to be taken. Whatever the answer, it is clear in this area as in others, that the most foolish thing to do would be to close off our own options for the future. And this is where I believe nuclear power fits into the picture. Supposing we do conclude -- and I repeat that no one can judge whether or not we shall -- that important steps must be taken in the next century to limit carbon dioxide emissions? Safely-managed nuclear power may then once again appear to be an environmentally attractive option. Nuclear power is not, alone, the solution to all our energy problems, but it is an essential part of a strategy for a secure energy future, nationally here in Japan and internationally in the world as a whole. Within this framework, your industry and your forum have an important role to play. I wish you well with your conference and in your daily working lives.

Energy Systems in the 21st Century and the Significant Role of Nuclear Energy *

by

Wolf Häfele
Kernforschungsanlage Jülich, Fed. Rep. of Germany

1. The evolution and fate of nuclear power

For 1985, the IAEA/OECD has listed the total capacity of nuclear power amounting to 253 GWel world-wide corresponding to a power generation of 1.4 x 10^3 TWh during the year [1]. Table 1 gives a breakdown into 9 countries as well as the customary categories of OECD Europe and Pacific (E + P), OECD America (A), Developing World Outside Communist Countries (WOCA), the Centrally Planned Economies (CPE) and the World total.

1.4 x 10^3 TWhel is equivalent to 0.49 TWyears thermal (assuming a thermal efficiency of 0.33) and thus 4.7 % of the world's total primary energy consumption of 10.52 TWyears [2]. The total electricity generation amounted to 9.4 x 10^3 TWh in 1985 and the nuclear share was therefore 15 %. In both measures the role of nuclear energy has thus become a significant one.

At the same time the accident at Chernobyl and other less drastic social and economic developments are questioning this role of nuclear energy. In the following a brief listing of the state of nuclear energy in various countries is given:

Belgium

The nuclear share from 8 stations in operation approximates 70 % of electricity generation. A further power station of 1.400 MW with participation of France (50 %) is expected for the nineties.

---

* invited paper, presented at the 21st JAIF Annual Conference, April 13 - 15, 1988, Tokyo, Japan

Canada

A nuclear power share of 14,7 % came in 1986 from 18 power stations, 5 units were under construction. In 1990 the nuclear power share is expected to reach 19 %.

Denmark

In 1985 the Parliament voted against the use of nuclear power.

France

70 % electricity share comes from 50 nuclear power stations. 14 further stations are under construction and one more is ordered.

Germany, Federal Republic

The building up of nuclear power reaches a saturation with 40 % electricity share coming from 22 power stations. The placing of new nuclear orders is presently not in sight and the political situation is ambivalent.

UK

20 % electricity share comes from 38 reactors, many of them of the MAGNOX type. In March 1987 the first pressurized light water reactor was licensed.

Italy

There is a de facto moratorium against nuclear power.

Netherlands

In 1985, two nuclear power stations contributed 6 % to electricity supply, the building up is now seriously delayed.

Spain

Nearly 30 % of the total electricity production is generated by 8 nuclear power stations. Out of eight power stations under construction in 1985, only four are being completed.

Finland

Up to the Chernobyl event 40 % electricity share came from 4 nuclear power stations. Since the Chernobyl event, the building up of nuclear power has stagnated, a termination of the use of nuclear power appears to be possible.

Austria

Austria abandoned the use of nuclear power in 1978.

Switzerland

40 % electricity share comes from five nuclear power stations. The construction of one more nuclear power station is envisaged but the political pressure for the termination of the use of nuclear power is strong.

Sweden

50 % electricity share comes from 12 nuclear power stations. In 1980 the Swedish Parliament decided to terminate the use of nuclear power by 2010.

Brazil

Mostly for economic reasons the building up of nuclear power is slowed down significantly.

Japan

25 % of total electricity generation was supplied by 35 nuclear power stations during 1986, and the building up of nuclear power continues as planned.

South Korea

7 Nuclear power stations were in operation at the end of 1986, the nuclear share in electricity generation was about 44 %. After Chernobyl two new orders were placed.

USA

99 nuclear power stations were in operation at the end of 1986, the nuclear electricity share during 1986 was 16.6 %. The commissioning of new power stations will reach an end and no new plants have been ordered since 1977.

CPE

In the Centrally Planned Economies the building up of nuclear power continues vigorously as planned. Nuclear power share in the East European Countries varies widely. Altogether there are now about 70 nuclear power plants in operation.

It is interesting to plot the development of nuclear power through the year 2000 for countries like Japan, France and Germany (Fig. 1 - 3). There is in all cases a steady development. In the case of Japan, the number of planned stations has lately increased again, while in the case of France there are no new plans in sight. In the case of Germany, a considerable share has remained in the planning stage. And in the case of the USSR (Fig. 4), there is even an explicit reduction for stations in the planning stage, while in the case of the USA (Fig. 5), not only those planned but even some in the stage of construction are being reduced.

For some countries the building up of nuclear power seems to be a logistic one. In that case the relative building up of the capacity F, 1/F dF/dt, is meant to follow a linear relation:

$$\frac{1}{F}\frac{dF}{dt} = \alpha(S - F)$$

S is the saturation value and α is a parameter. Table 2 gives the values of S and the correlation coefficients of the actual data fitting the linear behaviour shown above. One should note the low correlation coefficient for the Soviet Union, that of France was even lower (0.358) and therefore, the estimate was not given. It is then striking to see that saturation values are above the actual figure for 1985 and below the IAEA estimate for 1992 (made in 1985).

One should not overvalue such a kind of analysis but it may be appropriate to observe that nuclear power may expand more slowly than expected as late as 1985. This suggests that the figure for the installed capacity of 508 GWel for 2000 given in Table 1 may be too high. Alternatively we assume here that 360 GWel could be a reasonable estimate for 2000, a figure that is close to the IAEA estimate for 1990. This figure is based on the 1985 figure of 253 GWel multiplied by the ratio between S and the 1985 figure as indicated in Table 2, plus 24 GWel to meet conveniently the IAEA value of 1990. But it should be clear that the assumption of 360 GWel for the year 2000 is a straightforward estimate which is only meant to express the even further reduced expectations for the growth of nuclear power as seen in this analysis.

At 360 GWel the annual consumption of natural uranium is close to 60.000 tonnes. Assuming again that the use of nuclear power is saturated but continues at that level this would be ongoingly the annual consumption. Estimating natural uranium resources is a complex thing. OECD/IAEA have repeatedly assessed such estimates [3]. Table 3 compiles the estimates of 1986. If one only takes the 3647 x 10^3 t of the Reasonably Assured Resources and the Estimated Assured Resources of WOCA into account, such an amount would last 72 years, allocating here a capacity share of 300 GWel for the WOCA countries accordingly. And with the Speculative Resources of WOCA, the additional factor to be considered would be between 2.7 and 3.4.

If, by contrast, the building up of nuclear power continues as expected in the recent OECD/IAEA evaluation [1], such a development within WOCA would cumulatively require 3078 x 10^3 tonnes of natural uranium for the "Low" LWR strategy, with 675 GWel (WOCA) in the year 2025. The "High" LWR strategy would cumulatively require 5386 x 10^3 tonnes, within WOCA with 1555 GWel (WOCA) in the year 2025. Other reactor strategies would require lesser amounts of uranium. The "Low" case with a Fast Breeder Strategy would cumulatively require the least amount, namely only 1980 x 10^3 tonnes, whereas the "High" case world require 3656 x 10^3 tonnes, both within WOCA.

Thus an interesting staging of such future aspects arises:

- If the use of nuclear power is saturated at a level that is somewhere at 360 GWel the supply of natural uranium is not a real resource problem for something like the next hundred years.
- If nuclear power is build up according to the "Low" Scenario of OECD/IAEA yielding 675 GWel (WOCA) and 875 GWel (World) in 2025, the Reasonably Assured Resources and the Additional Resources would have been consumed by around that time. It would then be necessary to use Speculative Resources whose implications we do not understand today. For the "High" Scenario (1555 GWel (WOCA) and 2160 GWel (World) by 2025), this would occur accordingly earlier.
- If a Fast Breeder Strategy is involved this essentially permits staying within the use of Reasonably Assured and Additional Resources. Thus, it would not be necessary to touch Speculative Resources for at least one more century in any event.

In the past such reactor strategies have been evaluated extensively, and therefore, this aspect should not be pursued here any further. The point here was to reflect on the possible range of the Reasonably Assured Resources and Estimated Assured Resources.

If the use of nuclear power is saturated at a level of 360 GWel or so, this would be the effect of

- reduces economic growth
- low oil prices
- lack of social acceptance.

The latter refers in particular to the tail end of the nuclear fuel cycle. Transportation, intermediate storage, reprocessing and final waste disposal all become issues of a more and more political nature. As a new element, direct disposal of irradiated fuel elements has been suggested. Let us therefore assume that the construction and operation of civilian nuclear reprocessing plants will stagnate (one would not like to speak of saturation in this context). Table 4 compiles these reprocessing plants. Only plants of commercial significance are listed; pilot or experimental plants are not mentioned.

For purposes of orientation it is sufficient to relate 30 t of irradiated fuel ready for discharge with 1 GWel year. After discharge, about 0.2 t of fissionable Pu go along with it. From the early nineties onward, at 360 GWel world-wide and 300 GWel within WOCA, this would mean 10.800 or 9.000 t per year of irradiated fuel associated with 72 or 60 t of fissionable Pu per year. If only the existing reprocessing plants of WOCA continue to operate, only 22 % of the WOCA amounts could be reprocessed; in case all the reprocessing plants of WOCA now under construction or planned should also come into operation it would be 55 %, instead.

Reprocessed plutonium could go primarily to a recycling process in LWR. If fresh plutonium coming from a reprocessing plant is constantly added such recycling can continue [4]. Without recycling, 30 t per GWel year and 3 % enrichment (equilibrium cycle) mean 900 kg U^{235} per GWel year. Assuming that one quarter could be recycled the recycled plutonium thus would roughly meet the 200 kg of fissionable Pu coming from the reprocessing of the 30 t per GWel year of fuel discharge. Therefore, if 22 % (or 55 %, respectively) of all discharged fuel can be reprocessed also, 22 % (or 55 %, respectively) of the fissionable plutonium contained in the discharged fuel can be made use of. The remainder is contained in the unprocessed irradiated fuel. Within WOCA this would mean 47 (or 27, respectively) tonnes per year of such fissionable Plutonium.

Over two or three decades this accumulates to an amount in the order of 1.000 t within WOCA, thus significantly exceeding the amounts of plutonium in the military domain. It is often argued that such irradiated fuel elements should go to a direct final disposal. But after 100 - 150 years the self-defense of such disposed fuel by radiation from fission products has faded away, and a shielding of only a few centimeters of lead is sufficient should one want to handle these then old fuel elements. This is comparable to a problem arising just now in the second half of our century: It is the recognition of the fact that our generation has inherited from its ancestors the problem of toxic chemical waste. In the Federal Republic of Germany, toxic waste is produced in the order of 5 Mio tonnes per year and it becomes a growing problem within Germany to cope with old and new disposal sites of such toxic waste. One is only gradually realizing the dimension of that problem.

It is deemed here that a repetition of this toxic waste situation is not acceptable. Our generation is beginning to understand the aspects and constraints coming from the environment of man. Our generation cannot transfer 1000 t of Pu and more to the next generations. Direct waste disposal of irradiated fuel elements of that magnitude essentially means the creation of man-made Pu mines, it requires an IAEA type of safeguards for ever and means a burden of unknown quality. What then follows from this observation?

This question will be answered here in four stages:

1) Further building up of reprocessing capacities is a necessity, whether nuclear power stagnates, increases or fades away. Reprocessing capacity is necessary in much the same way as one is now building up combustion furnaces for toxic chemical waste treatment. It permits the conditioning of irradiated material and in particular a minimization of required storage volumes. So far as the disposal of fission products is concerned, only about 70 liters per tonne of original fuel are required. For the Pu, a typical figure would be about 100 l per tonne of original fuel. The latter observation requires further specifications in view of criticality, physical shielding and other factors that cannot be given here.

2) In view of this situation the approach of having an International Plutonium Storage handled by IAEA [5] appears in a new light. So far all these negotiations started from the viewpoints of Pu shortage, disposability and sovereignty. Environmental compatibility of thousands of tonnes of Pu could be a new element. The idea of Regional Fuel Cycle Centers that was considered by the IAEA in the seventies [6] should be reevaluated in such a context.

3) In those countries where the termination of nuclear power appears to be definitive, the development of special reactors should be envisaged that burn Pu without using fertile material. In such a case, the fuel elements could for instance be based on PuO_2ZrO_2, a ceramic material of benign properties [7].

4) Given the above considerations, it appears to be not only an easier pathway but also a more natural pathway to build up a population of Liquid Metal Fast Breeder Reactors (LMFBRs). These LMFBRs allow for several modes of operation [8]. The earliest mode used metallic fuel and minimized the doubling time of the Pu inventory. The early EBRII reactor of the US is a good example. The second mode does not concentrate so much on doubling times but emphasizes instead high fuel ratings, low fuel cycle costs and large cores. The present prototype reactors like the Phenix and Superphenix in France, the PFR in the UK, the BN 350 and BN 600 in the Soviet Union, the SNR 300 in Germany and the MONJU reactor in Japan follow that scheme. Not so well-known is a third mode of operation. It emphasizes large Pu inventories and thereby such fast reactors become active Pu storages. In that mode of operation one may delete the radial or even the axial blanket [8]. In our context, this mode of operating a LMFBR may become important. It may become important because it is relatively easy to adjust the operation to the varius modes. And this leads to a fourth mode of using advanced fuel and blankets that are specifically designed for the fuel supply of other reactors not necessarily of the LMFBR type. For instance, it may be desirable to breed thorium and to produce thereby U^{233} for the operation of High Temperature Reactors.

Briefly summarized, the extended use of LMFBRs with their various modes of operation permits increase, sustainment or decrease of the Pu contained in a whole commercial fuel cycle. It means a situation of flexibility and adaptability and this is probably most mandatory in the decades to come.

2. Energy systems in the 21st century

Given the fact that the investment decisions of today cover more or less the next ten years, the present century is over in such a context and the 21st century is beginning. At the International Institute for Applied Systems Analysis (IIASA) a comprehensive and global systems analysis of the energy problem was conducted and the results were published in 1981 [9]. There were, among others, two important conclusions that are of relevance here:

1. There is an energy problem within the energy problem. It is the adequate supply of liquid fuels and particularly so for the developing countries.

2. While it is certain that there has to be a transition of energy systems away from the carbon atom to nuclear and/or solar power as primary energy it is less well obvious that there is a second, earlier transition superimposed on the first one. This second transition is the transition from relatively clean, cheap and readily available fossil reserves to low grade, expensive and hardly accessible fossil resources.

Even if nuclear power was built up to the largest possible extent these two problems would prevail. What is important then is to understand the magnitude and more so the timing of these problems. It will turn out that not only the problems of appropriate fossil supplies but also the problem of fossil waste disposal could well become overwhelming issues.

The IIASA energy study identified two scenarios that were elaborated in detail, the IIASA "High" and the IIASA "Low" Scenario. During the seventies when the study was conducted, the world energy consumption was about 8 TWyears/year (1 TWyear is roughly a billion t of coal equivalent (tce)). The "High" Scenario identified an energy consumption of 35 TWyears/year by 2030 while the "Low" Scenario identified 22 TWyears/year by that year. In the meantime ten years have gone by, and it is interesting to compare the real development with the scenarios. It turns out that the real development fits rather well the "Low" Scenario as indicated in Fig. 6 for the world as a whole. But the IIASA "Low" Scenario distinguishes also seven World Regions and even within this break-down, the "Low" Scenario corresponds rather well with the reality of the BP data as given in Table 5. Besides there were other scenarios developed in the meantime; they are given for the world as a whole in Fig. 7. Against these comparisons it is concluded here that the IIASA "Low" Scenario turns out to be reasonable. Even so it cannot be a prediction: this is impossible.

H.C. Runge at the KFA Jülich [10] then studied the problem of oil supply and demand in greater detail, and his results are given in Fig. 8. It turns out that the time around 2010 is a time when the conventional oil supply will start fading out. Around that time the production rate will be about 3.8 billion toe/year or 5.5 TWyears/year. According to by H.C. Runge, it is the maximum rate simply from a technical point of view, and this is consistent with the findings of the IIASA "Low" Scenario [11]. Thus confirmed, we make use of the IIASA "Low" Scenario for further analysis.

Consumption according to the IIASA "Low" Scenario then leads to an accumulated value of 264 TWyears by the year 2030, and that is about 80 % of the conventional oil resources in question [12]. In the case of natural gas, the disparity between supply and demand occurs somewhat later, around 2020. At that time, the production rate is 3.5 TWyears/year or 2.7 billion m^3/year. The cumulative consumption by the year 2030 reaches about 50 % of the conventional gas resources, namely 130 TWyears [12].

The total of conventional oil and gas resources together amounts to 531 TWyears. Such values are not sharply defined and are to a certain extent a matter of definition. For instance C.D. Masters has recently presented an evaluation which identifies a total of 508 TWyear as the conventional supply of oil and gas [13], and other figures in that domain are equally possible. Therefore, only the broader statement can be made that the transition to non-conventional resources will gradually take place between 2010 and 2040. One should understand the implications of the transition: Oil continues to be the leading energy form, and this is consistent with the earlier observation that the adequate supply of liquid fuels is the energy problem within the energy problem. The oil price leads the energy market, and to a large extent the oil market influences the world market. A transition to non-conventional resources draws our attention to new areas like

Athabaska in Canada, Orinoco in Venezuela, or Olenek in Sibiria and, through the new technologies, new oil prices and a new political framework. It is therefore appropriate to expect major influences on other developments including nuclear power. It is fair to expect that this transition to non conventional oil resources is setting the path.

Furthermore, there is coal. As such, its situation is different. The conventional and more so the unconventional resources are very large. But the use of coal will follow the developments of the oil market in its own way, and be it only through prices. The IIASA "Low" Scenario identifies a total of 224 TWyears of coal consumed by 2030 [14].

Altogether the IIASA "Low" Scenario identifies a total of 633 TWyears of fossil fuel consumption by the year 2030. This is the sum of 264 TWyears for oil, 145 TWyears for gas and 224 TWyears for coal. It should be noted, however, that the IIASA "Low" Scenario does assume a substantial contribution from nuclear power. It assumes an installed capacity of nuclear electricity generation of 620 GWel for 2000 and 910 GWel for 2030 [15]. If nuclear power is saturated at 360 GWel the expected consumption of fossil fuel would be close to 660 TWyears even.

Such uses of fossil fuels do not only change the world energy market from the supply side, they also pose a large-scale fossil waste disposal problem. The fossil fuel cycle has a tail end, too!

What is already impinging upon us are the side streams of such fossil fuel uses, that is SO_2 and NO_x. For industrialized countries such as Japan, typical emissions are in the order of millions of tonnes. These are manageable amounts through the installation of appropriate abatement measures. But SO_2 and NO_x are only side streams. The main stream consists of CO_2 and the amounts released by man-made combustion processes are reaching global significance. According to the world's climatological community, a doubling of the CO_2 content would lead to a warming of the average world temperature between 1.5 and 4.0 Kelvin. What is more striking is the expectation that at the poles the warming could be as high as 10 Kelvin with all the consequences of ice melting and changes of climatic patterns. The important thing is that this expectation has become more and more confirmed [16], [17]; one can no longer discard it as mere speculation. It is equally true that by the very nature of this non-linear problem, it cannot be a firm prediction, either.

The so-called natural CO_2-content is the one measured at the end of the last century, i.e. 290 ppmv. Such an amount of CO_2 corresponds with CO_2-emissions originating from the combustion of 600 TWyears of carbon. For a more precise analysis, one has then to make a number of corrections: Hydrocarbons have a higher energy yield than carbon, about one half of the released CO_2 is absorbed by the upper layers of the ocean within a few years, and besides CO_2, there are other trace gases like CH_4, the FCHCs and others not coming from the energy domain.

The rather fundamental observation to be made here is to realize the coincidence of the fossil energy consumption of 600 - 800 TWyears by 2030 and the 600 TWyears of carbon combustion for the doubling of the natural CO_2-content. It is a rough coincidence and details will change this observation somewhat as indicated above, so it should not be overinterpreted. But for some general conclusions, it is significant enough:

1) During the early part of the 21st century, i.e. between 2020 und 2050, a transition from conventional to non conventional fossil resources is imminent while at the same time roughly a doubling of the CO_2-content of the atmosphere is to be expected.

2) Contrary to the past, it is therefore not only a matter of adequate supply of fossil fuels but more so and earlier, it is the problem of fossil waste disposal that has to govern the energy systems of the 21st century.

3) It should therefore be questioned whether an all out transition from conventional to non-conventional fossil resources is acceptable at all. Instead, primary and secondary fuels should be favored that are limited in the use of carbon, if not even carbon-free.

4) Thus, energy systems of the 21st century have to expect major evolutions including surprises and shocks. It is therefore of paramount importance to improve our understanding of the dynamics of these evolutions and to prepare for flexibility and adaptability.

5) Above all, it is necessary to buy time.

In principle, it is not too difficult to envisage a carbon free energy system. On the side of secondary energies, it must provide electricity and a storable and transportable energy carrier to supplement electricity. Hydrogen is the best candidate for it. Both electricity and hydrogen are environmentally benign to the fullest extent. On the primary energy side, the two candidates are solar and nuclear power. The so called alternative soft sources like wind, waves and others could and should be employed wherever possible. However, their power is limited. It is hard to expect more than a 5 - 10 % contribution from these sources. Therefore, the above-mentioned solar source refers to the hard version of solar power, the giant fields of photo voltaic arrays in desert regions, fields covering areas of 100.000 - 1 Mio km^2 and more. While this is technically feasible, it is a matter of cost and time to build these solar systems up. Marchetti has studied the long range dynamics of such transitions [18]. Fig. 9 gives the development of the H/C-ratio of the world's energy system. It is striking to see the regularity in the past development of that ratio. If one assumes that this path continues beyond the H/C-ratio of methane which is 4, then one has to conclude that it will take 100 - 150 years before hydrogen has taken over. This is a much longer time period than that considered for the oncoming CO_2-problem. And it is shorter than the time horizon of the possible uses of non-conventional fossil resources. It is therefore helpful to consider the time horizons as compiled in Tab. 6. It gives a first impression of the dynamics of the evolution of energy systems in the 21^{st} century.

3. The significant role of nuclear energy

If the long-term situation of energy systems is rather clear and even reassuring, what then is the situation for prudent measures in the forthcoming decades during the first part of the 21^{st} century?

Prudent measures must care for the tail end of the fossil fuel cycle and should aim at the largest possible H/C-ratio for the liquid secondary energy carriers while at the same time, the share of electricity should be made as large as reasonably possible. To care for the tail end of the fossil fuel cycle means first of all to reduce the emissions involved. At the Kernforschungsanlage (KFA) Jülich, the scheme of Novel Horizontally Integrated Energy Systems (NHIES) has been studied in depth and over a number of years. A principal way for doing so was the extension of the well known MARKAL code [19] into the MARNES code [20], both being large Linear Programs.

The NHIES scheme incorporates three principal ideas [21].

1) The first idea is to decompose and thereby clean all primary inputs to the energy system prior to their combustion. Obviously, this applies to coal and also to heavy crude oil or tar sands in view of their sulphur and heavy metal contents. Therefore, a number of processes can be envisaged: the TEXACO process, the SHELL-KOPPERS entrained flow process and even the use of a molten iron bath. In the latter cases the sulphur and heavy metal contents accumulate as slag on the surface of that molten iron bath. The product of these coal gasification processes is consistently synthesis gas with an H/C-ratio close to unity. But the idea of decomposing all primary inputs goes even further: Also the decomposition of natural gas should be examined by means of a shift reaction. The Jülich EVA scheme has demonstrated such a shift reaction with the help of external high-temperature process heat meant to come from the High Temperature Reactor [22]. The H/C-ratio of the resulting synthesis gas is essentially 6. In addition to the primary fuels, also air should be decomposed. The nitrogen can either be used or put back to the open air. The resulting oxygen is already required for the above-mentioned molten iron bath, and it will be required later in the fossil fuel cycle as a combustion partner instead of air. If necessary, also water should be decomposed, primarily by means of electrolysis, if an effective H/C-ratio of a particular synthesis gas is to be adjusted.

2) The gasification or splitting of all the fossil inputs results consistently in synthesis gas, that is a mixture of CO and H_2, and the separation of the components of air adds O_2 as a third component. So the second idea is to collect these already clean components and to adjust the H/C ratio, that is the H_2/CO ratio, to a desired value. Therefore, it is sort of a grid, somewhat in analogy to an electric grid that collects inputs from all sorts of power stations. Sometimes that was called the second grid. In any event, that is what is meant by horizontal integration.

3) The third idea is to allocate the synthesis gas and the oxygen only stoichiometrically to energy conversion stations. In the case of electricity

generation, this could be $\frac{1}{2}$ O_2 and CO given to a gas turbine of appropriate design. In any event, it would be a new combustion process without nitrogen thus avoiding the related NOx emissions right from the beginning. But obviously an inert gas must be used in order to avoid too high temperatures. It could be the appropriately recycled CO_2 of that very combustion. In the case of a liquid energy carrier, this could be $2H_2$ and CO resulting in methanol. Indeed, methanol has an H/C-ratio of 4 like methane, thus approximating hydrogen to the largest possible extent. But different from methane methanol is a liquid. As a matter of fact, it is appropriate to consider the carbon atom of methanol as a hydrogen carrier that allows for the liquid state.

These three principal ideas then serve the end uses, and so far, gaseous emissions were not necessary, at least in principle. Only the remaining end uses of methanol would lead to emissions of NOx and CO_2. In practice, there will always be emissions but they can be made smaller and smaller. In Fig. 6 these ideas are schematically represented. By the step of horizontal integration, it is possible to provide a high degree of interfuel substitutability so that it can again serve the purpose of flexibility and adaptibility. The NHIES approach also means the reduction of the use of the carbon atom to prudent uses, mainly as a hydrogen carrier of secondary fuel for motor purposes, most notably in the traffic sector. This implies the use of electricity wherever possible, and therefore nuclear power becomes essential. It does reduce the use of the carbon atom and the release of CO_2 if electricity comes from nuclear power. But in addition, that nuclear power would also be used in significant amounts for the purpose of providing high-temperature process heat. The endothermic methane-steam shift reaction for the splitting of methane is only one such application. Allothermal instead of autothermal coal gasification is another application, and the generation of hydrogen is perhaps the most important. This requires the High Temperature Reactor, which in turn could get its nuclear fuel supply from the radial blankets of Fast Breeders, an aspect that was already mentioned above. Therefore also the emissions of CO_2 could be reduced significantly. Recent computer runs at Jülich indicate the feasibility of CO_2-reductions down to 1/3 of today's value. This would mean that we would have gained time for further action - the principal goal of energy systems of the 21st century.

The significant role of nuclear energy in these energy systems of the 21st century can therefore be assessed as follows:

1) There is the quantitative aspect of the supply of electricity. As far as possible, it should come from nuclear power stations, thus leaving the supply of the carbon atom from conventional sources which is large but nevertheless limited to more prudent uses like methanol synthesis.

2) Besides the aspect of supply, there is the aspect of waste disposal, for both nuclear and fossil fuels. Large-scale uses of nuclear power would alleviate the situation of fossil waste disposal, but would instead lead to the problem of nuclear waste disposal. Nuclear waste disposal requires a high degree of meticulousness but is manageable, while at least the CO_2-waste is unmanageable.

3) Nuclear power as part of integrated energy systems contributes to the flexibility and adaptability of such systems. In view of the expected fast developments and even shocks, this would be of increasing importance surpassing even the aspect of economic optimization. The role of nuclear energy would then also include non-electrical applications.

4) Integrated energy systems and the use of nuclear power therein are meant to prepare and smooth the development of eventual energy systems that are limited in the use of carbon, if not even carbon-free. Prudent uses of the carbon atom therefore imply the understanding and management of the various time horizons involved.

The development of the practicability and the details of the NHIES scheme is a comprehensive task, and a tedious one. The whole approach and the detailed NHIES results will soon be published as a book [23]. Some results have been reported already [24]. Here are a few features of these results of the computer runs at Jülich:

The NHIES concept is meant to compete with the existing energy systems that have essentially a vertical integration. In the case of oil one speaks of upstream and downstream operations and their managerial integration, a vertical integration. And the natural gas companies are similarly integrated; they compete with oil, and so does coal. Evaluations that use the LP approach are by their very nature macroeconomic ones, or top-down approaches neglecting thus managerial aspects. With that clarification put forward it may be reported here that already now, the NHIES concept can claim a certain share of the end user market. That share is naturally a function of the oil price, of constraints for coal, market shares and CO_2-limits. The overall result of these more detailed calculations is the observation that particular local conditions favor particular parts of the NHIES scheme earlier than others.

Thus, one has to envisage the NHIES approach more broadly and generally, and this leads to the notion of Integrated Energy Systems (IES). Such Integrated Energy Systems are analysed by a number of groups in various countries and in IIASA. In Sweden, for instance, the plan of developing an energy complex at Nyneshamn is an example [25]. This plan anticipates the large-scale use of coal, its gasification, the production of ammonia and/or methanol together with electricity and district heat for Stockholm. The Cool Water Project in the USA follows similar lines often referred to as cogeneration. Its starting point is a gas-turbine/steam-turbine combined cycle plant, with electricity, ammonia and district heat as principal products [26]. In Oklahoma, USA, the use of large amounts of natural gas is to the force. They are meant to go to an oxygen/natural gas turbine whose exhaust would be clean CO_2 (and H_2O) that could be used there for tertiary oil recovery [28]. Also the Siberian Energy Institute at Irkutsk of the Siberian Branch of the Soviet Academy of Sciences studies Integrated Energy Systems, primarily with regard to the development of the Kansk-Achinsk area around Krasnoyarsk, East Siberia. This is a very large field of low-grade lignite and permits an annual production of a billion tonnes of lignite per year if the environmental problems of related emissions involved can be solved [27]. Analysis groups of Tokai Mura in Japan, in Taiwan, of MIT in Boston and of IIASA in Austria are following similar lines [28].

4. Final Remarks

If the present development and the presently recognizable fate of nuclear power is confronted with the significant role that nuclear power has to play in the evolution of energy systems in the 21st century, one realizes a significant discrepancy. To over come this discrepancy it is necessary to reach a much better understanding of the dynamics, both short-range and long-range, of the evolution of energy systems and to communicate that understanding to the public. In particular, the interplay of time horizons and choices to be made is of paramount importance. And this is the context for passing judgement on nuclear power in the 21^{st} century.

5. Acknowledgements

The author wishes to thank W. Stoll and E. Merz for help in assessing the situation of the nuclear fuel cycle, H.-J. Hoffmann and H. Müller-Spaeth for compiling and reviewing data of the nuclear capacities, and E. Geißler for the finalization of Figures and Tables.

Literature

[1] - OECD/NEA - IAEA
Nuclear Energy and its Fuel Cycle, Prospects to 2025
OECD Nuclear Energy Agency and International Atomic Energy Agency, Paris, 1987

- OECD/NEA
Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries
OECD/NEA Nuclear Energy Agency, Paris, 1986

- IAEA
Nuclear Power Reactors in the World
Reference Data Series No. 2
Vienna: International Atomic Energy Agency, 1986

[2] - British Petroleum Company
BP Statistical Review of World Energy
London: The British Petroleum Company, June 1986

[3] OECD Nuclear Energy Agency - International Atomic Energy Agency
- Uranium. Resources, Production and Demand
1975, 1977 and 1978 Issues
Paris: Organization for Economic Cooperation and Development (OECD), Dec. 1975, Dec. 1977, Dec. 1978
- World Uranium Potential, An International Evaluation
Paris: Organization for Economic Cooperation and Development
OECD, Dec. 1986

[4] Mehrfachrezyklierung von Plutonium und Uran in thermischen Reaktoren
Ergebnisse eines Statusseminars im Bundesministerium für Forschung und Technologie, 14. Oktober 1981
Bonn: Bundesministerium für Forschung und Technologie, FRG

[5] IAEA-Expert Group on International Plutonium Storage
Report to the Director General
Vienna: International Atomic Energy Agency, Nov. 1982

[6] IAEA
Regional Fuel Cycle Centres
1977 Report of the IAEA Study Project, Vol. 1 & 2
Vienna: International Atomic Energy Agency, 1977

[7] The Irradiation Behavior of ZrO_2 - PuO_2 Fuels
In: O.J. Wick (Edr.), Plutonium Handbook, Vol. II, Chap. 20, pp. 680 - 83
New York, London, Paris: Gordon and Breach, Science Publishers, 1967

[8] W. Häfele
Fast Breeder Futures after Chernobyl
In publication in Energy Exploration and Exploitation, Elsevier Applied Science Publisher Ltd., London, 1988

[9] W. Häfele (Program Leader)
Energy in a Finite World
Report by the Energy Systems Program Group of the International Institute for Applied Systems Analysis
Vol. 1: Paths to a Sustainable Future
Vol. 2: A Global Systems Analysis
Cambridge, Massachusetts, Ballinger Publishing Company, 1981

also:
Japanese Translation by Prof. Atsuyuki Suzuki under supervision of Prof. Keichi Oshima
Japanese Copyright by Denryoku Shimposha Co. Ltd., Tokyo, 1983

[10] H.C. Runge, W. Mönig
Überlegungen zur längerfristigen Verfügbarkeit des Erdöls
Jülich: Internal KFA-Report (Nov. 1987) in preparation as Jül-Spez-Report.

[11] see Ref. [9], Vol. 2: p. 557, Fig. 17-10 B

[12] see Ref. [9], Vol. 2: p. 531, Tab. 17-6; p. 589, Tab. 17-14; p. 597, Tab. 18-3

[13] C.D. Masters et al.
World Petroleum Resources of Crude Oil, Natural Gas, Natural Bitumen and Shale Oil.
Paper presented to the 12th World Petroleum Congress, (Topic 25), April 1987. Proceedings of the Congress in print.

[14] see Ref. [9], Vol. 2: p. 589, Tab. 17-14

[15] see Ref. [9], Vol. 2: p. 580, Tab. 17-11

[16] J. Jäger
Climatic Change: Floating New Evidence in the CO_2-Debate
Environment, 28, 7, pp. 6 - 9, 38 - 41, Sept. 1986

[17] B. Bolin, B.R. Döös, J. Jäger, R.A. Warrick (Edrs)
The Greenhouse Effect, Climatic Change and Ecosystems
Chichester and New York: John Wiley & Sons, 1985

[18] C. Marchetti
When will hydrogen come?
IIASA Report WP 82-123
Laxenburg: International Institute for Applied Systems Analysis, 1982

[19] L.G. Fishborne et al.
User's Guide MARKAL (BNL-KFA Version 2.0)
A Multi-Period Linear-Programming Model for Energy Systems Analysis
Jülich: Kernforschungsanlage Jülich, KFA-Report, April 1982

[20] M. Walbeck, H.J. Wagner, D. Martinsen, V. Bundschuh
Energie und Umwelt als Optimierungsaufgabe
Das MARNES-Modell
Berlin, Heidelberg, New York, London, Paris, Tokio: Springer Verlag 1988

[21] W. Häfele, H. Barnert, S. Messner, M. Strubegger
Novel integrated energy systems: The case of zero emissions
In: W.C. Clark, R.E. Munn (Edrs), Sustainable Development of the Biosphere
Cambridge University Press, 1986

[22] Kernforschungsanlage Jülich GmbH - Rheinische Braunkohlenwerke AG (Edrs)
Nukleare Fernenergie - Zusammenfassender Bericht zum Projekt Nukleare Fernenergie (NFE)
Jülich: Kernforschungsanlage Jülich, Report Jül-Spez 303, März 1985

[23] Energiesysteme im Übergang unter den Bedingungen der Zukunft
Jülich: Kernforschungsanlage Jülich (KFA), in preparation 1988

[24] W. Häfele, D. Martinsen, M. Walbeck
The concept of novel horizontally integrated energy systems
In: 10th World Congress on Automatic Control, IFAC,
München 27.-31.7.1987, Vol. 5, pp. 155 - 161
München: International Federation of Automatic Control, 1988

[25] The Nyneshamn Integrated Energy Project,
Paper given at the 6th International Symposium on "Large Chemical Plants" at Antwerp, October 9 -11, 1985

[26] Electrical Power Research Institut (EPRI)
- EPRI Reports, AP-2487 (1982); AP-3232 (1983); AP-3876 (1985), AP-4832 (Oct. 1986); Palo Alto, California
- EPRI Journal Article, November 1986

[27] L. S. Belyaev, B.M. Kaganovich, A.N. Krutov, S.P. Filippov, Siberian Energy Institute
D. Martinsen, M. Müller, H.J. Wagner, M. Walbeck, Kernforschungsanlage Jülich
Wege zu einer umweltfreundlichen Energieversorgung - zwei methodische Lösungsansätze
In: Brennstoff-Wärme-Kraft (BWK), 39, 3, pp. 80 - 85 (1987)
English version available as
Ways of transition to clean energy use: two methodological approaches
IIASA-Report WP 87-15
Laxenburg: International Institute for Applied Systems Analysis, 1987

[28] There was an informal meeting of the IES group at Tallberg, Sweden, Sept. 1 -5, 1986, organized by Vattenfall, The Swedish State Power Board. No formal proceedings are available.

Fig. 1

Development of Nuclear Capacity in Japan
(Source: Atomwirtschaft Essen, as of 1987)

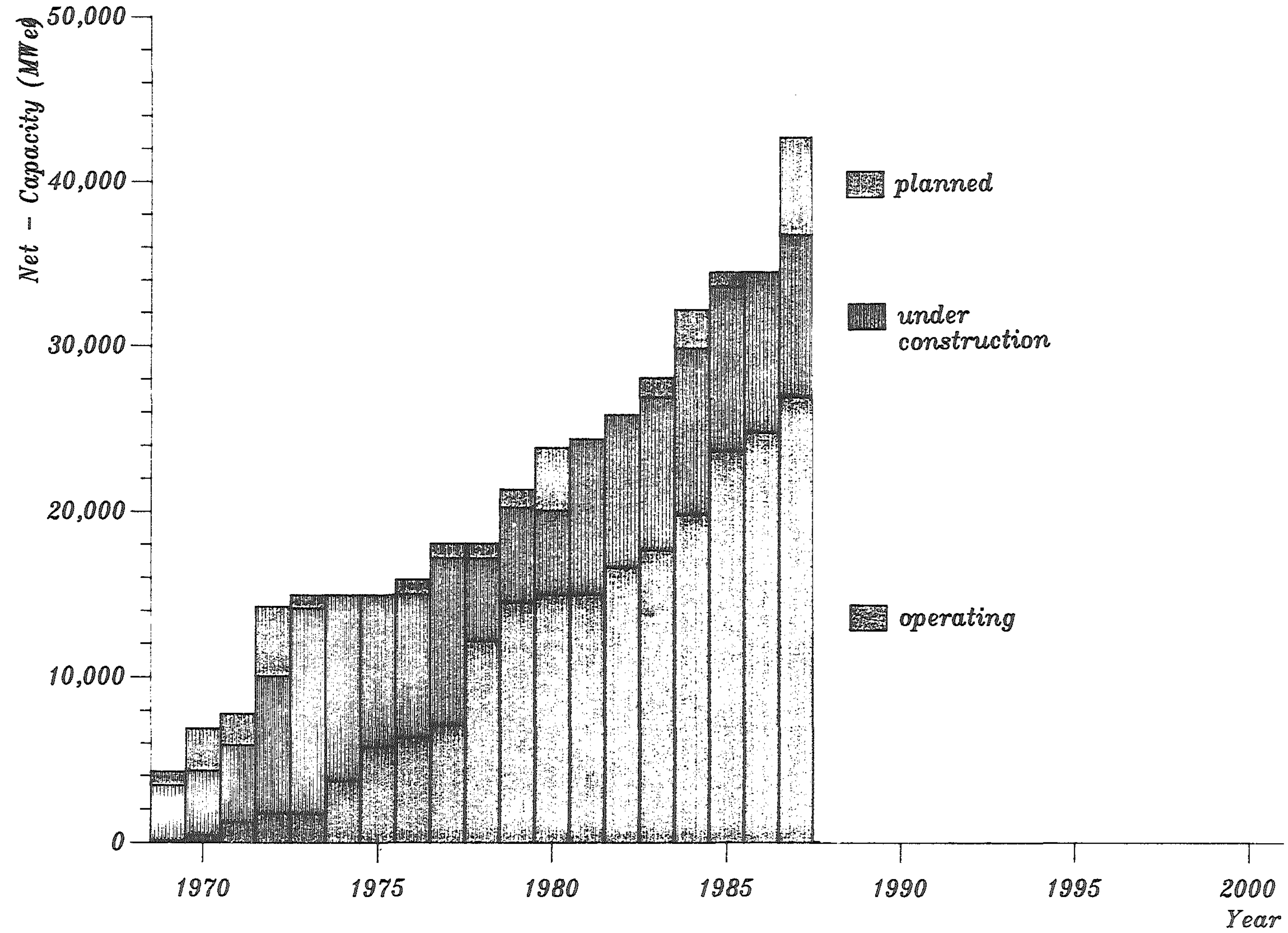


Fig. 2

Development of Nuclear Capacity in France
(Source: Atomwirtschaft Essen, as of 1987)

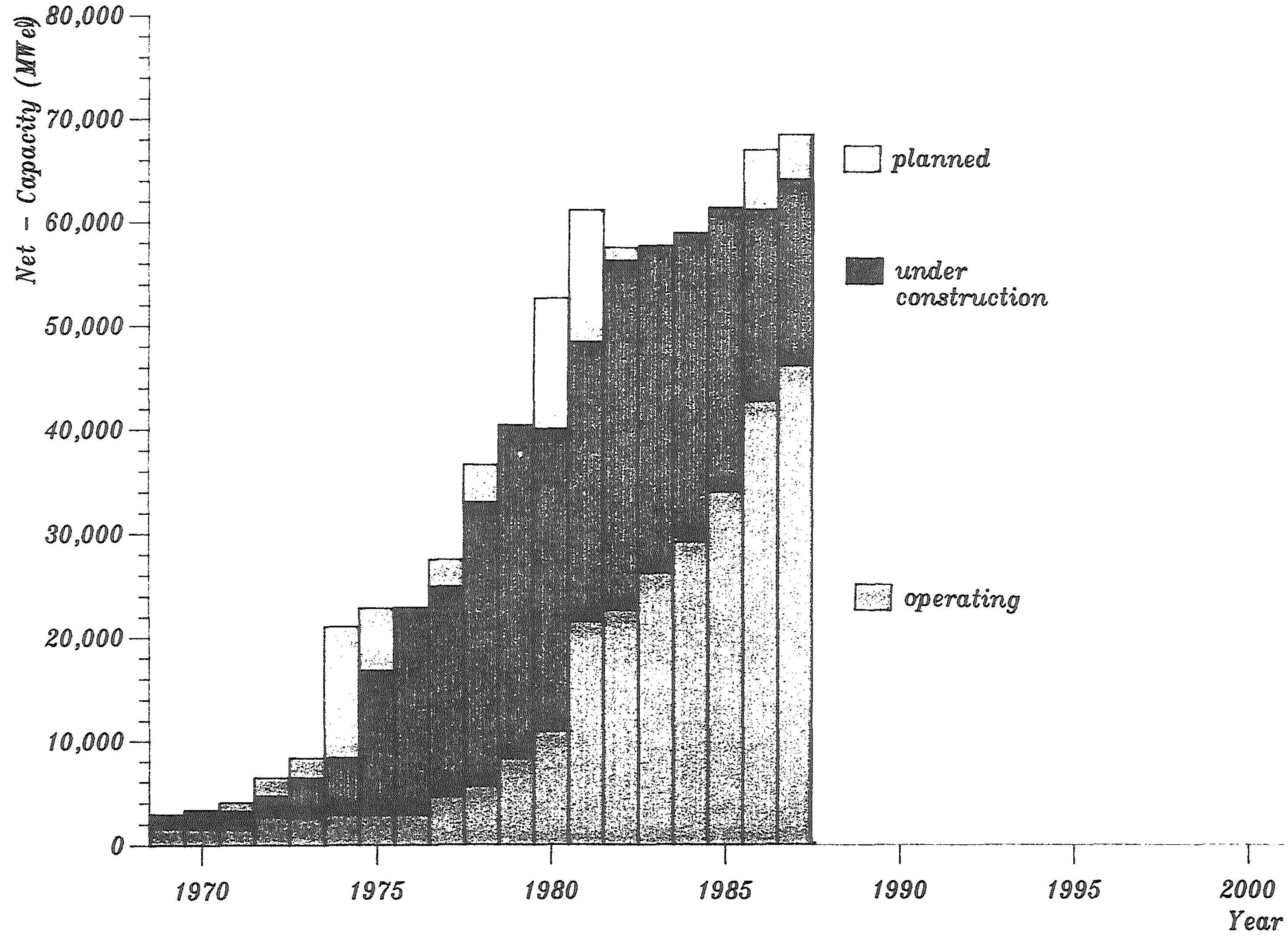


Fig. 3

Development of Nuclear Capacity in the Federal Republic of Germany
(Source: Atomwirtschaft Essen, as of 1987)

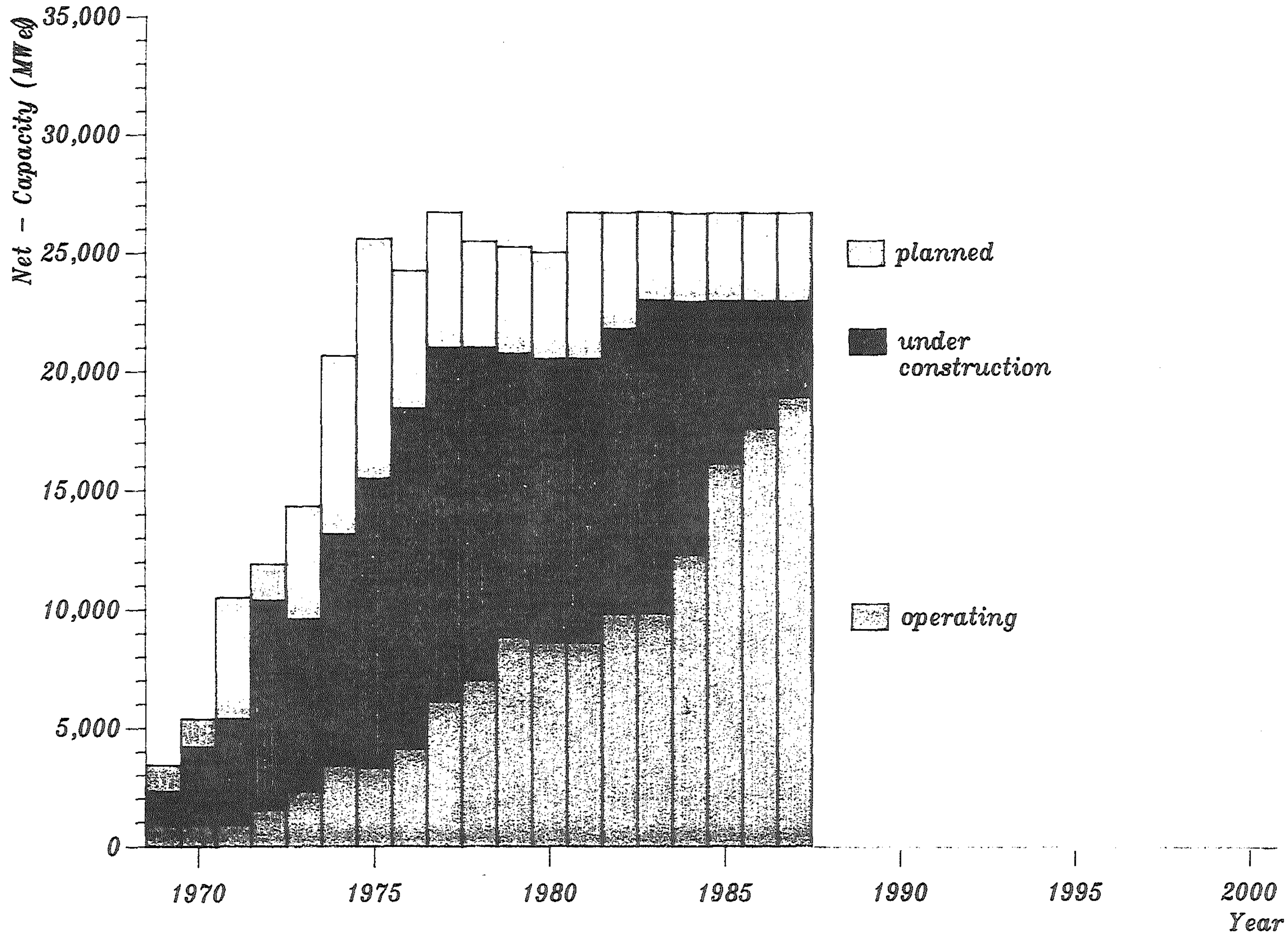


Fig. 4 *Development of Nuclear Capacity in the USSR*
(Source: Atomwirtschaft Essen, as of 1987)

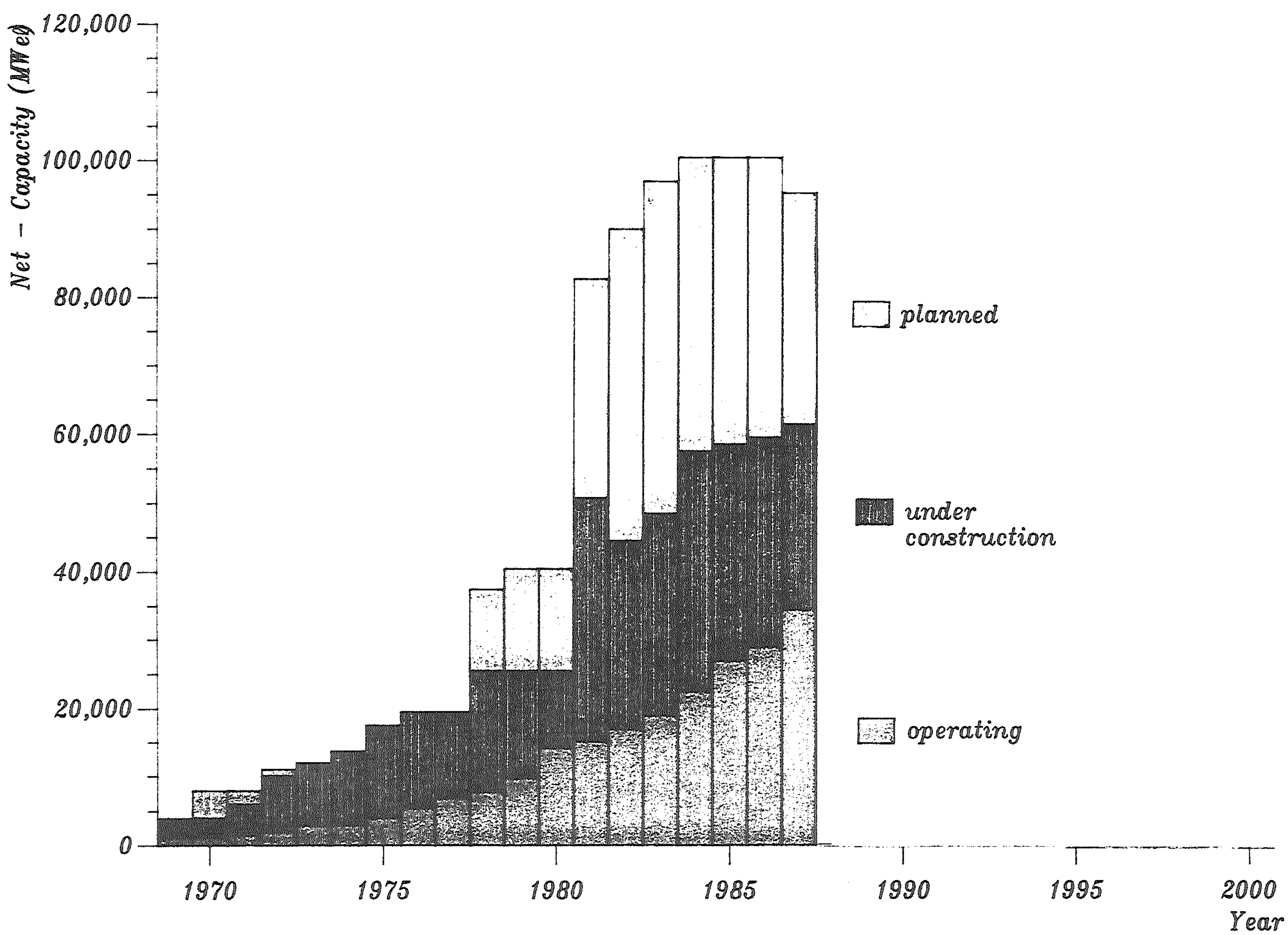
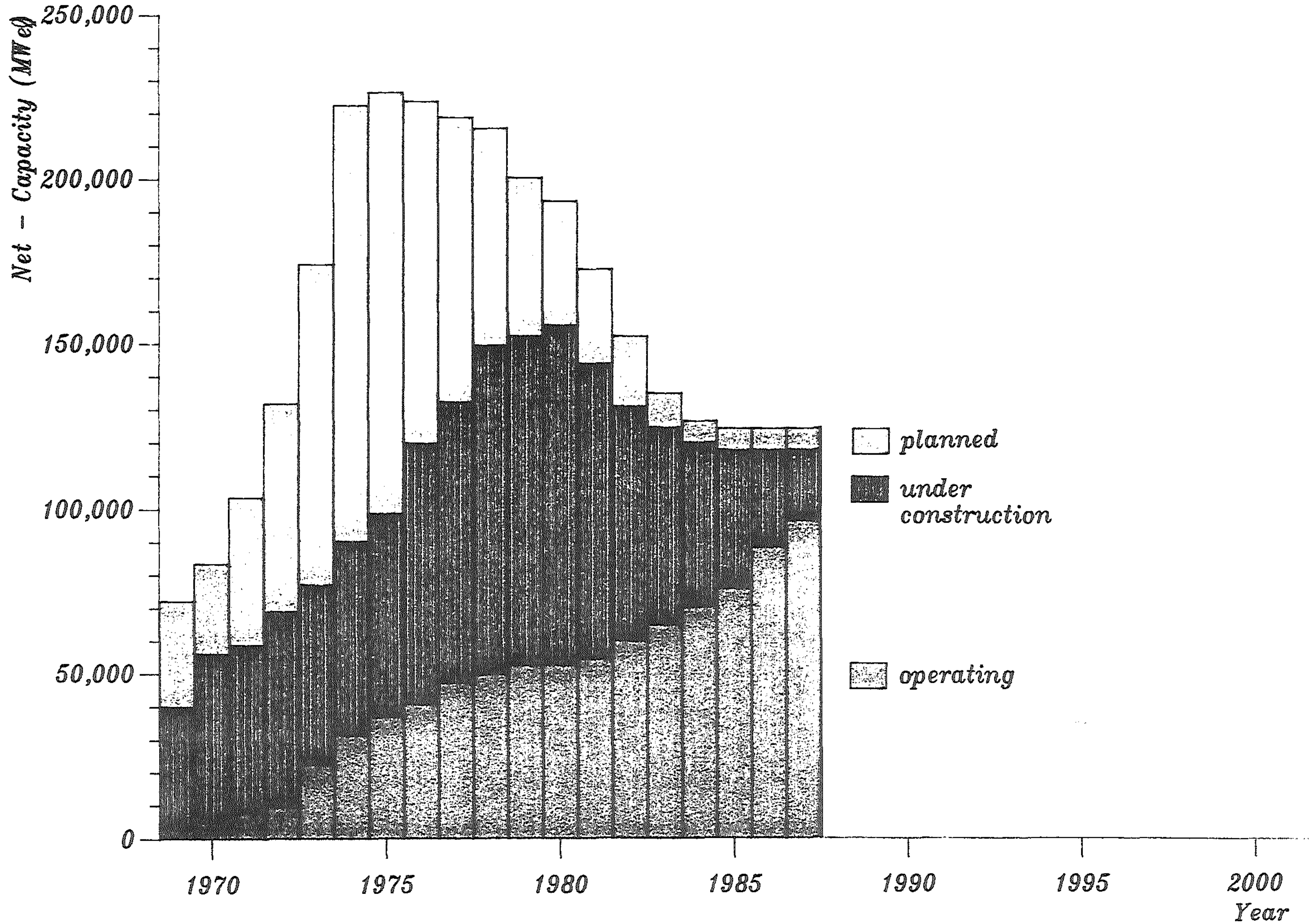


Fig. 5 *Development of Nuclear Capacity in the USA*
(Source: Atomwirtschaft Essen, as of 1987)



World primary energy consumption (commercial energy), a comparison of actual data according to IIASA and BP with the IIASA Low Scenario generated in 1975

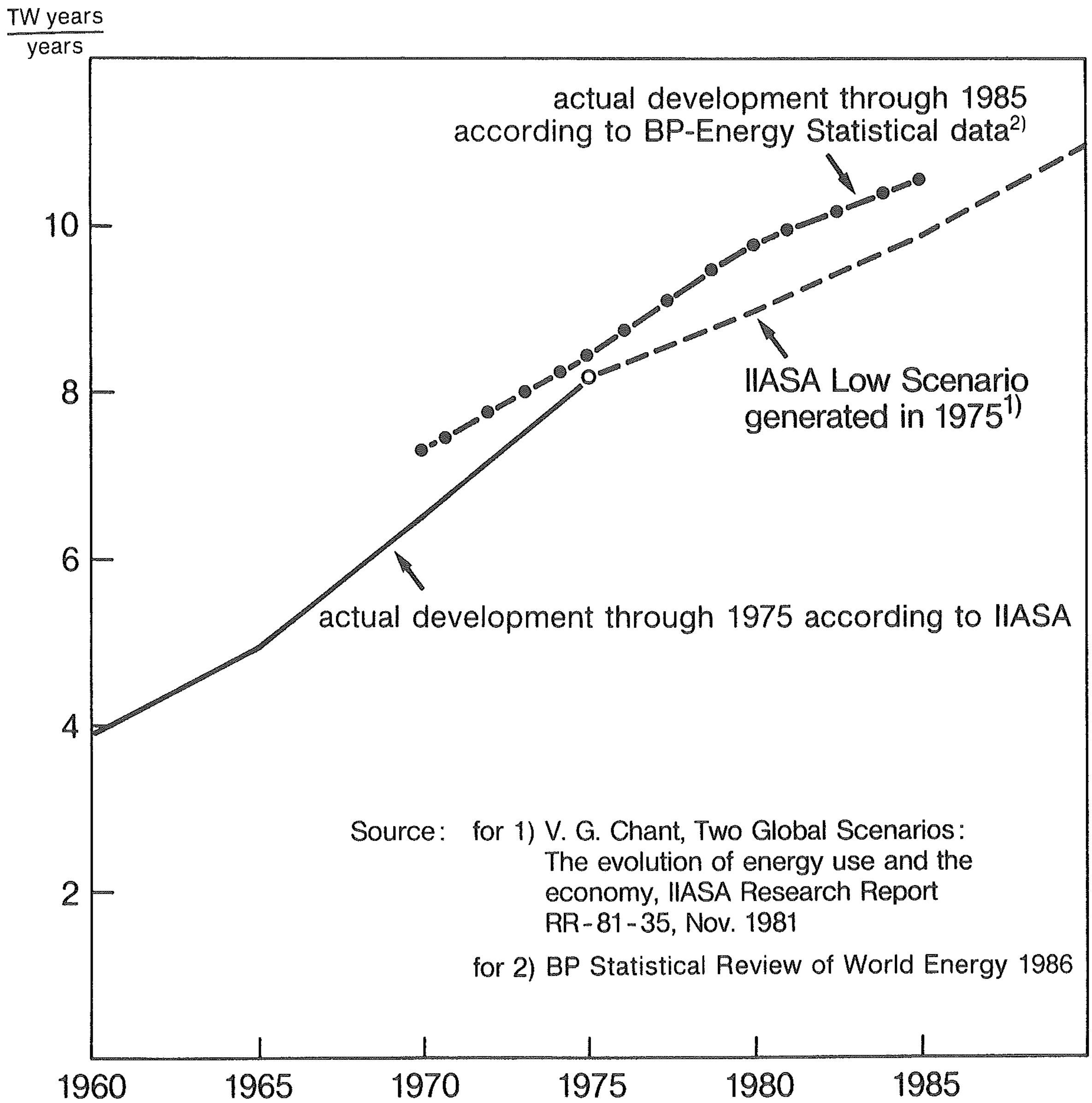
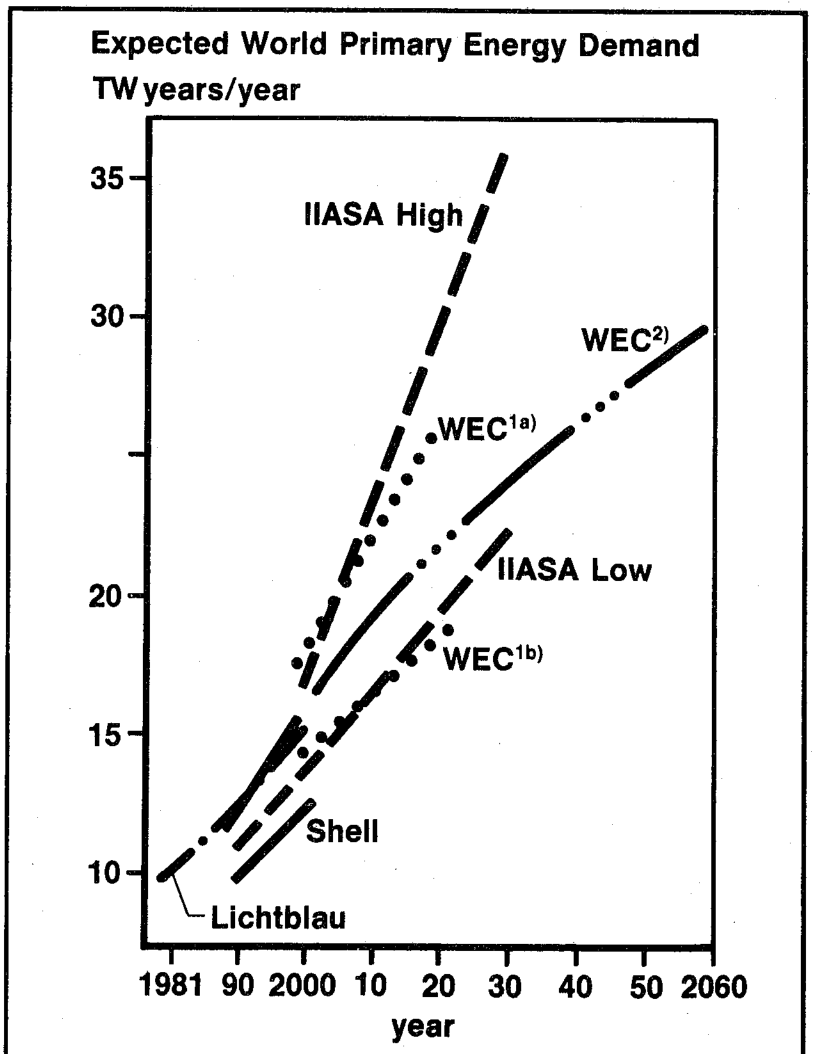


Fig. 6



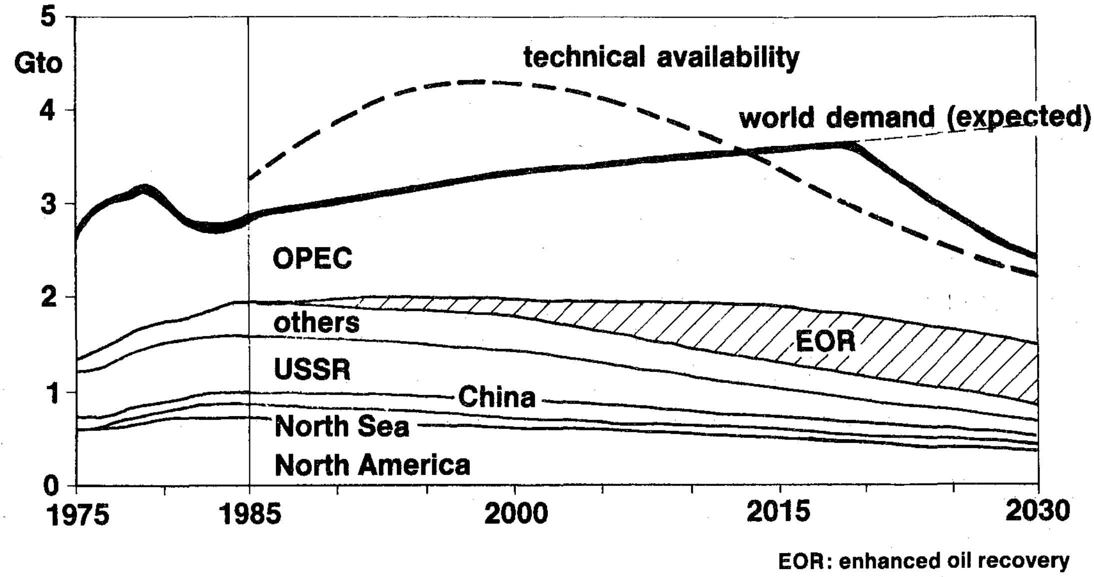
WEC: Conservation Commission of the World Energy Conference

[1)] 12. WEC, New Delhi (1983): a) "Normal Scenario"
b) "Restricted Scenario"

[2)] 13. WEC, Cannes (1986): "Case C"

Fig. 7: Comparison of Energy Scenarios

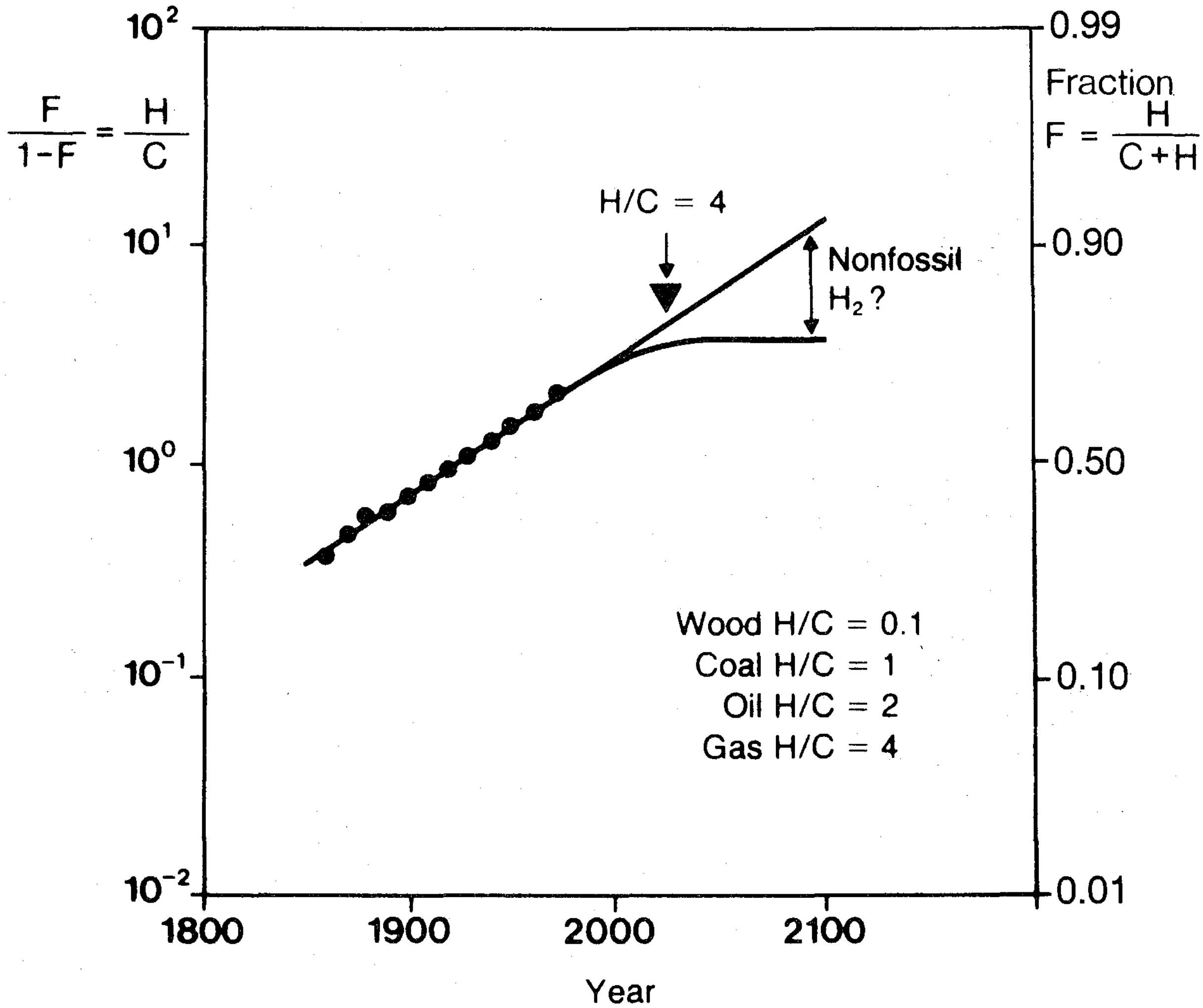
Regional Distribution of Expected World Oil Production



Source: H.C. Runge, W. Mönig, KFA

Fig. 8

Hydrogen to Carbon Ratio (H/C) of Fossil Fuels in the World, 1860 to 2100



Source: C. Marchetti, IIASA

Fig. 9

Novel Horizontally Integrated Energy Systems (NHIES)

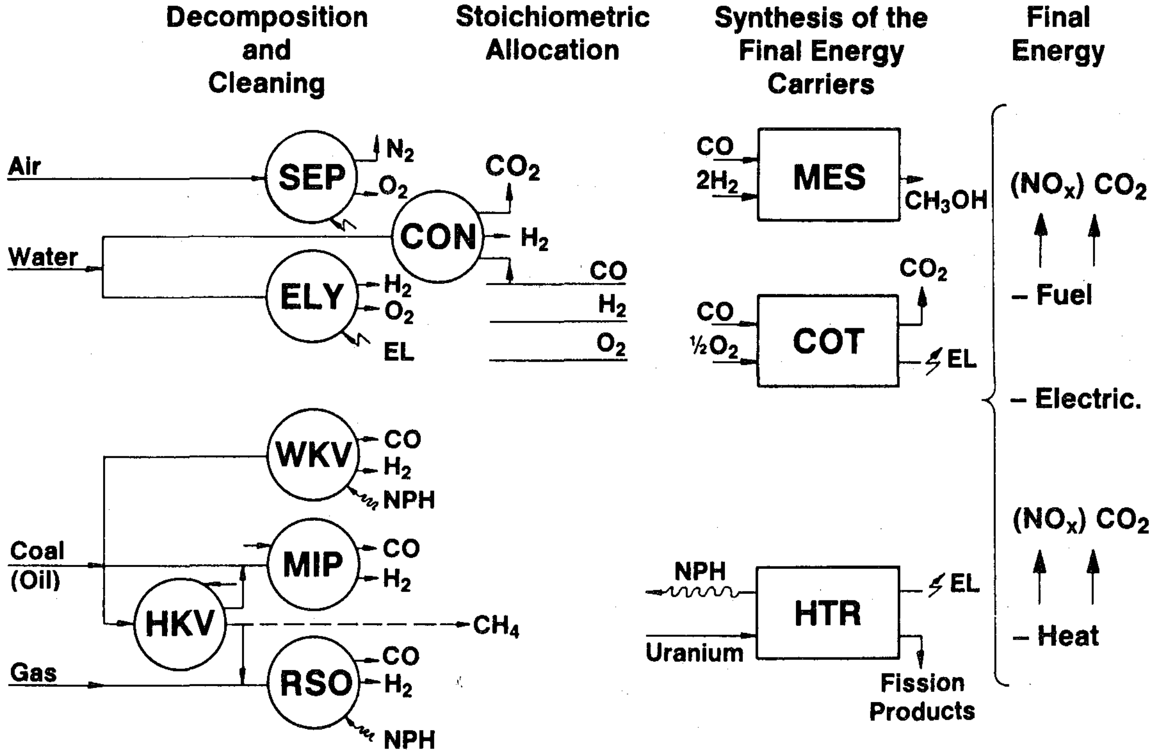


Fig. 10

SEP: air separation
CON: CO-conversion
ELY: electrolysis

WKV: steam gasification
HIP: molten iron bath
HKK: hydrogasification

RSO: methane reformer
HTR: high temp. reactor
MES: methanol synthesis
COT: CO-O_2-turbine

Table 1: Nuclear Installed Capacity and Nuclear Electricity Generation

Country	1985		2000*	
	GWel	TWh	GWel	TWh
Canada	9.776	57.1	15.9	109.1
France	37.533	213.1	77.0	392.0
Germany (FRG)	16.413	119.8	24.3	154.2
Japan	23.665	152.0	62.6	370.0
South Korea	2.720	13.9		
Sweden	9.455	55.9	9.1	63.4
UK	10.120	53.8	18.0	121.0
USA	77.804	383.7	115.7	659.0
USSR	27.756	152.0	79 (?)	544 (?)
OECD, Europe + Pacific	117	710	233	1.400
OECD, America	90	440	132	800
Developing WOCA**	12	60	32	200
WOCA total	219	1.210	397	2.300
CPE***	35	200	111	700
World	253	1.400	508	2.900

* Values estimated in 1986 prior to the Chernobyl accident
** WOCA: World Outside Communist Areas
*** CPE: Centrally Planned Economies

Source: Nuclear Energy and its Fuel Cycle, OECD und IAEA, Paris 1987 and Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries, OECD 1986 and Nuclear Power Reactors in the World, Ref. Series No 2, IAEA, April 1986 Energy, Electricity and Nuclear Power Estimates for the Period up to 2000, refr. Series No 1, Aug. 1987, IAEA

Table 2: Logistic Saturation values S, IAEA estimates for 1992 and actual figures of 1985 of nuclear capacity for a few selected countries, all in GWel

	S	Correl. coefficient	IAEA 1992*	IAEA 1985 (actual)
Canada	12.346	0.895	14.565	9.776
Germany (FRG)	20.146	0.863	22.998	16.413
Japan	28.256	0.981	30.934	23.665
UK**	9.944	0.618	11.420	10.120
USA	101.821	0.685	104.592	77.804
USSR	46.884	0.433	58.672	27.756
	219.397		243.181	165.534

Note: the ratio S over the actual value for 1985 is 1.325

* estimate made in 1985

** In case of the UK the value S and that for 1985 are very close and statistics leads thus to a formal contradiction in the sequence of the data

Table 3: Uranium Resources (10^6 Tonnes U)

	RAR[1]	EAR I[2]	SR[3]	ETPR[4]
WOCA[5]	2.315	1.332	6.600 - 12.100	
outside WOCA				3.300 - 8.400
	3.647		9.900 - 20.500	

(1) Reasonably Assured Resources, up to 130 $/kg
(2) Estimated Additional Resources, Category I (see OECD/IAEA Source)
(3) Speculative Resources
(4) Estimated total potential resources
(5) WOCA: World Outside Communist countries

Source: URANIUM, Resources, Production and Demand, OECD/IAEA, 1986

Table 4: Civilian Nuclear Reprocessing Plants (WOCA)

A. In Operation

Name	Country	Start of Operation	tonnes per day	Capacity tonnes per year*
Sellafield, B205	UK	1964	5	1000
La Hague, UP 2	France	1966/89	4**	800
WAK	Germany, F. R.	1971	0.2	40
Tokai Mura	Japan	1977	0.7	140
Tarapur	India	1978	0.5	100
				2080

B. Planned or under Construction

		planned start of operation			
Kalpakkam	India	1986	0.5	100	under construction
La Hague, UP-3A	Frankreich	1989	4	800	under construction
Sellafield, Thorp	UK	1992	4	800	under construction
Rokkosho Mura	Japan	1959	4	800	planned
Wackersdorf, WAW	Germany, F. R.	1997	2	400	under construction
				2900	

* assuming 200 d/year of operation
** capacity doubling completed by 89

Table 5: Comparison of the IIASA Low Scenario for seven world regions with the actual development 1970–1985

Consumption of primary energy in GWa/a

Region	1970		1975		1980		1985	
	IIASA	BP	IIASA	BP	IIASA	BP	IIASA	BP
I (NA)	2363	2586	2654	2706	2742	2933	2830	2875
II (SU/EE)	1462	1611	1835	2048	2067	2453	2300	2777
III (WE/JANZ)	1825	1995	2256	2179	2473	2387	2690	2402
IV (LA)	247	269	338	360	449	482	560	540
V (Af/SEA)	266	360	328	442	449	639	570	819
VI (ME/NAf)	59	98	126	134	198	166	270	204
VII (C/CPA)	285	411	461	620	545	735	630	900
World	6507	7332	8210	8453	9030	9799	9850	10521

Region I: North America (NA)
Region II: Soviet Union and Eastern Europe (SU/EE)
Region III: Western Europe, Japan, Australia, New Zealand, South Africa, and Israel
Region IV: Latin America
Region V: Africa (Except Northern Africa and South Africa)
South and Southeast Asia (Af/SEA)
Region VI: Middle East and Northern Africa (ME/NAf)
Region VII: China and Centrally Planned Asian Economies (C/CPA)
Source: For IIASA – V. G. Chant, Two global scenarios: The evolution of energy use and the economy, IIASA – Research Report RR-81-35, 1981
For BP: BP Statistical Review of World Energy, 1986 (Ref [2])

Time Horizons*

Regional impacts of NO_x-und SO_2-emissions	now
Emergence of the CO_2-problem (doubling of the CO_2-content)	50 years
Supply from conventional resources (oil + gas)	50 years
Development of environmentally benign energy systems	100 – 140 years
Supply of non-conventional resources (oil, gas, coal)	250 years
Decay of additional CO_2-emissions in the atmosphere	500 – 1000 years
Decay of nuclear waste down to levels of deposits of natural resources	1000 years
Supply from nuclear resources	15000 years
Supply from solar radiation	billions of years

* rough indications only

Tab. 6

日本原子力産業会議　1988年年次大会

「世界のエネルギー問題と日本の進路」

生田理事長

日本原子力産業会議の1988年年次大会におきまして，「世界のエネルギー問題と日本の進路」というテーマでプレゼンテーションを行なう機会を与えられましたのは，私の光栄とするところであります。

今年（1988年）は，1973年の第１次オイルショックから15年，そして1979年の第２次オイルショックからは９年の歳月が経過しております。他方，今年から今世紀末，または21世紀初頭までの時間の長さを考えますと，実は12年しか残されていないのであります。言い換えれば，これから12年後に我々は新しい世紀に入ることになります。ということは，第１次オイルショックから21世紀の入り口までの道程において，現在の時点はすでにその半ばを過ぎている。オイルショックから現在までの時間よりも，現在から21世紀への時間のほうがもう短くなっているということになります。そして，この間に世界のエネルギー情勢は大きく変化し，また現在も変動を続け

ております。

エネルギー情勢の変動の中心になっている石油情勢を見ますと，1973年から1980年までの7年間と，その後，1981年という年を分水嶺にして，1982年から最近までの7年間という，二つの部分に分けられると考えられます。すなわち1973年から1980年までは石油の需給がほとんど一貫してタイトであり，つまり売り手市場が形成され，そして石油価格が上昇を続けた時期であります。また，1982年から最近までの7年間については，石油情勢は一転してグラットになり，石油価格も変動を繰りかえしながら，トレンドとしては下落，あるいは低い水準での安定という形に変わってきております。そして，「分水嶺」の1981年は，世界的に石油需要が減少し，売手市場が買手市場に変わって行ったのに，石油価格は逆に上昇するという，需給関係と価格との不思議な交錯が起きた年でした。その後の情勢は，ＯＰＥＣの団結力と市場支配力とが次第

に弱くなり，減産の歯止めが効かなくなって，価格は弱含みを続け，ついに1986年の石油価格崩壊（collapse）につながりました。その後，ＯＰＥＣは再団結に成功し，石油価格も回復のあと安定に向いましたが，昨年の夏以降再びＯＰＥＣの減産態勢は破綻し，一昨年（1986年）の年末に設定された，いわゆる18ドル固定価格制もほとんど崩壊をしてしまいました。

これから先の短期の石油価格の見通しを的確に行うのはかなり難しいことでありますけれども，私は少なくとも現時点の価格水準か，あるいはもう少し低い価格水準でしばらく推移すると思いますし，場合によっては一昨年，1986年に見られたような価格の崩壊の現象，つまり原油価格が10ドルを割る底値にまで転落する，そういう状況が再びあらわれることも可能性としては依然として残されていると思われます。

しかし，そのような低い石油価格水準が今

後ともかなり長い間続き，石油の需給も供給過剰の状態が続いて行くということが予測されるわけでは決してありません。恐らく短期的にしばらく石油価格が低迷を続けた後で，中期的な展望としては石油の需給は再びタイトになってくると考えられますし，それに対応して石油価格もまた上昇の方向に変わってくることはほぼ確実と考えられるのであります。

いわば現在の時点は，1973年から1988年に至る15年間の変化，つまり第１ステージは需給のタイト化，石油価格の上昇であり，第２ステージは需給の緩和，石油価格の下落傾向であったわけですが，それがその次のステージ，つまり第３のステージに移行する，いわば“階段の踊り場”のようなポジションに現在はあると考えていいと思います。

このようなわけで，いまこの時点に立ってこれまで我々が努力をしてきたエネルギー政策とは一体何であったのか，エネルギー政策

のベースとしてのエネルギー問題とは一体何であったのか，そしてこれから先の時点，つまり現在から21世紀の初頭にかけての中期的な展望において，エネルギー問題，エネルギー政策はどのように展開していくのか，ということを考えることは非常に重要であり，換言すればこの“階段の踊り場”ともいえる現在の時点は，そのようなエネルギー政策のレビューと新らしい将来展望を行なうのにもっとも適した時点ではないかと考えられるのです。

歴史をさかのぼってみますと，19世紀から20世紀にかけての時代は，エネルギーを大量に消費することによって経済の発展を目指してきた，そしてそれが実現されてきた時代だと思います。そして，その経済発展の原動力になったエネルギーは，当初はまず石炭であり，そしてそれに続いて石油が登場し，エネルギーの主役になったわけであります。

そのようなエネルギー多消費型の経済発展

に対して急激なブレーキをかけたのは，言うまでもなく1973年の第１次オイルショックであります。もちろんこの第１次オイルショックは突如としてあらわれたものではなく，そのしばらく前からいずれはそのような変化があらわれることは予想されていたわけですけれども，現実には1973年に第４次中東戦争を契機にしてアラブの産油国が石油戦略を発動し，そこでオイルショックが発生したわけであります。そして，それから６年後には，イラン革命が引き金になって，第２次オイルショックが発生しました。これは石油の入手，いわゆる石油のアクセスの問題が，地政学的な問題に深くかかわっていることを実証したものといえましょう。

そして，この第１次オイルショックに対応するために，世界の先進工業国，すなわち石油消費国はいろいろの対策を考え，立案し，そして実行してきました。例えば国際エネルギー機関（ＩＥＡ）が設立され，ＩＥＡを中

核として石油消費国の間での国際協力体制が整備されたことなどがそれであります。具体的な政策としては，短期の石油供給の減少あるいは途絶に対応するために，石油の備蓄を増加すること，あるいは石油代替エネルギーの利用をさらに拡大すること，また将来にわたって新しいエネルギーの供給源として新エネルギーの開発についての国際協力をより強化することなどがそれです。

エネルギー供給面の政策のほかに，エネルギーの需要面でも，省エネルギー，いわゆるエネルギーのコンサーベーションが推進されました。その効果はきわめて大きく，過去10年間にＧＮＰ一単位当たりのエネルギー消費量は，ＯＥＣＤ諸国において約30％減少したものと考えられます。特に日本ではそのパフォーマンスが一段と高かったわけであります。

そして，このようなエネルギー政策の積み重ねの効果によって，世界のエネルギー市場，特に石油市場は大きく変化をいたしました。

つまり石油市場はかつての売り手市場から徐々に買い手市場に転換をしてきたのです。

このような石油市場の構造変化は，二つの手段によって達成されたものと考えられます。第1は，これまで述べたような政策の成果であります。そして第2は，マーケット・メカニズム，いわゆるマーケット・フォースが大きな力を発揮した。特にそれがエネルギー政策と結びついた形で大きな効果を発揮したことが挙げられます。いわば第1次オイルショック後8年間，いわゆる第1のステージにおいて実現したエネルギー市場の構造変化，言い換えれば売り手市場から買い手市場への変化は決して自然に起きた変化ではなく，いわば人工的につくり上げられた買い手市場であると考えられるのであります。

例えば非ＯＰＥＣ産油国の石油生産が急激に，かつ大幅に増大したことは，石油需給のバランスを変えるのに大きく寄与しました。そしてこれは，ＯＰＥＣが石油価格を引き上

げたことによって，従来は採算ベースに乗らなかったコストの高い油田が採算に乗るようになり，開発から商業生産に移行することを可能にしたためであります。また，石油代替エネルギーについても，従来安い価格の石油には競争し得なかった代替エネルギー，例えば石炭などが石油価格の上昇によって十分な価格競争力を持つようになったということも挙げられるわけであります。原子力発電も同様で，第１次オイルショック前には価格競争力がなかったものが，第１次ショックによる石油価格の上昇によって，一挙に競争力を獲得したのです。

しかし，もしもそれらがただ石油価格の急上昇によるマーケット・フォースだけに依存していたとするならば，その変動の幅はより大きく，また変動のタイミングもアンバランスで，その結果，世界経済も世界のエネルギー需給もより大きな不安にさらされていたと思います。それがエネルギー政策と結合する

ことによってパフォーマンスはより高く，しかも全体としてより安定した需給を維持することができたと考えられるのであります。

私たちは，このように現在も続いている世界のエネルギー市場，特に石油市場の需給の安定，価格の低水準での安定など，石油消費国にとって恵まれたような条件が前述のように決して自然につくり上げられたわけではなく，人工的につくり上げられた買い手市場であって，その人工的な買い手市場をいま我々はエンジョイしているということを忘れてはならないと考えるのであります。

このように考えていきますと，私はエネルギー問題，あるいはエネルギー政策というものは，まず何をおいてもセキュリティ，あるいは安定供給の問題ではないかと考えるのです。もしもエネルギー問題，エネルギー政策からセキュリティの問題を取り去ってしまうとしますと，それはほかの商品，あるいはほかの産業についての問題や政策とあまり大き

な差がなくなってくるのではないかと思います。

エネルギーが重要であるということは改めて言うまでもないことでありますし，先程も言いましたように産業革命以後の世界経済の発展は，エネルギーの大量消費によって形成されてきたわけであって，その延長線上に，1973年の第１次オイルショック，1979年の第２次オイルショックという二つのオイルショックがあらわれ，そこで従来の路線の継続が危ぶまれた。つまり世界経済の継続的安定的な発展・成長に不安の影が差してきたという点が，エネルギー問題，あるいはそれに対するエネルギー政策のスターティング・ポイントではないかと思うのであります。

それに対して，エネルギー資源の枯渇の問題があります。第１次，第２次オイルショック及びその直後の時期，つまり第１ステージの時期においては，このエネルギーの入手（アクセス）の問題と，エネルギー資源の枯

渇の問題とが，時には混同されて取り上げられ，考えられたこともありました。特に第1次オイルショックの前，世界経済が石油の大量消費をベースとして経済成長を続けていた時期に，もしもそのような成長がかなり長い期間続く場合には，エネルギー資源の枯渇の問題に将来は直面するかもしれないという警告が出されたのでありますが，これはその予測の真実性を別にしても，その直後に起きたオイルショックと混同されて，時には問題点の発見が混乱するということにもなったと思います。

私は，エネルギー問題を中長期のタイムスパンで考える限りは，エネルギー資源の枯渇の問題は当面，考慮する必要はないと思います。しかし，後で申し上げるように，超長期の問題として考える場合には，やはり資源の枯渇の問題を忘れるわけにはいかないのであります。

そして，重要な点は，この二つの側面，つ

まりエネルギーのアクセスの問題とエネルギー資源の枯渇の問題の双方について，エネルギーの価格と需要の関係また価格と供給の関係，この二つの問題が大きな意味を持ちながら関与しているということであります。

まず第1に，中期及び長期の問題について考えてみたいと思います。これは現在から紀元2000年まで，あるいは21世紀に入っての最初の30年ないし40年の間のエネルギー問題であります。これについては，石油の需給がどうなるかということをまず考える必要があります。先程も言ったように，現在の状況及び短期の見通しとしては，石油の需給はグラットぎみであり，価格は低い水準で停滞するか，場合によってはさらに一段と下がる恐れがあると考えられます。しかし，世界経済が順調な成長を続けていく限りにおいては，エネルギー全体の消費及び石油の消費は徐々に増加をしていくことは避けられません。

特に1973年以降，各国が積極的に進めてき

た省エネルギー政策によって，経済構造，産業構造がエネルギー多消費型の構造から省エネルギー型の構造に変化してきたこと，また技術の開発と進歩によってエネルギーの原単位が低下してきたこと，つまりＧＮＰ一単位当たりに使われるエネルギーの消費量が少なくなってきたことなど，かなりドラスティックな変化が続いてきたのであります。そして，このドラスティックな変化の結果が，計量的にはＧＮＰとエネルギー消費との間の弾性値がかなり低い水準にとどまるという結果をもたらしました。

しかし，今後はこれまでのような低い弾性値がそのまま続く，あるいはさらに弾性値が低下すると予測するのはかなり困難だろうと思います。つまり，これまでのような大きな構造変化や技術の進歩が今後とも継続するということでなければ，現在のような低い弾性値は続かないことになるのであります。現実には今後もそのような構造変化，技術進歩は

継続するとは考えられますが，そのスピードが徐々に鈍化してくることは避けられないと思われます。その結果として，弾性値は少しずつ上昇してくると思います。ということは，世界経済が順調に発展すれば，エネルギー消費量も経済成長率に近い率で増加の傾向に向かうと考えなければいけません。

このようなエネルギー全体の動向は，石油についても同様であります。そして石油から石油代替エネルギーへの転換がかなり進んでしまった，まだ飽和状態とは言い切れないにしても，転換が相当進んでしまったことを考えると，これから先の石油から代替エネルギーへの転換は従来よりもスピードダウンすると考えざるを得ないのであります。とくに，ＬＤＣやＮＩＣＳの経済成長がＯＥＣＤ諸国よりも高い率で持続すると，それらの国はエネルギー消費の対ＧＮＰ原単位が高く，また代替エネルギーの供給に制約があるので，石油消費の増加は顕著になるものと思われます。

そうだとすると，そのようなエネルギー需要，その中でも石油の需要の増加に対応する供給は果たしてどうなるのか，というのが大きな問題になってくるわけであります。私はそれについては二つのシナリオがあると思います。

第1は，石油価格が低い水準で停滞して，その後，乱高下に移るケースであります。そしてもう一つのケースは，石油価格が比較的早い時期にバランスのとれた水準（例えば20ドル／バーレル）に回復して，それが続く，あるいは石油価格がさらに上昇を続けても，その上昇が比較的モデレートな水準にとどまるというケースであります。この二つのケースのどちらがいいかということになれば，言うまでもなく第2のケースのほうが世界全体にとって望ましいといえましょう。

しかし，現実にどちらのケースが実現する可能性が高いかということになりますと，残念ながら私は第1のケースのほうが実現の可

能性が高いのではないかと思います。現在の程度の石油の価格水準，つまり１バーレル当たり13ドルから15ドルぐらいの石油価格水準が今後とも継続するとすれば，まず非ＯＰＥＣの石油生産についての影響は，現在操業中の油田の生産を維持することは可能であって，新規の開発投資はかなりスローダウンすることになってきます。これはＯＰＥＣの中でもペルシャ湾岸以外の比較的コストの高い産油国については同じような状況になることが考えられます。

また，石油と石油代替エネルギーの関係については，個々のエネルギーについての条件をどう考えるかによっていろいろ違ってきますが，例えば発電用の燃料としての経済性を取り上げた場合，石油と非石油燃料，例えば石炭，天然ガス，原子力などとを比較してみた場合，これまでに比べて非石油燃料のコスト優位性がさらに小さくなるという結果をもたらすことになります。

ということは，例えば石油火力発電と原子力発電を比較した場合，石油価格が13～15ドル程度にとどまっていれば，原子力発電のほうが経済的にやや有利であるという状況はそのまま続くと思いますが，原子力発電所の建設コストがさらに上昇するとか，あるいは何らかの原因によって原子力発電所の稼働率が低下するというような場合には，原子力発電と石油火力発電との経済性の相対的なポジションが逆転する可能性さえもあるわけであります。これは石炭火力についても同じであります。

天然ガスの場合は，ヨーロッパ，アメリカと日本とはかなり状況が違います。日本の場合は天然ガスはすべてＬＮＧという形で輸入され，消費され，そしてＬＮＧの輸入契約は，石油価格を基準にして価格が設定されていますので，石油価格が下がるとＬＮＧの競争力も同じように増加してくることになってくると思います。

つまり，石油そのものについても，また石油代替エネルギーについても，石油の中ではＯＰＥＣの石油と非ＯＰＥＣの石油の関係，それからエネルギー全体としては，石油と石油代替エネルギーの関係を考えてみた場合に，石油価格が低水準で停滞を続けるということは，これまでのエネルギー政策の推進の大きな協力者であったマーケット・フォースをかなり弱めることになります。したがって，これまでと同じようなエネルギー政策をそのまま今後も継続し，進めることは，少なくとも従来よりはかなり難しくなってくるということが考えられます。

このように考えますと，石油価格の低水準ということは，石油消費国にとっては当面望ましいことではありますけれども，将来について不安の種をつくり上げることにもなってくると考えられます。

ということは，今後の世界的なエネルギー需要の増加に対応して，石油から石油代替エ

ネルギーの転換もこれまでほどはアクティブには進められないと考えられますし，また非ＯＰＥＣの石油生産は，次第に飽和点に達し，その後，徐々に減少に転じていくと考えられますので，つまり世界の増加するエネルギー需要に対応するための供給は，終局的にはＯＰＥＣ，その中でもペルシャ湾岸の産油国の石油生産への依存度が大きくなってくる，あるいはほとんどそれに依存しなければいけないことになるかもしれない，ということを意味するわけであります。

そして，そのような状態が続き，ＯＰＥＣ石油への需要が現在よりも相当増加してくる。例えば2,300～2,500万バーレル／日のラインに接近し，それを超えるようなことになりますと，たぶんＯＰＥＣは再び価格の引き上げ，しかも継続的な引き上げに着手し，成功するだろうと考えられるのであります。

一方，石油価格が現在のような低い水準での低迷から脱して，徐々に，しかも早い機会

に上昇に向かう。それも極端な上昇ではなくて，１バーレル20ドル程度まで比較的早い時期に回復をしますと，この場合には非ＯＰＥＣ産油国での新規の油田開発のための投資を継続することは可能であります。したがって，非ＯＰＥＣ産油国の石油生産は，より長い期間，現在のような高い水準を維持することが可能になってくると思います。

また，石油と石油代替エネルギーとの関係についても，石油価格の上昇によって原子力，石炭などの石油代替エネルギーの価格競争力は再び強くなってきますので，石油から石油代替エネルギーへの転換は再び復活してくる可能性があります。それがもしも全体としてモデレートな，そしてリーズナブルな形で進められるのであれば，世界のエネルギーの需給バランス，あるいは価格の動向は比較的穏やかな形で推移する。そして石油のアクセスに対応するための政策，つまり石油依存度の低下も穏やかな形で進行するということにな

ります。しかし，このようなソフト・ランディングは理想的な形であっても，現実的にはかなり難しいのではないかと私は考えます。

一方，エネルギー資源の枯渇の問題も重要であります。先程も言ったように，当面，エネルギー資源の枯渇の問題を政策の対象として強く意識する必要はないと考えられます。しかし超長期の展望をしてみた場合，石油，石炭，天然ガスのような化石燃料は，いずれにしてもいつの日かは枯渇するいわゆる枯渇性のエネルギーであるという点がまず一つ挙げられます。また，需要面としては，ＬＤＣ（発展途上国），特に巨大な人口を持つ発展途上国の経済成長がエネルギー資源の枯渇の問題に大きな影響を与えると考えられます。例えば中国，あるいはインドのような国の動向がそれであります。

それらの国だけではなく，発展途上国全体として，現在でも，いわゆるノンコマーシャル・エナジー（非商業エネルギー）が相当大

量に使用されております。そして，この問題が，例えば熱帯林の枯渇のような自然環境の破壊をつくり出していることも事実であります。したがって，そういう自然環境問題への対応だけでなく，それらの巨大な発展途上国が早く経済的にテイクオフし，経済発展の路線に乗った場合の世界のエネルギー問題を慎重に考える必要があります。それらの国々の経済成長はその国の国民だけではなく，世界全体としても望ましいことでありますが，巨大な人口を抱えたそれらの国で消費されるエネルギーが，非商業エネルギーから化石燃料などの商業エネルギーに転換され，しかも人口１人当たりのエネルギー消費量が次第に増加をしていって，現在の先進工業国の水準に近づいていくということになれば，世界全体としてのエネルギー消費の増加は格段に大きくなるわけであります。

そして，このような傾向が続き，しかも世界的に化石燃料の資源の枯渇の問題に対する

適切な対応がとられない場合は，私は，人類はあまり遠くない未来においてエネルギー資源の枯渇の問題に当面せざるを得ないと考えます。繰りかえしになりますが，エネルギー問題は，現在においても，それから1973年以後，現在までの近い過去においても，それから中長期の展望においても，まずセキュリティの問題であります。言い換えればエネルギーのアクセスの問題であります。

しかし，このエネルギーのアクセスの問題は，先程も述べたように，決して問題が解決したわけではない。現在は“階段の踊り場”にいるので，あたかもエネルギー問題が解決し，すでにそれを考える必要性がなくなった，と錯覚を起こしがちでありますが，これから再び新しいエネルギー問題が発生してくる，いわゆる第3のステージに移行してくるということが言えると思います。

しかし，第3のステージに移行して，石油を中心にしてエネルギー価格が再び上昇する

ことになっても，私は石油価格の上限は，現在のドル価値を基準にした実質価格で，１バーレル30ドルの水準は上回らないのではないかと思います。つまり30ドルを上回った場合には，再びそれに対するリアクションがいろいろの面であらわれてくる。つまり，第１次オイルショック後の第１ステージでの石油価格の上昇に対してあらわれた政策的なリアクションとマーケット・フォースのリクアションがまたあらわれてくる。それによって一時的には30ドルを突破しても，ある一定の期間をとった場合には30ドルが上限になって，また石油価格は下がってくると思うのであります。

しかし，一方においてエネルギー資源の枯渇の問題を考える。それに対応するために新しいエネルギー資源，例えばソーラーその他のような再生可能なエネルギー資源の開発を進めようと思えば，恐らく石油価格が１バーレル30ドルを上限として変化するということ

では，新エネルギーの開発，あるいは商業的な利用は経済的に難しくなってくると思われるのであります。

したがって，このギャップをいかにして埋めるか。つまり中長期と超長期の展望と間のギャップを埋めるために，効果的な対策が現時点から考えられ，準備されていかなければいけないと思います。これが世界のエネルギー問題の最大の問題点ではなかろうかと考えるのであります。

日本は経済大国と言われております。しかし，国内にほとんどエネルギー資源を持たない経済大国であります。ということは，エネルギーのセキュリティについても非常に弱い，いわゆるバルネラブルな体質を持っているわけでありますし，将来のエネルギー資源の枯渇の問題につきましても，その影響を一番強く受ける。言い換えれば自力でその影響を緩和することが難しいと思います。

ということは，これまで言いましたような

世界全体としてのエネルギー問題の変化，そしてその変化に対応するエネルギー政策のあり方を，日本の場合はより強くエネルギーの確保——これは中長期におけるアクセスの問題，超長期の資源の枯渇問題の両方について，日本の場合は日本以外の先進工業国，ＥＣあるいはアメリカなどよりもさらに強い努力をエネルギー政策につぎ込んでいかなければ，世界の発展に対して日本があるいは脱落するという危険も多分にあると考えられます。

その意味において，私はエネルギー政策は決してその重要性を失ったのではない。これからは従来にも増してエネルギー政策は重要であり，そのバックグラウンドとしてエネルギー問題に対する認識はさらに強められていかなければいけないと考える次第であります。

（おわり）

セッション1
エネルギー複合時代と原子力政策

THE NUCLEAR DEVELOPMENT AND SAFETY POLICIES OF THE FEDERAL REPUBLIC OF GERMANY

FEDERAL MINISTER FOR THE ENVIRONMENT
KLAUS TÖPFER, BONN

JAIF MEETING, TOKYO
APRIL 13, 1988

LET ME BEGIN BY SAYING THAT MR. WALLMANN, MY PREDECESSOR AS FEDERAL MINISTER FOR THE ENVIRONMENT IN BONN, HAD BEEN INVITED TO THE 1987 JAIF MEETING, BUT THAT HE WAS UNFORTUNATELY NOT ABLE TO ATTEND FOR SCHEDULING REASONS RELATED TO AN ELECTION AND THE FORMATION OF A NEW GOVERNMENT IN THE STATE OF HESSE LAST YEAR.

WE HAD BEEN WANTING TO COME TO JAPAN TO DISCUSS ENVIRONMENTAL POLICY MATTERS FOR SOME TIME, SO THIS YEAR'S JAIF MEETING PROVIDED US WITH A GOOD OCCASION TO DO SO.

AT THE SAME TIME, WE WANTED TO TAKE THIS OPPORTUNITY TO CONCLUDE A BILATERAL AGREEMENT -- FULFILLING AN INTENTION WE HAD HAD FOR SEVERAL YEARS OF ESTABLISHING A FORMAL EXCHANGE OF INFORMATION IN THE FIELD OF NUCLEAR SAFETY.

1. HISTORICAL OUTLINE

1.1 PRELIMINARY REMARK

FIFTY YEARS AGO -- SHORTLY BEFORE THE SECOND WORLD WAR BROKE OUT -- NUCLEAR FISSION WAS DISCOVERED AND THE PREDICTION MADE THAT UNDER CERTAIN CONDITIONS A CONTROLLED CHAIN REACTION MIGHT BE POSSIBLE AS WELL AS THAT THERE MIGHT BE TECHNICAL USES FOR THE ENERGY RELEASED.

IT WASN'T UNTIL 1945 THAT PUBLIC BECOME AWARE OF NUCLEAR ENERGY -- IN CONNECTION WITH THE DEVASTATING EFFECTS OF AN UNCONTROLLED CHAIN REACTION -- IN OTHER WORDS THE ATOMIC BOMB. AS NUCLEAR TESTS WERE CONDUCTED IN THE ATMOSPHERE, THE PUBLIC ALSO BECAME AWARE THAT THE WORLD WAS BEING CONTAMINATED BY NUCLEAR FALLOUT. THE FACT THAT NUCLEAR ENERGY IS STRONGLY ASSOCIATED WITH THE MUSHROOM-SHAPED CLOUD OF THE ATOMIC BOMB HAS, FROM THE OUTSET, BEEN AN OBSTACLE TO PUBLIC ACCEPTANCE OF THE PEACEFUL USE OF NUCLEAR ENERGY.

1.2 BEGINNINGS IN THE FEDERAL REPUBLIC OF GERMANY

AFTER THE WAR, THE ALLIES STRICTLY PROHIBITED ANY ACTIVITY RELATED TO NUCLEAR ENERGY IN GERMANY. THIS BAN PLACED GERMANY UNDER OBLIGATION NOT TO PRODUCE, PURCHASE, POSSESS OR USE NUCLEAR MATERIALS IN ANY WAY, SHAPE OR FORM. IT CONTINUED TO BE EFFECTIVE AFTER THE FOUNDING OF THE FEDERAL REPUBLIC -- AND REMAINED SO UP UNTIL THE SIGNING OF THE SOVEREIGNTY TREATY OF 1955. RESEARCH AND DEVELOPMENT WORK AIMED AT THE PEACEFUL USE OF NUCLEAR ENERGY BEGAN THAT SAME YEAR -- IN CONNECTION WITH THE "ATOMS FOR PEACE" POLICY PROCLAIMED BY PRESIDENT EISENHOWER.

A COMBINED EFFORT ON THE PART OF THE GOVERNMENT, THE SCIENTIFIC COMMUNITY AND INDUSTRY WERE REQUIRED TO MAKE UP FOR THE FACT THAT GERMANY HAD FALLEN TEN YEARS BEHIND THE REST OF THE WORLD IN THE NUCLEAR FIELD. IN 1955 A FEDERAL MINISTRY WAS CREATED FOR THE PLANNING, COORDINATION AND FINANCING OF ATOMIC ENERGY PROGRAMS APPROVED BY PARLIAMENT. VERY SOON AFTER THAT THE DECISION WAS MADE TO PURSUE A POLICY OF USING CLOSED NUCLEAR FUEL CYCLES, INVOLVING FUEL

REPROCESSING, PLUTONIUM RECYCLING AND FINAL STORAGE OF NUCLEAR WASTE IN REPOSITORIES BUILT IN DEEP UNDERGROUND ROCK SALT FORMATIONS, AS WELL AS OF DEVELOPING ADVANCED REACTOR SYSTEMS. THE MINISTRY WAS ADVISED BY A COMMISSION OF APPOINTED EXPERTS. A SPECIAL COMMITTEE ESTABLISHED BY THIS COMMISSION DEALT WITH MATTERS REGARDING RADIATION PROTECTION. IN 1974 THE PRESENT RADIATION PROTECTION COMMISSION WAS CREATED FROM THIS SPECIAL COMMITTEE. IN 1958 A REACTOR SAFETY COMMISSION WAS SET UP -- INDEPENDENTLY OF THE GERMAN ATOMIC ENERGY COMMISSION -- AND IS STILL IN EXISTENCE TODAY.

THIS DEVELOPMENTAL PHASE INVOLVED:

O THE ESTABLISHMENT OF LARGE-SCALE NUCLEAR RESEARCH CENTERS (IN KARLSRUHE AND IN JÜLICH), EACH WITH SPECIFIC RESEARCH AND DEVELOPMENT FOCUSES.

O PARTICIPATION OF THE FEDERAL REPUBLIC OF GERMANY AS A FOUNDING MEMBER IN THE FOLLOWING INTERNATIONAL ORGANIZATIONS:

- THE EUROPEAN ATOMIC ENERGY COMMUNITY (EURATOM) IN 1956

- THE UNITED NATIONS INTERNATIONAL ATOMIC ENERGY ORGANIZATION (IAEO) IN 1957

- THE NUCLEAR ENERGY AGENCY (NEA) IN 1957 (INITIALLY A EUROPEAN AND THEN LATER A WORLD-WIDE ORGANIZATION IN THE OECD CONTEXT).

O THE CONCLUSION OF BILATERAL COOPERATION AGREEMENTS (E.G. WITH THE UNITED STATES, FRANCE, GREAT BRITAIN, CANADA, ...)

O LICENSING AGREEMENTS BETWEEN GERMAN AND AMERICAN COMPANIES ON THE DEVELOPMENT OF COMMERCIAL NUCLEAR POWER PLANTS USING LIGHT WATER REACTORS (LWRS).

- SIEMENS AND WESTINGHOUSE ON DEVELOPMENT OF PRESSURIZED WATER REACTOR (PWR) TECHNOLOGY.

- AEG AND GENERAL ELECTRIC ON DEVELOPMENT OF BOILING WATER REACTOR (BWR) TECHNOLOGY.

1.3 INDEPENDENT NUCLEAR TECHNOLOGY

AFTER A PERIOD OF ABOUT FIFTEEN YEARS THE NUCLEAR SECTOR IN GERMANY HAD PRETTY MUCH CAUGHT UP WITH DEVELOPMENTS ELSEWHERE IN THE WORLD. BY 1970 THE FEDERAL REPUBLIC OF GERMANY HAD LIGHT WATER REACTORS IN THE 300 MW_E CLASS IN OPERATION, IN THE 650 MW_E CLASS ABOUT TO GO INTO OPERATION AND IN THE 850 MW_E CLASS UNDER CONSTRUCTION. THE 1200 MW_E BIBLIS-A POWER PLANT BEING PLANNED WAS THE LARGEST PROJECT OF ITS KIND ANYWHERE IN THE WORLD AT THE TIME. IN 1968 AND 1969 THE GERMAN NUCLEAR INDUSTRY REGISTERED ITS FIRST EXPORTS -- THE ATUCHA HEAVY WATER REACTOR AND POWER PLANT IN ARGENTINA AND THE BORSSELE PRESSURIZED WATER REACTOR POWER PLANT IN THE NETHERLANDS. SINCE THEN THE FEDERAL REPUBLIC OF GERMANY HAS BEEN AN EXPORTER OF ADVANCED NUCLEAR TECHNOLOGY.

IN THE EARLY 1970S SIEMENS AND AEG CONCENTRATED THEIR LIGHT WATER REACTOR ACTIVITIES IN THEIR JOINT SUBSIDIARY, "KRAFTWERK-UNION" (KWU). THIS DEVELOPMENT RAN PARALLEL TO A GRADUAL WITHDRAWAL FROM LICENSING AGREEMENTS WITH U.S. COMPANIES AND THE DESIGN REQUIREMENTS ASSOCIATED WITH THIS. IN THE COURSE OF

TIME, A SPECIFICALLY GERMAN LWR TECHNOLOGY AND PHILOSOPHY ON SAFETY STANDARDS EMERGED, BASED ON EXPERIENCE ACCUMULATED IN THE BUILDING AND OPERATION OF NUCLEAR POWER PLANTS. THE GERMAN ATTITUDE TOWARDS SAFETY REQUIREMENTS WAS CHARACTERIZED BY CONCEPTS SUCH AS "DOUBLE CONTAINMENT", "4 X 50% OR 3 X 100% DESIGN" AND "BASIC SAFETY". THIS LINE OF DEVELOPMENT WAS PRETTY MUCH COMPLETED WITH A 1300 MW_E STANDARD POWER PLANT TYPE.

IT IS INTERESTING TO OBSERVE THAT THE SITUATION IN JAPAN EVOLVED PRETTY MUCH ALONG THE SAME LINES TIME- AND TECHNOLOGY-WISE. IN ADDITION TO THE TRADITIONALLY GOOD RELATIONS BETWEEN GERMANY AND JAPAN, THIS IS DOUBTLESS A MAJOR FACTOR IN THE INTEREST THAT HAS BEEN SHOWN ON BOTH SIDES FOR CLOSE COOPERATION IN THE NUCLEAR TECHNOLOGY SECTOR. [IN THIS CONNECTION I WELCOME THE FACT THAT YESTERDAY AN AGREEMENT ON COMPREHENSIVE INFORMATION EXCHANGE WAS CONCLUDED BETWEEN THE RESPONSIBLE AUTHORITIES IN JAPAN AND THE FEDERAL REPUBLIC OF GERMANY IN THE FIELD OF NUCLEAR SAFETY ENGINEERING AND RADIATION PROTECTION.]

1.4 SEPARATION OF FUNDING AND CONTROL FACTORS

WITH THE COMMERCIALIZATION OF NUCLEAR TECHNOLOGY A NEED EMERGED FOR GOVERNMENT CONTROLS INDEPENDENT OF FUNDING FACTORS. THIS MEANT THAT THERE WAS A NEED TO RESTRUCTURE THE RESPONSIBILITIES FOR FUNDING, ON THE ONE HAND, AND FOR NUCLEAR SAFETY AND RADIATION PROTECTION, ON THE OTHER, WHICH, UP TO THAT POINT IN TIME, HAD BOTH BEEN IN THE HANDS OF ONE MINISTRY. SINCE THE EARLY 1970S THE RESPONSIBILITIES IN THIS AREA HAVE BEEN DIVIDED UP AS FOLLOWS:

- FUNDING OF DEVELOPMENT IN THE FIELD OF NUCLEAR TECHNOLOGY BY THE FEDERAL MINISTRY FOR RESEARCH AND TECHNOLOGY

- ASSESSMENT OF ENERGY-SECTOR IMPORTANCE AND USE OF NUCLEAR ENERGY BY THE FEDERAL MINISTRY OF ECONOMICS

- DEFINITION OF AND CONTROLS ON STANDARDS OF NUCLEAR SAFETY AND RADIATION PROTECTION IN CONNECTION WITH THE CONSTRUCTION AND OPERATION OF NUCLEAR FACILITIES BY THE FEDERAL MINISTRY OF THE INTERIOR. AFTER CHERNOBYL THIS RESPONSIBILITY WAS TRANSFERRED TO THE NEWLY ESTABLISHED FEDERAL MINISTRY FOR THE ENVIRONMENT, NATURE CONSERVATION AND NUCLEAR SAFETY WITH REPRESENTATION IN MATTERS HAVING TO DO WITH THE ESTABLISHMENT OF EMERGENCY REGULATIONS BEING PLACED IN THE HANDS OF THE FOREIGN OFFICE. RESPONSIBILITY FOR CONTROLS ON THE MOVEMENT OF FISSIONABLE MATERIALS REMAINED WITH THE FEDERAL MINISTRY FOR RESEARCH AND TECHNOLOGY.

NUCLEAR SAFETY AND RADIATION PROTECTION ARE TODAY AN INTEGRAL PART OF ENVIRONMENTAL PROTECTION. AS SUCH, THE POLLUTER-PAYS PRINCIPLES APPLIES TO NUCLEAR TECHNOLOGY AS MUCH AS TO DOES TO OTHER AREAS. THIS IS THE CASE IN PARTICULAR WITH REGARD TO THE PROBLEM OF DISPOSING OF NUCLEAR WASTES. IN AGREEMENT WITH THE STATE GOVERNMENTS, THE FEDERAL GOVERNMENT DEMANDED PROOF BE PROVIDED OF HAVING MADE PROVISION FOR SAFE DISPOSAL OF NUCLEAR WASTE OVER A PERIOD OF SIX YEARS AS A PREREQUISITE FOR THE OPERATION NUCLEAR POWER PLANTS AND THAT THIS PROOF BE RENEWABLE ON A REGULAR

BASIS. THE FEDERAL GOVERNMENT ASSUMED RESPONSIBILITY FOR THE LONG-TERM STORAGE AND FINAL DISPOSAL OF RADIOACTIVE WASTE WHICH THE WASTE PRODUCER MUST APPROPRIATELY PROCESS. THE COSTS FOR THIS WILL BE BORNE BY THE WASTE PRODUCER.

2. LICENSING AND SUPERVISORY PROCEDURES

2.1 CONSTITUTIONAL PROVISIONS

IN 1955, FOLLOWING SUSPENSION OF THE ALLIED BAN ON NUCLEAR ENERGY USES IN THE FEDERAL REPUBLIC OF GERMANY, RESEARCH AND DEVELOPMENT EFFORTS IN THIS FIELD WERE INITIATED IN A NUMBER OF LOCATIONS UNDER THE ADMINISTRATION OF THE RELEVANT STATE GOVERNMENTS. AS SUCH, THERE WAS A NEED TO CREATE A UNIFORM BODY OF REGULATIONS COVERING THIS KIND OF ACTIVITY. IN AN AMENDMENT TO THE BASIC LAW -- THE CONSTITUTION OF THE FEDERAL REPUBLIC OF GERMANY -- IT WAS STIPULATED THAT THE USE OF NUCLEAR ENERGY IS TO BE DEFINED BY FEDERAL LAW AND THAT AUTHORITY FOR IMPLEMENTING THIS LAW IS TO BE DELEGATED TO THE INDIVIDUAL STATE GOVERNMENTS. IN OTHER WORDS, THE STATE GOVERNMENTS HAVE AUTHORITY FOR LICENSING AND EXERCISING SUPERVISORY CONTROL OF NUCLEAR FACILITIES, WHILE THE FEDERAL GOVERNMENT HAS SUPERVISORY POWER IN MATTERS OF LAW AND EXPEDIENCY. IN THIS WAY IT IS GUARANTEED THAT THE SAME REGULATIONS APPLY EVERYWHERE IN THE COUNTRY, BUT, AT THE SAME TIME, THAT THOSE AUTHORITIES HAVE RESPONSIBILITY IN EACH CASE WHO ARE INFORMED ON LOCAL CONDITIONS

AND WHO DO THE DECISION-MAKING ON NON-NUCLEAR-SPECIFIC MATTERS ANYWAY. WITH REGARD TO SAFETY-RELATED FACTORS, THE STATE GOVERNMENTS ARE REQUIRED TO ACCEPT FEDERAL ORDERS AND TO IMPLEMENT THEM.

2.2 LEGAL REQUIREMENTS

GERMAN NUCLEAR LAW CONSISTS OF THE ATOMIC ENERGY ACT OF 1959 -- WHICH HAS BEEN BROUGHT UP TO DATE A NUMBER OF TIMES SINCE THEN AND IS CURRENTLY VALID IN THE VERSION OF JULY 15, 1985 -- AND A NUMBER OF ORDERS BASED ON POWERS ESTABLISHED UNDER THE ACT. THE MOST IMPORTANT OF THESE FEDERAL ORDERS CONCERN REGULATIONS ON RADIATION PROTECTION, LIABILITY INSURANCE FOR NUCLEAR-RELATED DAMAGES, AND LICENSING PROCEDURES FOR NUCLEAR FACILITIES. THESE LEGAL REQUIREMENTS ARE SUPPLEMENTED BY NUCLEAR-SPECIFIC ADMINISTRATIVE RULES, AGENCY GUIDELINES, ADVISORY GROUP RECOMMENDATIONS, ENGINEERING SAFETY REGULATIONS, AS WELL AS BY NUMEROUS NON-NUCLEAR-SPECIFIC REGULATIONS. THIS STRUCTURE WITH REGARD TO REQUIREMENTS MAKES IT POSSIBLE TO CARRY OUT FLEXIBLE ADJUSTMENTS TO KEEP UP WITH THE CONTINUOUS ADVANCES OF TECHNOLOGY. A KEY ASPECT OF NUCLEAR LAW IS THE REQUIREMENT TO TAKE THE NEEDED PRECAUTIONS, NOT JUST IN ACCORDANCE WITH THE CURRENT STATE OF TECHNOLOGY, BUT IN ACCORDANCE WITH THE CURRENT STATE OF SCIENCE AND TECHNOLOGY. THIS GUARANTEES A PROTECTION AGAINST RISK BASED ON THE BEST POSSIBLE PRECAUTIONARY MEASURES.

2.3 ADVISORY BODIES, EXPERTS, FEDERAL-STATE COORDINATION

THE STATE LICENSING AND SUPERVISORY AUTHORITIES CALL IN EXPERTS FOR SAFETY ENGINEERING ASSESSMENTS IN THE COURSE OF LICENSING PROCEDURES AND FOR THE PURPOSE OF CARRYING OUT REGULAR INSPECTIONS OF FACILITIES IN OPERATION. THE FEDERAL MINISTRY RESPONSIBLE FOR THE ENVIRONMENT, NATURE CONSERVATION AND NUCLEAR SAFETY -- TODAY A MINISTRY IN ITS OWN RIGHT -- CREATED A FEDERAL-STATE COMMISSION FOR PURPOSES OF COORDINATION WITH STATE AUTHORITIES AND A NUCLEAR SAFETY AND RADIATION PROTECTION COMMISSION FOR THE PURPOSE OF ADVISING THE MINISTRY. THE MEETINGS OF THIS LATTER COMMISSION CAN BE ATTENDED BY REPRESENTATIVES OF STATE AUTHORITIES. IN THIS WAY IT CAN BE ASSURED THAT THERE WILL BE MUTUAL AND PROMPT AWARENESS OF PERTINENT ISSUES AND VIEWS AND THAT A BASIS WILL BE THERE FOR ARRIVING AT JOINT SOLUTIONS.

COOPERATION BETWEEN GOVERNMENT AUTHORITIES AND EXPERT ADVISERS, ON THE ONE HAND, AND LICENSE APPLICANTS OR NUCLEAR FACILITY OPERATORS, ON THE OTHER, HAS PROVED PROVED EFFECTIVE (VIRTUALLY A CONTINUATION OF THE JOINT EFFORT THAT HAS EXISTED FROM THE OUTSET BETWEEN GOVERNMENT, THE SCIENTIFIC COMMUNITY AND INDUSTRY). THIS KIND OF COOPERATION HAS HELPED MAKE IT POSSIBLE FOR NUCLEAR TECHNOLOGY IN THE FEDERAL REPUBLIC OF GERMANY TO ACQUIRE THE HIGH LEVEL OF PRESTIGE IT CURRENTLY HAS IN THE WORLD. IT IS THE AMBITION OF THE FEDERAL GOVERNMENT IN BONN TO PRESERVE THIS IMAGE.

3. CURRENT SITUATION

3.1 DISILLUSIONMENT AND SKEPTICISM

MOST EVERYWHERE IN THE WORLD, A KIND OF NEW FRONTIERS SPIRIT OF THE 1950S AND THE INITIAL SUCCESSES OF THE 1960S CREATED EUPHORIC HOPES WITH REGARD TO THE USE OF NUCLEAR ENERGY. THE OIL CRISIS OF THE EARLY 1970S AND THE SHOCK OF POLITICAL AND ENERGY-RELATED DEPENDENCIES ON UNCONTROLLABLE RISES IN OIL PRICES GAVE ADDITIONAL IMPETUS TO THIS TREND, LEADING -- SEEN FROM TODAY'S STANDPOINT -- TO GROSS OVERESTIMATES OF NUCLEAR ENERGY USE GROWTH RATES.

HOWEVER, THE WORLD-WIDE INTRODUCTION OF ENERGY-SAVING MEASURES -- IN PARTICULAR THE DEVELOPMENT OF ENERGY-SAVING TECHNOLOGIES -- AND THE SIMULTANEOUS STAGNATION OF THE WORLD ECONOMY, RESULTED IN THE NEED TO REVISE THE NUCLEAR ENERGY USE FORECASTS DOWNWARD FROM YEAR TO YEAR. EVERYWHERE THERE WAS A SURPLUS OF NUCLEAR POWER PLANT CAPACITIES. THE GROWING DISCREPANCY BETWEEN NUCLEAR POWER PLANT CAPACITIES THAT COULD NO LONGER BE MADE OPTIMUM ECONOMIC USE OF

AND DECLINING REQUIREMENT FORECASTS -- IN CONNECTION WITH GROWING PUBLIC AWARENESS OF ENVIRONMENTAL ISSUES -- LED IN THE 1970S TO PROFOUND SKEPTICISM MOTIVATED BY PERCEIVED "MISTAKES" IN ENERGY PLANNING AND BY NUCLEAR ENERGY IN PARTICULAR.

THROUGHOUT THE COUNTRY GRASS-ROOTS INITIATIVES SPRANG UP, ORGANIZING RESISTANCE TO NUCLEAR ENERGY. IN MANY PLACES THERE WERE MASS DEMONSTRATIONS AGAINST NUCLEAR ENERGY PROJECTS -- IN SOME CASES WITH MANIFESTATIONS OF VIOLENCE. THE UNCONTESTABLE HAZARD POTENTIAL IMPLIED BY THE USE OF NUCLEAR ENERGY WAS REFERRED TO AS A REAL AND -- ALLEGEDLY -- INEVITABLE DANGER AND WAS ALMOST ALWAYS CONNECTED WITH THE THREAT POSED BY THE GROWING ARSENALS OF NUCLEAR WEAPONS AND THE POSSIBILITY OF MILITARY ABUSE OF PEACEFUL NUCLEAR ENERGY USES. THE EUPHORIC WELCOME ONCE GIVEN TO NUCLEAR ENERGY HAD TURNED INTO A MOVEMENT TO GET RID OF IT.

THE POLITICAL DECISION MADE BY THE U.S. GOVERNMENT ON THE BASIS OF THE NUCLEAR NON-PROLIFERATION TREATY (DECISION MADE ON APRIL 7, 1977) NOT TO ENGAGE IN THE COMMERCIAL REPROCESSING OF NUCLEAR FUEL RESULTED IN ADDITIONAL PROBLEMS, IN PARTICULAR FOR COUNTRIES POOR IN ENERGY RESOURCES -- SUCH AS THE FEDERAL REPUBLIC OF GERMANY AND JAPAN -- THAT HAD ESTABLISHED POLICIES BASED ON FUEL RECYCLING. WE NEED ONLY THINK OF THE WORLD-WIDE EFFORTS UNDERTAKEN IN CONNECTION WITH THE INTERNATIONAL NUCLEAR FUEL CYCLE EVALUATION (INFCE).

3.2 DOUBTS WITH REGARD TO NUCLEAR SAFETY

IN MARCH 1979, DURING THE PERIOD OF GROWING RESISTANCE TO NUCLEAR ENERGY, A SERIOUS ACCIDENT TOOK PLACE AT AN AMERICAN NUCLEAR POWER PLANT IN HARRISBURG, PENNSYLVANIA (TMI-2). THE WORLD WAS SHOCKED BY AN EVENT THAT -- BASED ON SCIENTIFIC PREDICTIONS -- COULD NOT BE RULED OUT, BUT WAS CONSIDERED EXTREMELY IMPROBABLE. CONFIDENCE IN REACTOR SAFETY AND IN STATEMENTS BY EXPERTS HAD BEEN SEVERELY SHAKEN. IN SOME COUNTRIES THIS LED TO ABANDONING THE INTENTION OF USING NUCLEAR ENERGY OR OF CANCELLING NUCLEAR ENERGY PROGRAMS ALREADY BEGUN.

IN ALL THE NUCLEAR ENERGY COUNTRIES -- IN PART IN INTERNATIONAL COOPERATION -- PROGRAMS WERE CARRIED OUT FOR THE MONITORING, SURVEILLANCE AND -- WHERE NECESSARY -- FOR THE IMPROVEMENT OF SAFETY DESIGNS. THE ASSESSMENTS CARRIED OUT ON NEEDED STANDARDS CONFIRMED IN ESSENCE THE TECHNICAL AND ADMINISTRATIVE SAFETY REQUIREMENTS ALREADY APPLIED IN THE FEDERAL REPUBLIC OF GERMANY.

THE HARRISBURG SHOCK HAD JUST BEEN OVERCOME AND A CERTAIN AMOUNT OF CONFIDENCE IN NUCLEAR SAFETY REGAINED ON THE BASIS OF GOOD EXPERIENCE WITH THE GROWING NUMBER OF NUCLEAR ENERGY FACILITIES IN OPERATION AROUND THE WORLD -- WHEN THE CHERNOBYL DISASTER OCCURRED ON APRIL 26, 1986. A TRAGIC COMBINATION OF PHYSICAL PROPERTIES AND SAFETY DESIGN OF THE TYPE OF REACTOR IN QUESTION, AS WELL AS ADMINISTRATIVE SHORTCOMINGS AND A CONSCIOUS VIOLATION OF OPERATIONAL REGULATIONS LED TO THE BIGGEST REACTOR ACCIDENT THAT HAS OCCURRED THUS FAR WITH A MASSIVE RELEASE OF RADIOACTIVE MATERIAL AND RADIOLOGICAL REPERCUSSIONS THROUGHOUT EUROPE.

AT THE TIME THE WORLD ECONOMIC SUMMIT WAS IN SESSION IN TOKYO. ALL OF THE SUMMIT PARTICIPANTS WERE IN AGREEMENT THAT THE DISASTER COULD HAVE BEEN AVOIDED AND THAT IT SHOULD NOT, AS SUCH, BE TAKEN AS A REASON FOR PREMATURELY CONDEMNING THE PEACEFUL USE OF NUCLEAR ENERGY. IT WAS FELT, HOWEVER, THAT THE INCIDENT NEEDED TO BE CAREFULLY ANALYSED IN AN INTERNATIONAL CONTEXT WITH A VIEW TO POSSIBLE CONCLUSIONS REGARDING PRESENT SAFETY CONSIDERATIONS.

THE CHANCELLOR OF THE FEDERAL REPUBLIC OF GERMANY PROPOSED AN INTERGOVERNMENTAL CONFERENCE OF ALL NUCLEAR ENERGY COUNTRIES TO DISCUSS THE PRACTICAL AND POLITICAL CONSEQUENCES OF THIS NUCLEAR ACCIDENT, THE MOST SERIOUS IN HISTORY. HIS PROPOSAL WAS AGREED TO BY ALL SIDES AND LED WITHIN A FEW MONTHS TO A SPECIAL CONFERENCE IN VIENNA ORGANIZED BY THE IAEA AT WHICH, AMONG OTHER THINGS, CONVENTIONS WERE CONCLUDED (SEPTEMBER 26, 1986) ON EARLY NOTIFICATION OF A NUCLEAR ACCIDENT AND ON ASSISTANCE IN THE CASE OF A NUCLEAR ACCIDENT OR RADIOLOGICAL EMERGENCY [WITH TRANSBOUNDARY IMPLICATIONS]. IN THE SAME CONTEXT AN AGREEMENT WAS REACHED ON A JOINT PROGRAM FOR CHECKING THE SAFETY OF NUCLEAR FACILITIES. THE BONN GOVERNMENT STRONGLY ADVOCATED THE VIEW THAT THERE WAS A NEED TO ACHIEVE THE HIGHEST POSSIBLE LEVEL OF SAFETY AND A WORLDWIDE HARMONIZATION OF LIABILITY RULES. BONN CONTINUES TO PURSUE THIS GOAL.

3.3 FURTHER DEVELOPMENT OF NUCLEAR SAFETY

THE BASIC PRINCIPLE FOLLOWED BY THE GOVERNMENT IN BONN IN THIS CONTEXT IS THAT SAFETY HAS PRIORITY OVER ANY AND ALL ECONOMIC CONSIDERATIONS. AS IN THE CASE OF HARRISBURG, CHERNOBYL MOTIVATED COMPREHENSIVE TESTS OF THE SAFETY FEATURES OF ALL OUR NUCLEAR POWER PLANTS. IN THIS CONTEXT WE WERE NOT ABLE TO IDENTIFY ANY PHENOMENA THAT WERE NOT ALREADY KNOWN TO US AND TAKEN INTO ACCOUNT.

IN THE CASE OF THE CHERNOBYL-TYPE REACTORS -- IN OPERATION AND UNDER CONSTRUCTION ONLY IN THE SOVIET UNION -- IT WAS FOUND THAT THERE IS A NEED FOR CONSIDERABLE SAFETY-RELATED MODIFICATIONS. NO FURTHER REACTORS OF THIS TYPE ARE TO BE BUILT AS A CONSEQUENCE. IN THE CASE OF OUR REACTORS, ON THE OTHER HAND, IT WAS FOUND THAT THERE IS NO CAUSE TO DOUBT THE SAFETY FEATURES.

THE FOCUS OF ATTENTION HAS NOW SHIFTED SOMEWHAT FROM ACCIDENT PREVENTION MEASURES (AVOIDANCE OF ACCIDENTS BY MEANS OF APPROPRIATE SAFETY DESIGN FEATURES) TOWARDS MORE INTENSIVE MEASURES AIMED AT DEALING WITH THE CONSEQUENCES OF ACCIDENTS WHEN THEY HAVE HAPPENED (EMERGENCY PROTECTION MEASURES IN THE REACTOR IN THE SENSE OF "ACCIDENT MANAGEMENT"). AS SUCH, THE IDEAS THAT WERE DEVELOPED IN THE WAKE OF THE HARRISBURG MISHAP ARE BEING IMPLEMENTED MORE RAPIDLY. THEY INCLUDE SUCH THINGS AS "FILTERED CONTAINMENT PRESSURE RELIEF", "FILTERED CONTROL ROOM VENTILATION", "INTERTING OF THE HEAVY WATER REACTOR CONTAINMENT" AND "RISK ANALYSES".

IN PUBLIC DEBATE DOUBTS ARE CONTINUOUSLY RAISED IN CONNECTION WITH THE CONTINOUS FURTHER DEVELOPMENT OF REACTOR SAFETY AS TO WHETHER THE SAFETY FEATURES OF OLDER REACTORS ARE SUFFICIENT. DOUBTS OF THIS KIND WOULD ONLY BE JUSTIFIED IF IT COULD BE PROVED THAT IMPOSED SAFETY REQUIREMENTS ARE NOT BEING FULFILLED. IF THIS WERE DETERMINED, THEN OPERATION OF THE REACTOR IN QUESTION WOULD HAVE TO CEASE IN ANY CASE. CLAIMING THE UNSAFETY OF A REACTOR ONLY BECAUSE

EFFORTS ARE BEING MADE TO IMPROVE SAFETY FURTHER STILL WOULD MAKE PROGRESS IN THE FIELDS OF NUCLEAR ENGINEERING AND NUCLEAR SAFETY ENGINEERING IMPOSSIBLE. SIMPLY BECAUSE IT IS POSSIBLE TO DO SOMETHING BETTER DOES NOT MEAN THAT THE PREVIOUS STATE OF AFFAIRS WAS BAD.

THE INTENTION UNDER THE PROVISIONS OF GERMAN LAW ON NUCLEAR MATTERS IS TO PROVIDE BASIC PROTECTION -- BASING THIS ON THE GIVEN CURRENT STATE OF SCIENCE AND TECHNOLOGY IN PRACTICE AND, AS SUCH, COMPLYING WITH THE PERMANENT OBLIGATION TO MINIMIZE THE RESIDUAL RISK.

AN OFTEN CITED EXAMPLE OF THE ADVANCE OF SAFETY REQUIREMENTS IS THE QUESTION OF DESIGNING REACTORS TO WITHSTAND THE IMPACT OF A CRASHING AIRCRAFT. DESPITE DIFFERING STANDARDS, THERE IS STILL SUFFICIENT PROTECTION IN THE CASE OF OLDER REACTORS TO GUARANTEE COMPLIANCE WITH LIMIT VALUES REQUIRED BY LAW -- SO THAT, BASED ON THE PRINCIPLE OF REASONABLENESS, DEMANDS FOR MODIFICATIONS OF THIS KIND CAN ONLY BE MADE IN QUALIFIED CASES. THE REFERENCE TO FURTHER TECHNICAL DEVELOPMENT OF AUTOMOBILES WITHOUT THE NEED FOR IMPOSING BANS ON THE OPERATION OF OLDER MODELS ILLUSTRATES THIS PRINCIPLE.

IT SHOULD BE SAID THAT THERE IS A DEFINITE NEED TO SEEK STEADY IMPROVEMENT IN THE SAFETY OF NUCLEAR POWER PLANTS -- AND, INDEED, THIS IS SOMETHING THAT SHOULD CONTINUE TO BE DEMANDED. THIS HAS TAKEN PLACE THUS FAR ON THE BASIS OF REGULAR REVISIONS. OUR SYSTEMATIC POLICY ON REACTOR SAFETY IS ALSO REFLECTED BY OUR INTENTION TO SUBJECT ALL NUCLEAR POWER PLANTS IN THE FEDERAL REPUBLIC OF GERMANY TO PERIODICAL AND COMPREHENSIVE SAFETY ENGINEERING TESTS.

3.4 IMPROVEMENT OF MONITORING OF RADIOACTIVITY IN THE ENVIRONMENT

AFTER THE CHERNOBYL DISASTER JURISDICTIONAL PROBLEMS LED IN SOME CASES TO VERY DIFFERENT ASSESSMENTS AND REACTIONS IN THE VARIOUS STATES IN CONNECTION WITH THE REPORTING OF RADIOACTIVE CONTAMINATION IN THE FEDERAL REPUBLIC OF GERMANY. THIS, IN TURN, GENERATED A GREAT DEAL OF UNCERTAINTY IN THE PUBLIC. PARALLEL WITH THE THE CREATION OF A MINISTRY FOR THE ENVIRONMENT AND IN COORDINATION WITH THE INDIVIDUAL STATE GOVERNMENTS, THE FEDERAL GOVERNMENT IN BONN PASSED LEGISLATION FOR THE PURPOSE OF ESTABLISHING A COUNTRY-WIDE NETWORK OF STATIONS TO MEASURE RADIOACTIVITY LEVELS IN THE ENVIRONMENT. UNDER THIS LEGISLATION, IT IS THE RESPONSIBILITY OF THE FEDERAL GOVERNMENT TO ASSESS REGISTERED MEASUREMENTS AND DETERMINE NECESSARY RESPONSES.

3.5 DOUBTS AS TO THE RELIABILITY OF THOSE RESPONSIBLE

THE TURBULENT ATMOSPHERE AFTER CHERNOBYL HAD JUST BEGUN TO CALM DOWN AND PUBLIC DEBATE TO RETURN TO A MORE OBJECTIVE LEVEL WHEN THE TN/NUKEM SCANDAL EMERGED -- STRIKING ANOTHER BLOW TO PUBLIC CONFIDENCE. THIS TIME THE ISSUE WAS NOT REACTOR SAFETY AND RADIATION PROTECTION. THE FEARS THAT AROSE WERE IN REFERENCE TO THE RELIABILITY OF MANAGERS IN POSITIONS OF RESPONSIBILITY. DOUBTS WERE CREATED AS TO THE EFFECTIVENESS OF GOVERNMENT CONTROLS IN SUCH CASES -- CAUSING A MAJOR POLITICAL CONTROVERSY.

THE FEDERAL GOVERNMENT IN BONN RESPONDED -- IN CLOSE COOPERATION WITH THE AFFECTED PARTNER COUNTRIES AND INTERNATIONAL ORGANIZATIONS, IN PARTICULAR THE EUROPEAN COMMUNITY AND THE IAEA -- BY MAKING AN EFFORT TO CLEAR UP THE AFFAIR. THE FEDERAL PARLIAMENT IN BONN CREATED AN INVESTIGATIVE COMMITTEE IN THIS CONTEXT THAT WILL WORK TOWARDS UNCOVERING ALL THE DETAILS OF THIS VERY REGRETTABLE CASE OF UNSCRUPULOUS BEHAVIOR ON THE PART OF A FEW PROFIT-MOTIVATED MANAGERS OF GERMAN COMPANIES.

TODAY WE ARE ABLE TO SAY WITH REGARD TO THIS MATTER THAT NO PUBLIC RISK WAS INVOLVED IN NUCLEAR SAFETY OR RADIATION PROTECTION TERMS. THE MANIPULATIONS THAT WERE CARRIED OUT WERE EXCLUSIVELY OF THE WHITE-COLLAR-CRIME VARIETY. AGAINST THE BACKDROP OF INTERNATIONAL RESPONSE TO THIS AFFAIR, I WOULD LIKE TO TAKE THIS OPPORTUNITY TO STRESS THAT -- IN AGREEMENT WITH THE PUBLIC PROSECUTION AUTHORITIES IN OUR COUNTRY -- WE WERE UNABLE TO DETERMINE ANY ACT IN VIOLATION OF THE NUCLEAR NON-PROLIFERATION TREATY.

4. DISPOSAL OF NUCLEAR WASTE

4.1 ADHERENCE TO AN INTEGRATED WASTE DISPOSAL STRATEGY

AT THE PRESENT TIME PUBLIC DEBATE IN OUR COUNTRY IS STRONGLY FOCUSED ON THE PROBLEM OF NUCLEAR WASTE DISPOSAL. THE FEDERAL CABINET SUBMITTED A COMPREHENSIVE REPORT TO PARLIAMENT ON THE SUBJECT EARLY THIS YEAR. IN ITS REPORT THE CABINET REITERATES ITS ADHERENCE TO AND PROMOTION OF WORK ON THE WASTE DISPOSAL STRATEGY AGREED ON WITH THE STATE GOVERNMENTS IN 1979 AND INCLUDING

- PRIORITY REPROCESSING OF SPENT NUCLEAR FUEL, RE-USE OF URANIUM GAINED VIA THIS PROCESS, AND FINAL DISPOSAL OF RADIOACTIVE WASTE MATERIALS IN UNDERGROUND FORMATIONS, AS WELL AS

- SIMULTANEOUS DEVELOPMENT AND REALIZATION OF FACILITIES FOR FINAL STORAGE OF UNREPROCESSED FUEL.

THE GOVERNMENT IS GUIDED IN ITS EFFORTS BY THE PRINCIPLE OF NOT PASSING PROBLEMS CREATED BY THE PRESENT GENERATION ON TO FUTURE GENERATIONS.

FEDERAL GOVERNMENT PROJECTS AIMED AT FINAL DISPOSAL OF NON-HEAT-PRODUCING WASTE MATERIALS IN THE FORMER KONRAD IRON ORE MINE AND AT FINAL STORAGE FOR ALL CATEGORIES OF RADIOACTIVE WASTE -- INCLUDING UNREPROCESSED FUEL -- IN THE ROCK SALT FORMATION AT GORLEBEN ARE CURRENTLY UNDER CONSIDERATION. POSITIVE DECISIONS ARE EXPECTED SOMETIME IN THE NEXT FEW YEARS. THIS IS TRUE, DESPITE THE ACCIDENT THAT OCCURRED IN CONNECTION WITH SINKING A SHAFT IN GORLEBEN. THIS WILL MEAN A DELAY IN GETTING THE SITE READY, BUT IT HAS NOTHING TO DO WITH THE SUITABILITY OF THIS ROCK SALT FORMATION FOR NUCLEAR WASTE STORAGE PURPOSES. IT CAN THUS BE BE ASSUMED THAT SUFFICIENT WASTE DISPOSAL CAPACITIES WILL BE AVAILABLE ON SCHEDULE. OF COURSE, WE SHOULD MENTION IN THIS CONTEXT THE PROBLEMS BEING ENCOUNTERED IN GAINING ACCEPTANCE FOR THIS USE OF THE SITE AND THE ADMINISTRATIVE COURT PROCEEDINGS THAT CAN BE EXPECTED.

5. ADVANCED REACTOR SYSTEMS

AS YOU ARE AWARE, WORK IS ALSO BEING CARRIED OUT IN THE FEDERAL REPUBLIC OF GERMANY ON ADVANCED REACTOR SYSTEMS. DEVELOPMENT EFFORTS ARE CURRENTLY FOCUSED ON IMPROVING FUEL EFFICIENCY IN LIGHT WATER REACTORS, ON FAST BREEDER TECHNOLOGY AND ON HIGH-TEMPERATURE REACTOR TECHNOLOGY. A 300 MW_E PROTOTYPE OF THE THTR-300 HIGH-TEMPERATURE REACTOR HAS BEEN OPERATED SUCCESSFULLY SINCE 1986 AND A NUMBER OF COUNTRIES HAVE SHOWN AN INTEREST IN JOINT FURTHER DEVELOPMENT OF THIS SYSTEM. THE SNR-300 PROTOTYPE IN KALKAR IS NEARING COMPLETION. WHEN FINISHED IT WILL SERVE AS A DEMONSTRATION PROJECT IN THE USE OF GERMAN FAST BREEDER REACTORS. LAST FALL THE REACTOR SAFETY COMMISSION UNDERTOOK A RENEWED THOROUGH SAFETY ASSESSMENT OF THIS PROTOTYPE, INVITING EXPERTS FROM OTHER COUNTRIES, INCLUDING JAPAN, TO TAKE PART. AT THE PRESENT TIME THERE ARE STILL QUESTIONS THAT NEED CLARIFICATION BETWEEN THE FEDERAL GOVERNMENT IN BONN AND THE GOVERNMENT OF THE STATE OF NORTH RHINE - WESTPHALIA, WHICH IS RESPONSIBLE FOR GIVING OPERATIONAL APPROVAL. WHEN THE FACILITY WILL BE ABLE TO GO INTO OPERATION WILL DEPEND ON FINAL CLARIFICATION OF THESE QUESTIONS.

6. INTERNATIONAL COOPERATION

6.1 MAXIMUM SAFETY REQUIREMENTS, INTERNATIONAL COOPERATION IN THE FIELD OF NUCLEAR SAFETY

THE DISASTROUS EFFECTS OF THE UNCONTROLLED CHAIN REACTIONS IN THE ATOMIC BOMBS THAT EXPLODED OVER HIROSHIMA AND NAGASAKI, THE CONSEQUENCES OF THE 1957 FIRE AT THE WINDSCALE REACTOR IN BRITAIN, THE SEVERE ACCIDENTS AT THE HARRISBURG POWER PLANT IN THE UNITED STATES IN 1979 AND AT THE CHERNOBYL PLANT IN THE SOVIET UNION IN 1986, ILLUSTRATE THE DANGER POTENTIALS OF NUCLEAR ENERGY AND UNDERSCORE THE IMPORTANCE OF EFFORTS IN THE AREA OF NUCLEAR SAFETY AND RADIATION PROTECTION -- AS WELL AS PROTECTIVE MEASURES TO HELP DEAL WITH NUCLEAR EMERGENCIES IF THEY SHOULD OCCUR.

IN VIEW OF THE HUGE POTENTIAL THREAT THAT HAS ALWAYS EXISTED IN CONNECTION WITH THE USE OF NUCLEAR ENERGY, IT CAN BE SAID WITHOUT EXAGGERATION THAT STRICTER SAFETY REQUIREMENTS ARE NEEDED HERE THAN IN ANY OTHER FIELD OF ENGINEERING. THE FACT SHOULD NOT BE OVERLOOKED THAT SAFETY STANDARDS ARE NOT THE SAME EVERYWHERE -- AND THAT EFFORTS ON THE PART OF INTERNATIONAL ORGANIZATIONS TO BRING ABOUT A HARMONIZATION OF STANDARDS HAS NOT EXACTLY BEEN CROWNED BY SUCCESS THUS FAR.

IT IS AN UNCONTESTED FACT THAT NUCLEAR ENERGY WILL ONLY GAIN ACCEPTANCE IF COMPARABLY HIGH SAFETY STANDARDS ARE APPLIED AND ENFORCED EVERYWHERE IN THE WORLD AND IF THERE IS NO NEED TO FEAR THAT SAFETY STANDARDS WILL BE NEGLECTED. THIS PRESUPPOSES WORLD-WIDE COOPERATION IN THE NUCLEAR SAFETY SECTOR -- WITH THE OBJECTIVE OF HARMONIZING SAFETY STANDARDS TO THE GREATEST POSSIBLE DEGREE. IT BEGINS WITH RISK ASSESSMENT, INCLUDES THE CLASSING OF SPECIFIC OCCURRENCES OF ACCIDENTS IN DIFFERENT DANGER CATEGORIES AND EXTENDS TO HARMONIZED EMERGENCY PROTECTION PLANNING. THE ESTABLISHMENT OF A GLOBAL REGIME FOR NUCLEAR DAMAGE LIABILITY ALSO NEEDS TO BE MENTIONED IN THIS CONNECTION. THE FEDERAL REPUBLIC OF GERMANY IS WILLING TO ENGAGE IN AN OPEN EXCHANGE OF INFORMATION ON NUCLEAR SAFETY. OSART MISSIONS TO THREE GERMAN NUCLEAR POWER PLANTS AFTER CHERNOBYL ARE PROOF OF THIS OPENNESS.

7. INTERNATIONAL COOPERATION AND NATIONAL RESPONSIBILITY

EXPOSURE TO IONIZING RADIATION PRODUCED BY RADIOACTIVE MATERIAL THAT HAS BEEN RELEASED IN THE ENVIRONMENT IS NOT SOMETHING THAT CAN BE KEPT WITHIN NATIONAL BOUNDARIES. AS SUCH, IT IS A POLITICAL NECESSITY TO WORK TOGETHER INTERNATIONALLY IN THE TRANSBOUNDARY CONTEXT. INTERNATIONAL ORGANIZATIONS SUCH AS THE IAEA PLAY A CENTRAL ROLE IN THIS. THE NUSS CODES OF PRACTICE, RECENTLY DISCUSSED IN DETAIL AND REVISED BY THE IAEA'S NUCLEAR SAFETY STANDARDS ADVISORY GROUP (NUSSAG), REPRESENT A MAJOR STEP FORWARD TOWARDS INTERNATIONAL HARMONIZATION. THE BONN GOVERNMENT HOPES THAT THESE INTERNATIONAL STANDARDS WILL BE APPROVED BY THE IAEA BOARD OF GOVERNORS AND WILL BE FULLY APPLIED BY ALL IAEA MEMBER STATES.

HOWEVER, THE RESPONSIBILITY OF NATIONAL AUTHORITIES MUST NOT BE PRE-EMPTED THROUGH THE EXISTENCE OF AN INTERNATIONAL FRAMEWORK FOR SAFETY STANDARDS. THE NATIONAL AUTHORITIES WILL, OF NECESSITY, RETAIN DIRECT RESPONSIBILITY IN THESE MATTERS FOR THE SIMPLE REASON THAT THEY ARE THE ONLY ONES WHO CAN TAKE

APPROPRIATE ACCOUNT OF COUNTRY-SPECIFIC MATTERS SUCH AS POPULATION DISTRIBUTION, GEOLOGICAL FEATURES, CLIMATIC CONDITIONS, AS WELL AS ADMINISTRATIVE PARTICULARS.

FULL RESPONSIBILITY TOWARDS ONE'S OWN PEOPLE AS WELL AS TOWARDS THE REST OF THE WORLD MUST BE ACCEPTED FOR EVERY DECISION MADE IN CONNECTION WITH THE USE OF NUCLEAR ENERGY -- WHETHER THE RESULT IS POSITIVE OR NEGATIVE. THIS RESPONSIBILITY NOT ONLY PRESUPPOSES TAKING INTO ACCOUNT CURRENT NATIONAL FACTORS AS THE BASIS FOR DECISION-MAKING, BUT ALSO THE JUSTIFIED INTERESTS OF OUR CHILDREN AND CHILDREN'S CHILDREN, AS WELL AS A MORAL OBLIGATION TOWARDS THE FELLOW HUMAN BEINGS WHO HAPPEN TO LIVE BEYOND OUR NATIONAL BORDERS.

8. THE FUTURE OF NUCLEAR ENERGY IN THE FEDERAL REPUBLIC OF GERMANY

8.1 SAFETY ENGINEERING RESPONSIBILITIES AND THE NEED FOR NUCLEAR TECHNOLOGY IN THE ENERGY-PRODUCTION SECTOR

THE BONN GOVERNMENT IS CONVINCED THAT THE PREREQUISITES ARE THERE FOR THE SAFE USE OF NUCLEAR ENERGY -- PARTICULARLY IN THE ADVANCED INDUSTRIAL NATIONS OF THE WORLD. THIS ASSESSMENT IS VALID, DESPITE THE CHERNOBYL INCIDENT AND THE SEVERE CRISIS OF CONFIDENCE AND ACCEPTANCE IT HAS CAUSED. IT CONTINUES TO HOLD TRUE, DESPITE THE EMERGENCE OF IRRESPONSIBLE SCHEMES ON THE PART OF PROFIT-HUNGRY COMPANY MANAGERS IN THE FEDERAL REPUBLIC OF GERMANY. IN THE LATTER CASE RADIATION PROTECTION CONSIDERATIONS WERE NOT INVOLVED SO MUCH AS RELIABILITY FACTORS.

HOWEVER, WE HAVE NO CAUSE TO LEAN BACK AND FEEL SATISFIED WITH OURSELVES. THERE ARE STILL PLENTY OF QUESTIONS THAT NEED CLEARING UP. IN THE FEDERAL REPUBLIC OF GERMANY, AS IN OTHER COUNTRIES, CONSIDERABLE EFFORTS WILL BE NECESSARY TO FIND AN ACCEPTABLE SOLUTION TO THE PROBLEMS INVOLVED

IN SAFE FINAL STORAGE OF NUCLEAR WASTE -- IN OTHER WORDS THE ESTABLISHMENT OF SAFE REPOSITORIES FOR THESE MATERIALS. ON THE OTHER HAND, THE BONN GOVERNMENT HAS NO REASON TO BELIEVE THAT THE TECHNOLOGICAL SOLUTIONS BEING WORKED ON WILL NOT BE AVAILABLE IN THE NEAR FUTURE.

THE BONN GOVERNMENT FEELS THAT IT WOULD NOT BE RESPONSIBLE TO ABANDON THE USE OF NUCLEAR ENERGY IN THE FEDERAL REPUBLIC OF GERMANY, GIVEN THE OVERALL SITUATION IN THE ENERGY SECTOR -- EVEN THOUGH THIS WOULD BE FEASIBLE IN ENGINEERING AND IN FINANCIAL TERMS. TODAY, MORE THAN 80% OF THE ENERGY PRODUCED IN THE WORLD IS CONSUMED BY LESS THAN 20% OF THE WORLD'S POPULATION. THIS FACT ALONE IS REASON ENOUGH TO ATTACH A GREAT DEAL OF IMPORTANCE TO EFFICIENT FUEL USE AND ENERGY-SAVING MEASURES. THE RICH INDUSTRIAL COUNTRIES, INCLUDING THE FEDERAL REPUBLIC OF GERMANY, ARE MORALLY OBLIGATED TO HELP REDUCE THE INJUSTICES IN THE DISTRIBUTION OF WEALTH IN THE WORLD REFERRED TO AS THE "NORTH-SOUTH DIFFERENTIAL". IN THIS CONTEXT IT SHOULD BE TAKEN INTO ACCOUNT THAT ENERGY NEEDS ARE GOING TO BE GROWING AT A VERY HIGH RATE -- DUE TO THE POPULATION EXPLOSION IN THE POOR COUNTRIES AND THE CURRENTLY VERY LOW PER CAPITA ENERGY CONSUMPTION

LEVELS THERE. THUS, WE CANNOT AFFORD TO DO WITHOUT ANY OF THE TECHNICALLY POSSIBLE FORMS OF ENERGY PRODUCTION. AT THE SAME TIME, IT WOULD CERTAINLY NOT BE A RESPONSIBLE POLICY TO ABANDON NUCLEAR TECHNOLOGY IN THE HIGHLY DEVELOPED COUNTRIES AND TO DEPEND ON THE "SIMPLE" BURNING OF COAL AND OIL, LEAVING IT TO THE DEVELOPING COUNTRIES TO DEAL WITH THE COMPLEXITIES OF NUCLEAR TECHNOLOGY. AN ENVIRONMENTALLY RESPONSIBLE USE OF FOSSILE FUELS WILL PRESENT A HUGE PROBLEM IN ITSELF FOR THESE COUNTRIES AND REQUIRE ASSISTANCE FROM THE RICH INDUSTRIALIZED NATIONS. THE ENVIRONMENTAL PROBLEMS ASSOCIATED WITH THE USE OF FOSSILE FUELS, IN PARTICULAR EMISSIONS OF SO_2, NO_2 AND CO_2 -- WITH THE RESULTANT "GREENHOUSE EFFECT" -- CANNOT BE POINTED OUT OFTEN ENOUGH.

FINALLY, THERE IS A NEED TO POINT OUT A FACTOR IN THE ENERGY SECTOR THAT HAS NOT BEEN GIVEN SUFFICIENT ATTENTION EVERYWHERE:

ASIDE FROM OUR TRAIN SYSTEM, WHICH RUNS ON ELECTRICITY, THE TRANSPORT SECTOR IS ALMOST COMPLETELY DEPENDENT ON OIL -- THE RESERVES OF WHICH ARE QUITE LIMITED. WE WILL NEED TO BUILD UP SUFFICIENT RESERVES OF OIL SO AS TO BE ABLE TO SUSTAIN INDISPENSABLE TRANSPORT SERVICES OVER AN EXTENDED PERIOD OF TIME. WE NEED ONLY THINK OF THE VOLUME OF TRANSPORT REQUIRED TO SUPPLY OUR CITIES WITH FOOD EVERY DAY TO UNDERSTAND THE PROBLEMS INVOLVED.

WITH THIS IN MIND THE BONN GOVERNMENT PURSUES THE FOLLOWING STRATEGY:

o AN EFFORT IS BEING MADE TO SAVE ENERGY BY IMPROVING THE TECHNICAL EFFECTIVENESS OF ENERGY-CONSUMING DEVICES AND BY RECYCLING RESOURCES. THE SUCCESS EXPERIENCED IN THESE AREAS IN RECENT YEARS HAS BEEN NOTABLE AND ENCOURAGING AND HAS RESULTED IN PUTTING ENERGY CONSUMPTION LEVELS CONSIDERABLY BELOW WHAT IT WAS PREDICTED THEY WOULD BE ON THE BASIS OF PAST PROJECTIONS.

o AN EFFORT IS BEING MADE TO MAKE USE OF ALL TECHNICALLY AND COMMERCIALLY FEASIBLE FORMS OF ENERGY PRODUCTION -- AND TO DEVELOP FEASIBLE METHODS OF EXPLOITING ALTERNATIVE ENERGY SOURCES SUCH AS SOLAR ENERGY.

o OIL RESERVES ARE BEING BUILT UP FOR THE TRANSPORT SECTOR.

o OIL IS BEING REPLACED BY COAL WHEREVER THIS IS POSSIBLE.

o COAL IS BEING REPLACED BY NUCLEAR POWER IN THE ELECTRICITY-PRODUCTION SECTOR.

9. THE ROLE OF NUCLEAR ENERGY

LOOKING AHEAD TO THE FUTURE, PRIMARY ENERGY CONSUMPTION IN THE FEDERAL REPUBLIC OF GERMANY CAN BE EXPECTED TO STAGNATE AT AROUND 390 MILLION UNIT TONS OF COAL PER YEAR. THIS VOLUME OF ENERGY CONSUMPTION WOULD BE COVERED AT FAIRLY CONSTANT LEVELS OF AROUND 30% BY COAL, 15% BY GAS, AND LESS THAN 5% BY OTHER PRIMARY SOURCES. THE CURRENT 40% SHARE SHOWN BY OIL AT THE PRESENT TIME WILL DECLINE TO AROUND 35% BY THE YEAR 2000 -- ALTHOUGH CONSUMPTION WILL STAY AT ABOUT THE CURRENT LEVEL IN THE TRANSPORT SECTOR. THIS DECLINE WILL BE MADE UP FOR BY AN INCREASING IN THE SHARE OF NUCLEAR ENERGY IN THE TOTAL FROM 10% TO 15% IN THE SAME PERIOD. IN THE COMING YEARS ELECTRICITY PRODUCTION WILL INCREASE BY A THIRD -- FROM AROUND 400 BILLION KWH IN 1985 -- TO MORE THAN 520 BILLION KWH IN THE YEAR 2000. THE SHARE NUCLEAR ENERGY WILL HAVE IN THE OVERALL AMOUNT OF ELECTRICITY PRODUCED WILL REMAIN FAIRLY CONSTANT -- AT ABOUT 35%. IN ABSOLUTE TERMS THIS WILL AMOUNT TO AN INCREASE OF SOMEWHERE AROUND 140 TO 170 BILLION KWH PER YEAR.

THESE FIGURES MAKE IT CLEAR THAT REPLACING NUCLEAR ENERGY IN A SHORT-TERM SCENARIO WOULD NOT BE WITHOUT ITS PROBLEMS. GETTING OUT OF NUCLEAR ENERGY -- OR AS SOME POLITICIANS PREFER TO SAY, "GETTING INTO GETTING OUT" OF NUCLEAR ENERGY -- SIMPLY CANNOT BE DONE OVER THE SHORT TERM. IN OTHER WORDS, WHETHER WE WANT TO OR NOT, WE WILL SIMPLY HAVE TO LIVE WITH NUCLEAR ENERGY FOR THE FORESEEABLE FUTURE. THE SAFETY STANDARDS IN PLACE IN THE FEDERAL REPUBLIC OF GERMANY MAKE THIS FEASIBLE. TO MY WAY OF THINKING, IT WOULD NOT BE VERY CONSISTENT TO CONSIDER THE NUCLEAR ENERGY SAFETY RISK ACCEPTABLE FOR AN INEVITABLE TRANSITIONAL PERIOD, ONLY TO REJECT IS AS UNACCEPTABLE AT A LATER POINT IN TIME.

IT IS OUR TASK TO MAKE THE USE OF NUCLEAR ENERGY AS SAFE AS POSSIBLE -- AND NOT TO RELAX IN OUR EFFORT TO CONTINUE IMPROVING NUCLEAR SAFETY. CLOSE INTERNATIONAL COOPERATION IS THE PREREQUISITE FOR THIS. ANOTHER SERIOUS ACCIDENT SOMEWHERE IN THE WORLD WOULD CONFRONT THE NUCLEAR ENERGY SECTOR WITH SEVERE -- PERHAPS EVEN INSURMOUNTABLE -- PROBLEMS. IT CAN ALMOST BE SAID THAT OUR PAST DEPENDENCY ON THE

OIL-PRODUCING COUNTRIES -- A DEPENDENCY WE SOUGHT TO OVERCOME BY EXPANDING OUR USE OF NUCLEAR ENERGY -- HAS BEEN REPLACED TODAY BY AN INTERNATIONAL DEPENDENCY ON NUCLEAR SAFETY. IF THOSE RESPONSIBLE FOR THESE QUESTIONS ARE IN AGREEMENT ON THIS, THEN WE WILL BE ABLE TO LOOK AHEAD CONFIDENTLY TO A SECURE FUTURE IN ENERGY TERMS. THERE WILL BE A GOOD CHANCE THEN THAT WE WILL BE ABLE TO SATISFY ENERGY NEEDS RELIABLY AND SAFELY ALL OVER THE WORLD.

NUCLEAR ELECTRICITY, THE ANSWER TO THE ENERGY CHALLENGES OF THE NEXT CENTURY

J. P. Capron
Chairman
Commissariat à l'Energie Atomique
France

It is always a great pleasure and an honor to be invited to address the very select audience gathered during the JAIF; but this year, this pleasure is somewhat overcast by the unfortunate demise of Mr. Ari Sawa. We all know how closely he has been involved in the development of nuclear energy in this country and the personal care he has taken to make of these JAIF meetings one of most important yearly events on the international nuclear scene. I want to express again the profound sadness felt by the whole french nuclear community when it was reached by the news of his death.

In spite of his age, he had kept a young man's interest in all the developments of nuclear technology and I am quite sure that he would have had extremely wise comments to make on this exciting subject: the shape of our industry at the begining of the next century !

fig. 1

As each of you is certainly aware, France decided 15 years ago to launch a major nuclear effort in order to reduce dramatically its dependance on foreign energy. Up to now, we have met the challenge:

- more than 70 % of the electricity generated by EdF, our national utility, is nuclear,

- almost 50 % of the primary energy consumed in France is domestically produced, although our fossil fuel ressources are still not worth mentioning.

It is now obvious that the french nuclear industry has reached maturity: it is difficult to imagine how the share of nuclear energy could progress much further in our grid and our main concern is to reap the economic benefits which go with cheap electricity. Few new units are to be ordered between today and the early XXIst century, since capacity just has to follow the increase of the demand and all conventional power stations deserving to be phased out are idle.

The fact that the french energy problem has been successfully dealt with does not allow us by any mean to consider the issue as settled and, therefore, that the time has come to reduce speed on nuclear R&D.

We are convinced that it would be very risky to take it for granted, since leadtimes in our industry commonly exceed the decade. So, before taking any drastic course, we have to project ourselves into the next century and to answer two main questions:

- is nuclear power a transitory form of energy or is it there to stay ?

- how will the industry shape in ten to twenty years time and what are its main technological trends ?

Those are the two issues I intend to address in this presentation.

I. NUCLEAR ELECTRICITY IS THERE TO STAY

1. A few facts about demography.

fig. 2

In energy as well as in other economic fields, demography shapes the future and is the driving factor behind many an evolution. Today, the world population amounts to some 5 billion inhabitants, twice as much as only 25 years ago. According to most accepted models, based upon mortality and fertility rates, the asymptotic value of the world population is assessed at 10 billion people, this level being reached around the middle of the next century.

In the history of mankind, baring a major epidemic or war, the second half of the XXst century and the first one of the XXIst will remain as a period of unparalleled population growth, during which the number of human beings will have been multiplied by a factor of four.

fig. 3

Simultaneously, substantial changes in the geographic distribution of population will occur:

- the growth will take place mainly in Asia and Africa, the weight of this last continent almost doubling from 11 % to 20 %;

- people will tend to leave the countryside and to congregate in large conurbations, this move reflecting a shift from agriculture to industry in a growing number of countries.

2. The impact on global energy requirements.

fig. 4

The world primary energy consumption has reached some 7.5 billion tonnes oil equivalent (toe) in 1986, that is to say 1.5 toe per capita on the average. However, the consumption per capita is strongly correlated with the GNP per capita, leading to wide disparities from one country to the other. For instance, a scandinavian or a north american requires 7 toe when a japanese or an european is happy with 3 to 4 toe and when a chinese has to do with 0.6 toe and an ethiopan peasant with 10 kilograms !

The population of industrialized areas, which now accounts for three quarters of the world primary energy demand, will remain stable and it is the less developed regions which, at the same time, will experience the fastest demographic growth and move from an agricultural economy to an industry-driven one.

fig. 5

Although much has been done in industrialized countries since the 70's to save energy, improvements are still to be expected because the pattern of industrial development favors sectors in which the input of energy is low. Nevertheless, the overall effect should remain marginal when compared to the needs of developing countries, which will require more energy per capita in order to fuel their shift towards industry and provide more decent living standards to their citizens.

The last World Energy Conference, held in 1986, has shown that a large number of experts agree upon an average energy intensity of 2 toe per capita, roughly what is recorded today in the least industrialized parts of Europe, and on a global energy requirement of 20 billion toe by the middle of the next century. <u>It actually means that the world energy consumption is expected almost to treble when the world population will just double</u>.

3. The contribution of nuclear electricity.

To meet these needs, every available source of energy will have to be summoned, and the contribution of nuclear electricity could well be a decisive one:

- it is mass produced and is liable to no physical limitation, thanks to the breeder technology, whereas any sharp increase of the demand of fossil fuels is doomed to send the prices commanded by those commodities spiraling up;

- it is cost-efficient, since the nuclear kilowatthour is cheaper than the oil or coal generated one as long as the price of oil does not go under the 10 $/bl mark which, even if that would be the case, would not last very long;

- it locates the added value at the consumers rather than in the hands of the producing countries.

Moreover, I am convinced that the key argument in favour of nuclear energy is the protection of the environment, which will raise more and more concern in the general public with the fast increase of the world population as well as of the use of energy. To make my point, I will recall a few facts about pollution and public health:

fig. 6

- by careful examination of samples of polar ice, it has become possible to reconstruct the atmospheric concentration of carbon dioxyde during the historic times and the result is rather impressive as you can see on this slide. The causal interaction between temperature and carbon dioxyde in the so-called greenhouse effect is not yet fully understood and remains a subject of controversy; nevertheless, a growing number of scientists are expressing serious concern.

fig. 7

- a typical power station, stoked with coal or residual fuel oil, discharges huge amounts of pollutants in the environment, some of them being well known poisons such as sulphur dioxyde or nitrogen dioxyde. In comparison, a nuclear facility just releases a small amount of radioactivity, not so different from what comes from the natural radioactivity of coal.

fig. 8

  In that respect, the french case provide a good illustration of the environmental benefits derived from nuclear electricity: sulphur dioxyde releases in the atmosphere have been halved between 1980 and 1986 when, during the same period, the average reduction in other european countries has amounted to only 20 %.

fig. 9

- at this point, it is worthwhile to make a few comments about thresholds of toxicity, a subject which is very often misunderstood. This table shows that the norms for population exposure are much more conservative for radioactivity than for sulphur dioxyde.

  For this last pollutant, the different national limits are more or less in line with the concentrations you can find in some industrial areas during winter and remain close to the level at which you begin to record the first effects on health. They are actually one hundred times higher than the average natural background.

On the contrary, for radioactivity, a factor exceeding 10 is taken between those first effects and the international norm for populations, this norm being just slightly above the average natural background.

All this tends to prove that nuclear power is, in the present state of science, the only way to afford growth without triggering a major ecological disaster.

II. SHAPING THE NUCLEAR INDUSTRY OF THE XXIst CENTURY

fig. 10

Even if the pace at which it penetrates the energy mix may vary from one country to the other, nuclear electricity has now become a permanent feature and a major contributor to the energy supply of the industrial world. It means that we have to sustain an R&D effort consistent with the size of the industry and the deadlines it has to meet.

As regards France, our nuclear R&D is now organized along three main lines of action:

- persistence on safety,
- shift in favor of the fuel cycle,
- definition of the reactors of the next century.

1. Persistence on safety.

To my knowledge, nuclear energy is the first human activity in which research on safety has always gone together with technology. Since the very beginig, safety has been a strong concern for scientists and designers, because of a ingrained reluctance from the public towards something which remains somewhat mysterious and new, even 40 years after the first fission reactors.

After Tchernobyl, this distrust has grown more vigorous and it is vital for the nuclear industry to pay a maximum amount of attention to all questions related to safety even if, in a country such as France, there has been no easing off on the issue.

If the accident which occurred in Soviet Union does not provide us with so many teachings, as far as reactor design and operations are concerned, it nevertheless prompts us to maintain a significant effort on the following subjects:

- intervention procedures, intended to minimize the consequences of a serious accident;

- fast diagnosis of contaminated populations, in case of a large release of radioactive materials;

fig. 11

- work in hostile environments, especially with radiation-resistant robots;

- better command over the human factor;

- regeneration and recovery of contaminated soils.

Remains the endless controversy about the so-called "intrisically safe" reactor.

I personally think that it may be dangerous to let oneself be deluded by mere words. In OECD, nuclear safety is much more stringent than what is the accepted standard in any other industry, in order to reduce to something negligible the probability of an accident and to make sure that, even if that very unlikely accident occurred, its consequences for public health would remain minimal. I firmly believe that further improvements are possible and desirable; but it would be swindling the public, at the risk of raising justified criticism, to make it believe that absolute safety is, as if by magic, within easy reach.

2. <u>The stakes in the fuel cycle</u>.

In CEA, we are pursuing three major programs related to the fuel cycle:

- laser isotope separation,

- reprocessing,

- waste management.

a) Laser isotope separation:

Uranium enrichment is a key step of the fuel cycle, since it represents some 10 % of the cost of the kilowatthour and requires, in the present state of technology, huge and expensive facilities. Selective ionisation of atomic uranium vapor with laser light seems a very promising route to improve the economics of the next generation of enrichment plants, which could come on line at the begining of the next century:

- it could cut down costs by 30 to 50 %;
- it should take care of reprocessed uranium;
- it will require small modular units, providing a greater flexibility to market fluctuations.

I will not conceal you the fact that the program is not an easy one; but the progress made those last years in our labs is more than encouraging and we can now consider full system development. The main components:

- copper vapor lasers,
- tunable dye lasers,
- optics,

fig. 12

- evaporation and collection devices, one of which is shown on the present slide,

are currently being tested by CEA, in conjunction with the french industry, the next step being the complete integration in a pilot facility of representative size, in order to check the economics of the process. Preliminary evaluations already lead us to expect a reduction of at least 40 % of the enrichment cost.

b) Reprocessing:

The great affair is presently to start up successfully the extensions underway at La Hague and to implement a smooth transfer of technology in direction of the Rokkasho-Mura project.

fig. 13

You can look at a recent photograph of the site of La Hague, which gives you an idea of the progress of the construction of the plants.

fig. 14 Operating experience of UP 2 (which, at the end of february 1988, has reprocessed a total of 2200 tonnes) and careful engineering give a good guarantee that the commissioning of the new facilities will proceed according to schedule. All the major components undergo full scale testing by CEA: for instance, the bucket wheel continuous dissolver, which is presently shown, has been modified to allow final testing in Marcoule before incorporation in UP 3. Centrifuges, pulsed columns remote handling devices are also extensively tested before final design and installation.

When La Hague will have been started up, in the early 90's, R&D will have to be chanelled towards cost reduction through the return of experience from the operating plants, in order to justify fully the option to reprocess early, rather than accumulate in pools inventories of irradiated fuel.

c) Waste management:

Waste management requires special cares, because it is not only a technical problem, but has become a central issue in the debate with the general public about acceptance of nuclear energy.

fig. 15

As regards short-lived , low and medium activity wastes, I think that we have now a working solution available. A second site, located in Soulaines has received full approval of the relevant public authorities, construction work is now proceeding as you can see from this picture, and commissioning is planned for 1990.

fig. 16

As regards high level wastes, I consider that the theoretical and experimental work which has been made in CEA labs demonstrate the ability of certain geological formations, combined with engineered barriers, to safely confine radioactivity during the period it will take for each radioisotope to decay.

fig. 17

The time has now come for in situ testing. So, a proposal for an underground laboratory will be submitted to the Government by the end of 1989, mining should begin in 1990 in order to complete the validation program by 1996. If, then, the site proves adequate, the repository could become operational at the turn of the century.

3. The reactors of the next century.

The french electro-nuclear reactors constitute a major investment: they are worth more than 100 billon $; in consequence, our R&d has two purposes:

- making the most out of that investment, in terms of cost, availability and lifetime;

- preparing the decisions which will have to be made at the beginning of the next century to replace the oldest of these facilities.

fig. 18

To address the first of these two purposes, we try to improve fuel designs and we are introducing mixed-oxyde fuel incorporating plutonium oxyde in the 900 MW units. High penetration rates of nuclear electricity also imply load following: we started this mode of operation back in 1978 and we have found that PWR are quite flexible and work very smoothly at partial loads. Our experience is now extensive and we are quite confident in the safety of such a policy.

For the longer term, I feel that it will be made of a combination of two complementary designs: the advanced PWR and the fast breeder.

- Work on advanced light water reactors deals mostly with under-moderated or shift-spectrum type cores, loaded with mixed-oxyde fuel. Such designs take a better advantage of the energy potential of natural uranium and would give more time to commercially deploy the breeders which alone allow a full exploitation of that potential.

fig. 19

- Fast breeders have focused interest since a long time in several countries: Japan, France, the United Kingdom and other european nations. Unlike fusion or other "energies for the future", their feasibility is demonstrated. Recent work in CEA lead me to think that there is a large scope for cost-improvements, in reactor design as well as in fuel cycle. As you know the main european utilities, gathered in the European Fast Reactor Utility Group, are considering a study leading up to a precompetitive breeder. In France, we fully support that initiative.

fig. 20

It is extremely important that reliable datas about the economics of those two designs should be available to us between the years 2000 and 2010, in order to decide what will be the next generation of reactors. Personally, I think that breeders stand a very good chance of being fully competitive then, if the nuclear industry makes the necessary effort. We already possess strong evidence according to which design modifications can significantly reduce the investment gap between the breeder and the PWR and there is still scope available for further improvements.

In France, we have been very happy to see that this trust in the future of the breeder is shared in this country and we feel particularly honored that, when looking for exceptionnal achievements in the field of energy research, the jury of the Japan Prize has thought fit to pick the name of Dr. Vendryes.

III. CONCLUDING REMARKS

To conclude this presentation, I will try to summarize a few ideas about the future of nuclear energy:

1) Nuclear power is already highly competitive in electricity generation and there is still ample scope for further cost-improvements.

   The main obstacle to its development is an obvious reluctance from the public, which stems back to something rooted very deep in our unconscious: the fear of what is new and unfamiliar.

2) For that reason, a country takes the nuclear option only when it feels that it has no other choice: it has been the case of Japan, Belgium and France with the energy crisis of the 70's.

   In other countries, where alternative sources of energy are available, the penetration of nuclear electricity will be much slower, as long as some new drastic change on the energy scene does not convince their public opinions that the time has come to make the jump to nuclear.

3) Such an event could be triggered by the widening gap between supply and demand of electricity in several industrial countries.

   Electricity not being storable, a shortage of that commodity would be even more disruptive than a shortage of oil.

4) Anyhow, great care must be taken in the way nuclear energy is treated in terms of communication, in order to present honestly to the public opinion the different energy options and their consequences on dependance, environment, supply and costs.

Tokyo, le 13 avril 1988.

THE PROSPECTS OF NUCLEAR POWER DEVELOPMENT IN CHINA

Chen Zhaobo
Vice-Minister
Ministry of Nuclear Industry
People's Republic of China

Mr. Chairman, Ladies and Gentlemen,

I am greatly honoured to be invited to attend the 21st JAIF annual conference, and to address here. I would like to express my hearty thanks to my Japanese hosts.

I wish to take this opportunity to introduce energy situation and the prospects of nuclear power development in China.

I. ENERGY SITUATION INDICATING THE IMPORTANCE OF NUCLEAR POWER DEVELOPMENT IN CHINA

1. GENERAL REVIEW

China suffers energy shortage despite of a 36 times increase of primary energy production from 24 million TCE (tons of coal equivalent) of 1949 to 900 million TCE of 1987 and a 115 times increase of electricity generation from 4.3 TWh of 1949 to 496 TWh of 1987 (Tab. 1).

Statistical data in the mid of 1980s shows that China's total conventional energy resources amount to 700 billion TCE out of which, coal accounts for 85.6%, hydropower 11.8%, petroleum 2.5%, and natural gas 0.1% (Fig. 1).

China is characterized with a geographically uneven distribution of energy resources. Whereas 80% of coal are deposited in the interior of northern China, most of the hydropower potentials are scattered in the deep valleys of south-western China (Fig. 2). As a result, China's better-developed areas along the coast including some major industrialized provinces and cities which contribute 80% of the gross national industrial products are blessed with only 12% of China's total coal resources.

At present, China still depends on coal for its primary energy source. For example, in the year of 1987, coal accounts for 72.4%, oil 21.2%, hydropower 4.4% and natural gas 2% (Fig. 3), although since 1949, the big changes of the structure of primary energy production have been recorded (Fig. 4).

Electricity generation in China, however, consumes about 23% of the present primary energy, and coal makes up 60%, hydropower 23%, oil 15% and natural gas 2% (Fig. 5).

For a long time, China has been subject to insufficiency of electricity generating capacity. Presently, a shortage of 15 ~ 16 gigawatts capacity of 70 ~ 80 TWh electricity per year is plaguing China. Consequently, about 20% of industrial production capacity is not yet fully utilized. This is one of the constraints on the development of China's economy.

2. THE IMPORTANCE OF NUCLEAR POWER DEVELOPMENT

Since the policy reform and opening to the outside world was adopted, national economy in China has scored a rapid development. It is estimated by Chinese energy experts that with such a development, the total energy demand in China would increase to 1.6 billion TCE by the year of 2000 and 4.7 billion TCE by the year of 2030 (Tab. 2).

According to the estimates of many influential researchers, coal-fired plants can only afford half of the needed electricity whereas hydro powered stations can offer 20%, leaving 30% open to problem towards the year of 2030.

It would be insufficient to rely solely on conventional energy source in meeting the intermediate and long-term demand of economy development in China, whereas:

- The conventional energy resources per capita in China is lower than that of the world's average.
- The serious problem of coal transportation will become more serious as some 400 million tons of coal is estimated to be transported around by the year of 2000.
- If it is to build coal-fired plants somewhere about the coal provinces, the difficulty in long distance power transmission is hard to be well solved.
- Furthermore, coal-fired plants cause plaguing environmental problems and destruction of vast areas of farming lands.

A conclusion drawn from the above is that nuclear power plants are needed as a supplement in near term and as one of supporting energy sources in intermediate to long term consideration.

Therefore the Government of China pursues the policy of developing nuclear power. The known nuclear accidents have not hampered this established policy.

II. THE PERSPECTIVE NUCLEAR POWER PROGRAMME IN CHINA

1. THE REACTORS

No other than the common consideration of reactors development:

The first step: thermal reactors;

The second: fast breeders;

The third: fusion reactors, including hybrid reactors;

The last two steps are still under investigation.

As to the thermal reactors, PWR is now under construction with advanced PWR being investigated. At the same time, we keep research work on high temperature gas cooled reactors and carry on technical cooperation with foreign partners; carry out the research and design work on low temperature heat reactors towards building it in northern China.

2. THE CAPACITY

It is expected that some 5,000 ~ 7,000 MWe would be put into operation and about 5,000

MWe would be under construction towards the year of 2000, installed capacity would increase to 30,000 MWe by the year of 2015 (Tab. 3), share of nuclear pwoer could be increased to some similar degree as that of coal-fired plants towards 2030s. Now Qinshan 300 MWe Nuclear Power Plant is at the construction peak, wherein the containment has been closed and the erection started in the nuclear island. The civil construction in Daya Bay Nuclear Power Plant is now in full swing. The second phase of Qinshan 2 × 600 MWe project has been listed on the state plan and the negotiation with foreign firms is underway, with the successful realization of this programme, China's long-term electrical power gneration strucure would be changed with increasing of nuclear power portion (Fig. 6).

3. NUCLEAR FUEL CYCLE

1) Uranium Prospecting

Over the past 33 years of exploration, various types of uranium deposits have been discovered. The proven uranium reserves and potential resources could meet the demand for nuclear power development.

2) Uranium Mining and Milling

A number of uranium mines and mills are in operation. When needed, new mines will be developed, including heap leaching and in-situ leaching.

3) Uranium Conversion

The existing capacity can satisfy the demand of nuclear power development.

4) Uranium Enrichment

With upgrading of technology being carried out continuously, gas diffusion plants have been in operation for many years. Research is presently concentrated on centrifugal and laser techniques.

5) Fuel Element Fabrication

The 15 × 15 fuel assembly line has been put into stream. The fuel assembly is for Qinshan 300 MWe Nuclear Power Plant. It is expected to enlarge the capacity through cooperation with foreign firms in fabricating 17 × 17 or 18 × 18 fuel assemblies for 600 MWe and 900 MWe plants.

6) Spent Fuel Reprocessing

A pilot plant for power reactor spent fuel reprocessing is planned to be constructed in the near-term, and then a commercial reprocessing plant will follow.

7) Radwaste Management and Disposal

The bitiumen and cement solidification techniques for low and medium level radwastes have been grasped. Hydro cracking technology test for medium level radwaste has also been completed. Research work is currently carried out on vitrification for high level radwaste, vitrified block disposal, decommissioning and safety evaluation.

4. NUCLEAR SAFETY

The principle of "Safety First and Quality First" has been firmly implemented in all aspects of nuclear power development since its very begining under the strict supervision of the National Nuclear Safety Administration. Taking IAEA/NUSS for reference, a series of urgently needed regulations have been formulated and put into effect. The government and the public, as well as nuclear community itself, attach great importance to ensuring nuclear safety.

5. THE ORIENTATION OF R AND D

Research and development of nuclear science and technology is orientated to facilitate the building of nuclear power plants, to reduce the cost of nuclear fuel production, as well as to ensure the safety of nuclear industry as a whole. At present, 12 research and design institutes of MNI in 7 cities are carrying on these works (Fig. 7).

III. INTERNATIONAL COOPERATION

In accordance with the national policy of opening to the outside world, China has already established peaceful nuclear cooperative relations with many countries. For example, in recent years, we have signed bilateral agreements or protocols on peaceful use of nuclear energy with 13 governments and non-governmental organizations of Italy, France, FRG, Japan, United Kingdom, U.S.A., etc., and we have established close relations with foreign companies. All this has promoted China's nuclear energy development and fostered international relationship.

We hope to further develop the international cooperation and are ready to explore with a sincere attitude, any possibility of foreign participation in China's nuclear power programme, such as joint venture, foreign loans, "BOT (Building-Operate-Transfer)," and many others that might be suggested by industrial and commercial circles around the world.

IV. CONCLUSION

As stated above, China's economic development is handicapped by the shortage of power supply, and in meeting the intermediate and long-term demand of economy development in China, it is hard to solely rely on conventional energy source. We are confident that nuclear power in China will have a bright future.

China and Japan are friendly neighbors. We appreciate the great achievements of our Japanese counterparts. We command the good relations both in scientific-technical exchange and trade in the area of nuclear energy. We believe that, through mutual efforts, China and Japan will further intensify the cooperation in this field.

Mr. Chairman, Ladies and Gentlemen,

Let me once again express my thanks for inviting me to address the meeting.

I wish the conference a great success.

Thank you.

Table 1. The growth of primary energy production and electric power generation

	1949	1987	Multiplication of the growth	Average of annual growth rate
Production of primary energy (million tons of coal equivalent)	24	900	36	10%
Power generation (TWh)	4.3	496	115	13.4%

Table 2. The prediction of long-term needs of energy in China

	2000	2010	2020	2030
Gross needs of energy (billion tons of coal equivalent)	1.65	2.48	3.53	4.70

Table 3. The tentative program of nuclear power

	1990	1994	2000	2015
Programmed nuclear power (MWe)	300	2,100	5,000 ~ 7,000	~ 30,000

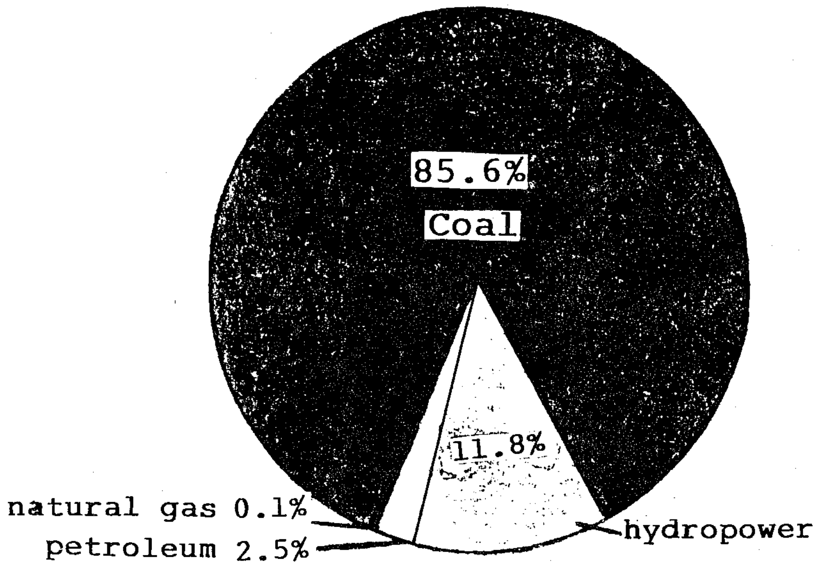


Fig. 1 The structure for the proven conventional energy resources (1987)

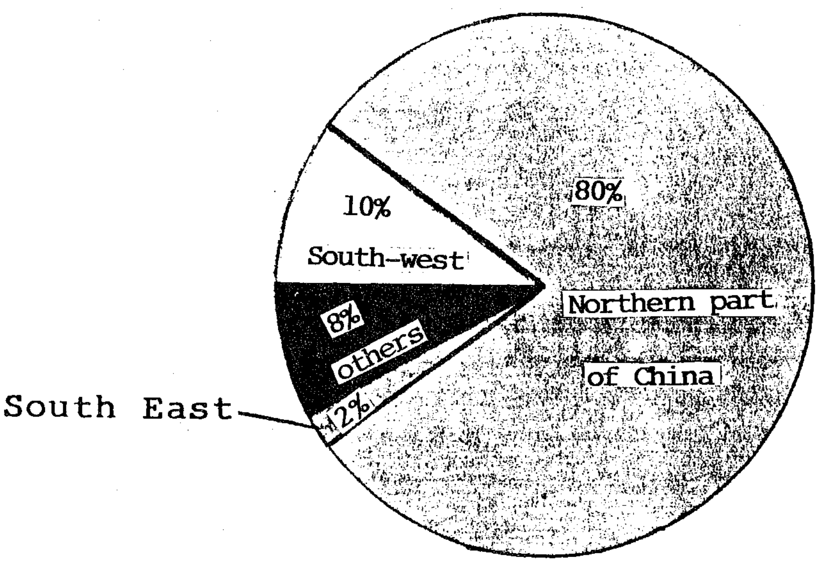


Fig. 2 Geographical distribution of the proven coal resources

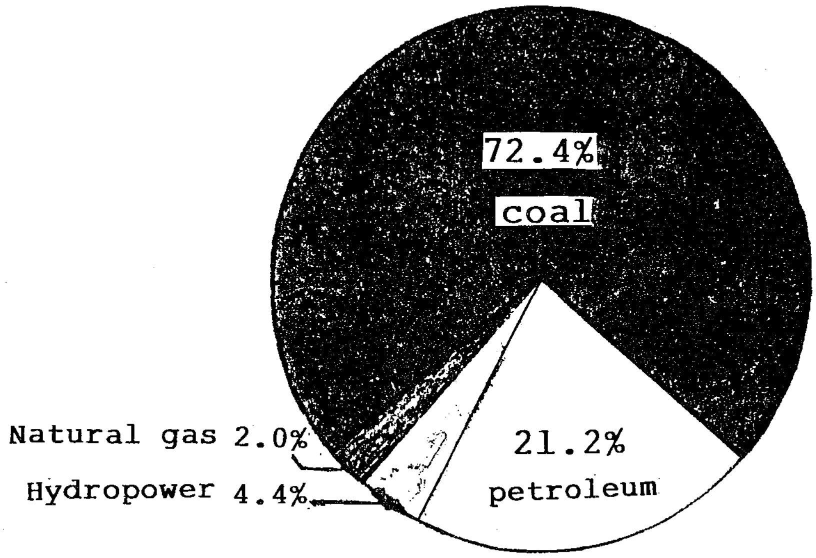


Fig. 3 Primary energy production structure in 1987

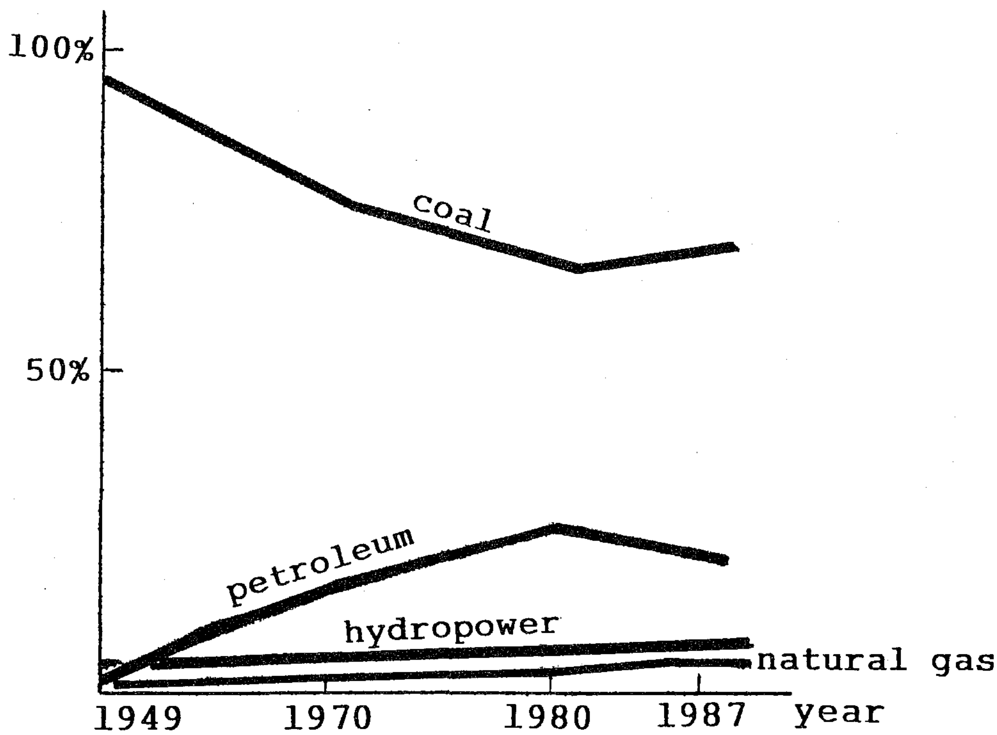


Fig. 4 Changes for the structure of primary energy production over the years

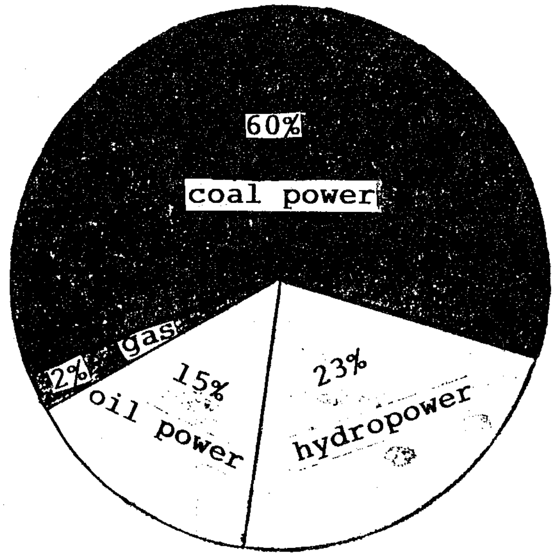


Fig. 5 The structure for electric power generation

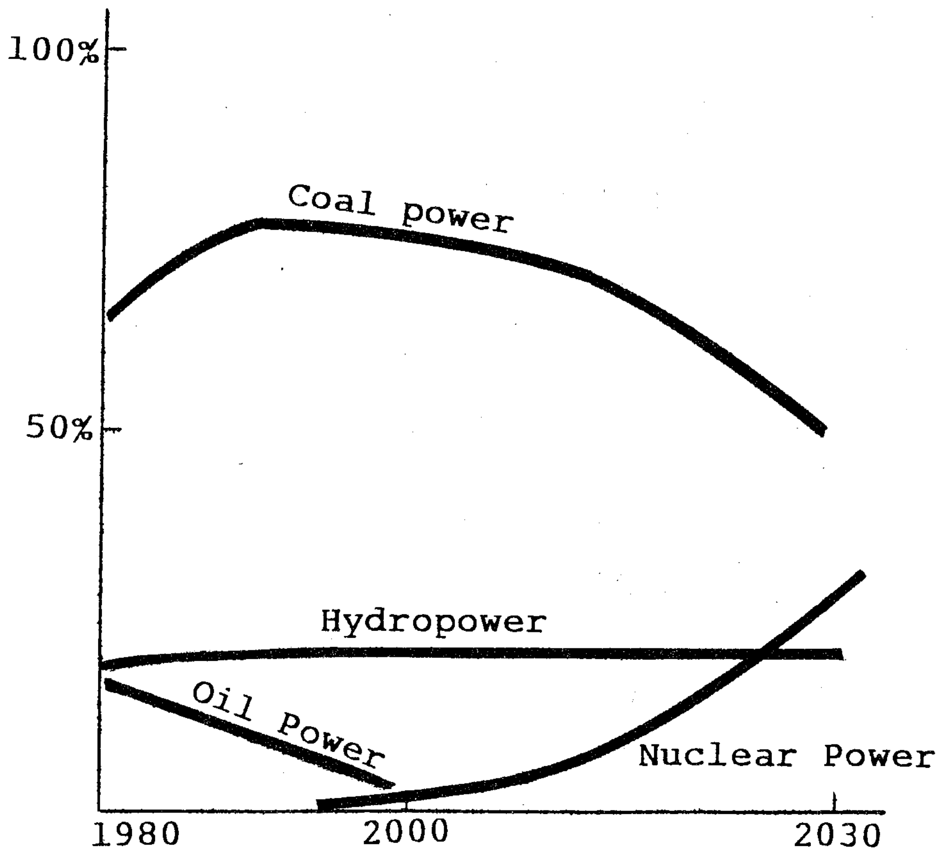


Fig. 6 The trend for long-term electric power structure

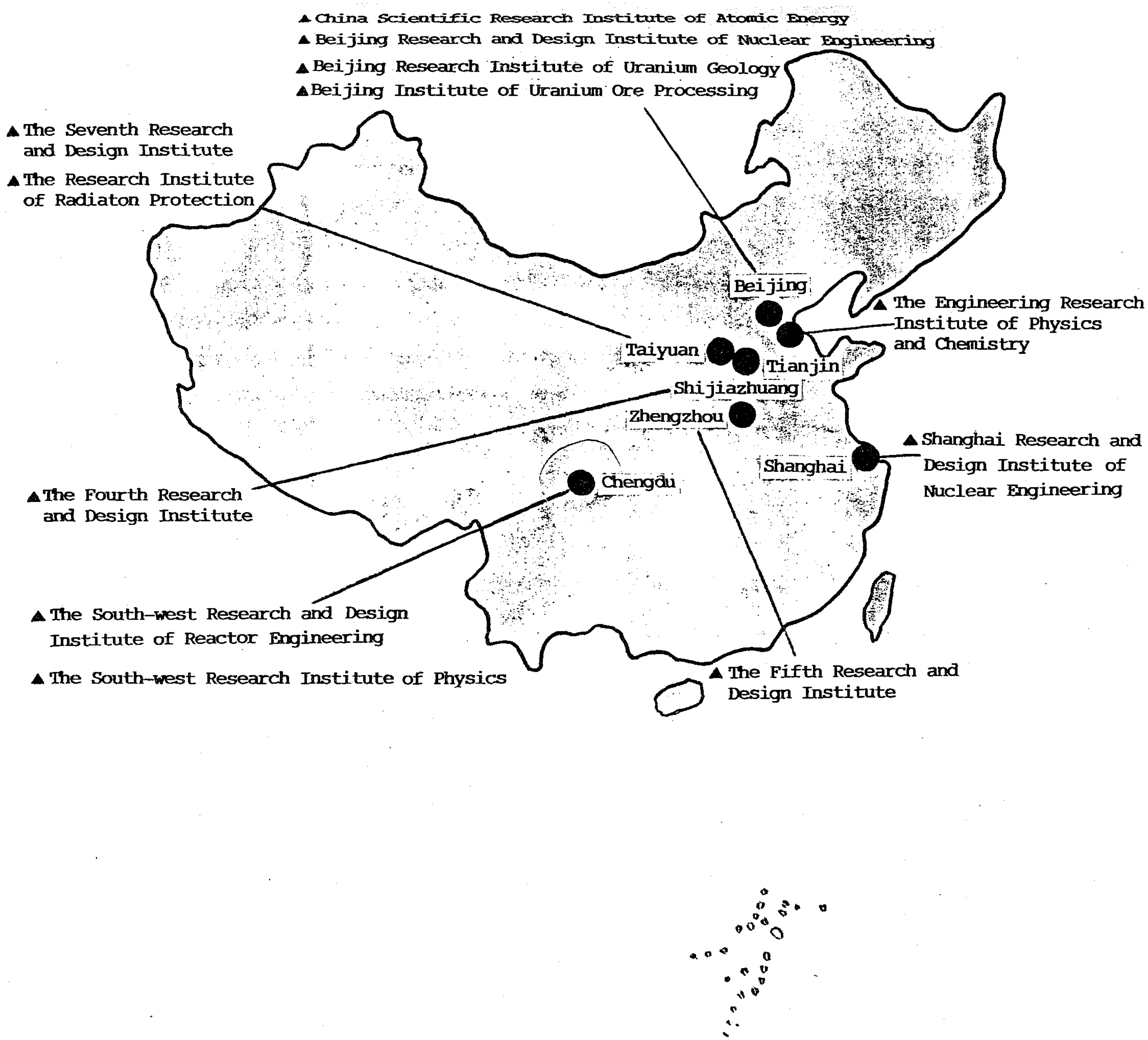


Fig. 7 The distribution map for the main institutes engaging in nuclear energy technical research and design in the Ministry of Nuclear Industry

日本のエネルギー政策と原子力開発のあり方

東京大学　名誉教授
大　島　恵　一

本日ここに、原産年次大会において「日本のエネルギー政策と原子力開発のあり方」と題してお話しをする機会を得ましたことは、まことに光栄に存ずる次第であります。この問題に関しましては、一昨年の通産省「原子力ビジョン」、「２１世紀エネルギー・ビジョン」と昨年の原子力委員会による「原子力開発利用長期計画」の日本政府関係のエネルギーおよび原子力に関する３つの重要な報告書が発表されましたが、たまたま私もこれらのとりまとめに参画いたしましたので、その時の内容を基礎に致しまして私の考えを申し上げたいと思います。

まず、基本的には日本のエネルギー政策が大きな転換期にあるということを指摘する必要があります。本セッションの題目である「エネルギー複合時代と原子力政策」の「エネルギー複合時代」とはまさにこのようなエネルギー政策の大きな転換を促すようなわが国内外のエネルギー情勢の基本的変化の時代が到来していることを意味していると考えます。

国内にエネルギー資源をもたない日本にとって、エネルギー政策は、常に国の産業政策、社会開発政策の中心課題でありました。薪炭；水力、石炭；石油、さらに原子力へとわが国の主要エネルギー源は転換していったのですが、この変化は、それぞれ日本の産業社会の新しい発展の時代と対応するものでありました。

現在、世界的なエネルギー情勢の変化の下において、２１世紀へむけて「エネルギー複合時代」という新しいエネルギーの時代を迎えるということは単にエネルギー問題においての日本の転換を意味するものではなく、大きな産業社会情勢の２１世紀にむけての新しい展開に対応するものといえます。

私はこの日本の産業社会の大きな転換を世界的な技術革新の新しい波によって支えられた新産業革命の一環として見ていのでありますが、これと対応してエネルギーにおいても資源集約から技術集約化時代に移行しているといえます。日本のエネルギー政策もこの様な変化を軸として転換しつつあるわけでありますが、原子力は最も技術集約性の高いエネルギーとして将来の中核的なエネルギー産業

の役割を果たすべきものであると考えます。

今日の日本のエネルギー政策において原子力は重要なエネルギーとしての位置づけを与えられたわけでありますが、このような視点から今後の原子力開発のあり方について述べてみたいと思います。

１． 世界のエネルギー情勢の変化

まず世界のエネルギー情勢をみますと、今日需給において基本的は変革の時を迎えています。１９７３年および１９７９年の２度におわたる石油危機はそれまでのエネルギー需要構造に根本的な変化をもたらしました。１９７３年石油危機によって４倍と高騰した石油価格は、さらに１９７９年の第２次石油危機において遂にバーレル３０ドルと２０倍の高騰を見たわけですが、その結果、世界的なエネルギー需要の低迷、それまでのＧＮＰとエネルギー消費との相関のかい離、さらに石油代替エネルギーの開発によるエネルギー供給の多様化などがおこりました。また、代替エネルギー供給の中心である電力の伸びが各国で相対的に高くなり、電力化が進んでいます。

特に先進工業国を中心として起こっているエネルギー消費とＧＮＰの伸びとの相関のかい離は、新エネルギー技術と省エネルギー技術の開発に支えられたエネルギー需給の変化と同時に、他方、エネルギー多消費からエネルギー非消費産業への大幅な産業構造の変化を伴ったものであります。すなわち第１次産業革命以来、豊富・低廉なエネルギー供給をもって、産業社会発展の基礎と考えられていたエネルギー需要と国民総生産との関係が、２度の石油価格の高騰によって根本的な変革を受け、エネルギー消費と産業社会の発展との関係に構造的変化をもたらしたということができます。

この変化の最も重要な意義は、エネルギー資源の有無によって強く支配されると考えられていた経済社会の発展が技術開発によってその様相を一変したという点であります。また、さらに重要な点は、これが単なるエネルギー技術における技術革新の現われではなくて、より大規模な産業社会の変革をもたらしつつある大きな技術革新の高まりの新たな波によるものでるといえることであります。

２． 新産業革命と技術革新

石油危機による世界経済の停滞と混迷が起こっていた１９７０年代中期から１９８０年代において、エレクトロニクスを中心とする新素材、バイオテクノロジー、メカトロニクスなどの技術革新は、いわゆる情報化革命をもたらしました。その結果としての産業構造の変化は世界的なエネルギー多消費の重化学工業から省エネルギー型の情報産業への転換となったのであります。

石油精製、大型火力発電所、製鉄所を中心とする大規模臨海工業地帯への集中産業立地から、より分散的は清浄な環境と水を持つ飛行場に近い地方立地へと変化していったのでありますが、このことは、ある意味で産業の物質離れ、知識集約化への転換であったわけです。また、メカトロニクスの導入による部品生産の技術の高度化は、部品産業を組み立て産業の下請け的性格からより独立した産業へと変化させました。そのことは必然的に単に国内での分散立地からより世界的規模での産業の国際化をもたらしたのであります。この情報化は、さらに「人」、「モノ」、「情報」の急速な国際化をもたらしました。。

すなわち、情報化技術における技術革新は、新産業革命というにふさわしい世界的な規模での産業構造の変化をもたらしたのですが、特にこのことは物質的な天然資源のない無資源国である工業国の日本に極めて有利な条件を作り出したといえます。すなわち、産業の技術集約化は、日本の国際的な比較優位を強化し、急速な先端技術分野における輸出の伸びと大幅は国際貿易の黒字をもたらすことになったわけです。その結果、国際的は貿易摩擦として、今日多くの問題を生じていることは御承知の通りでありますが、エネルギー政策においても大きな転換の必要をもたらしたのであります。特に１９８６以降の原油の供給過剰による価格の下落と円高による相乗効果は、エネルギー政策の根本的見直しを急務としたわけであります。

３． 日本のエネルギー政策の転換

エネルギーの国内資源をもたない日本にとって、水力、石炭の国産エネルギー資源依存の時代を経て、戦後の世界的に豊富・低廉な中東石油の供給は極めて有利なエネルギー情勢を作り出したわけであります。臨海工業地帯における輸入石油に依存する重化学工業立地を中心とした日本の産業発展は、戦後の荒廃の中か

ら今日の日本の経済的繁栄をもたらした最も基本的は要因でありました。

したがって、１９７３年の石油危機は、日本にとって致命的な重大な打撃を与えるものとみなされ、これに対応するために、エネルギーの安定供給、石油代替エネルギー・新エネルギーの開発、省エネルギー技術の推進、さらに産業構造の省エネルギー化といった政策は、今日まで日本のエネルギー政策の基本として推進されてきたのであります。すなわち、「セキュリテイー」と「コスト」が、日本のエネルギー政策の中心的基準でありました。

エネルギー需給構造の変化と１９８６年における急速な石油価格の下落は、日本のエネルギー政策の根本的な見直しを必要としたわけでありますが、もちろん、世界的な供給過剰と石油価格の下落に対応して、今後いかなるエネルギー政策をとるかということが２１世紀へ向けての重要な課題であります。しかし同時に、世界のエネルギー情勢と産業構造の変化の中にある日本にとってのエネルギー政策は、単なる石油代替、資源問題としてのエネルギー政策からさらに一歩ぽ進んで技術政策、社会政策さらに国際政策にわたる基本的かつ広範なエネルギー政策の構築を必要としたのであります。

すなわち、単に豊富・低廉なエネルギーの供給を求める量的な問題ではなく、より質的な、エネルギーの高品質、利便性、安全性、クリーン性など、新たしいエネルギー需要構造にみあうエネルギー供給が求められてきたのであります。また、エネルギー危機以後、十数年の変化は、エネルギー需給構造におけるより柔軟、強靱な構造の必要性を明らかにしました。すなわち、エネルギーの供給面においては、エネルギー供給源の分散化、多様化が極めて有効に働くことが明らかになりました。

特に重要なことは、技術協力によって新しいエネルギーの創出が可能となったことがあります。すなわち、エネルギーの資源集約性から技術集約性への変化であります。そしてこの点で最も典型的なのが原子力といえます。しかし、石炭復活にも大きな技術革新がみられますし、太陽・地熱エネルギー、その他の新エネルギーの重要性の増加も技術によるものであります。技術開発によって裏付けられた経済性により、各種エネルギーが市場メカニズムによって競合する形で多様なエネルギー供給が可能となりつつあるといえます。

さらに需要面での電力化の傾向が指摘できますが、今後のエネルギー需要も質

的要求の高まりにしたがって、単にカロリーベースでの経済性ではなく、より質的な要求を考慮したコストが適用されるようになってきております。そのために今後のエネルギー政策では重要な第３の柱として「ニーズ適合性」があげられております。すなわち、質的な要求、需要面の多様化、さらには環境快適性に対する要求、地球レベルの環境保全などエネルギーに対する要求はますます多様化していきているわけで、これらの「ニーズ」に適合するエネルギー供給がエネルギー政策の柱となるのであります。このような状況の下にわが国のエネルギー政策の見直しが行われ、将来のエネルギー政策は複合エネルギー時代、すなわち「セキュルティー」「コスト」「ニーズ適合性」の３点から最も最適なエネルギー供給、さらには形態をとるべきであるというのが日本のエネルギー政策の基本的な考えであります。

これに加えて重要な点は、わが国のエネルギー政策における国際的責務の増大であります。世界の一割経済国家としてのエネルギー消費においても世界の最大消費国のひとつであるわが国は、エネルギー問題を単なる国内の社会・産業問題としてではなく、国際的な視野においての責務を果たすことを重要視する必要が出てきたのであります。

特に発展途上国を中心とする将来のエネルギー需要の増大を考慮すれば、世界的な視野でのエネルギー供給の確保のため、その力を注ぐべきであります。特にエネルギーが技術集約化する点で日本の役割は重要であると考えます。また、環太平洋地域の将来のエネルギー需要の増大が見込まれる時に、この地域のエネルギー資源に強く依存しているわが国の立場を考えるならば、環太平洋地域における国際協力も今後のひとつの重要課題といえます。

このように、多様化、技術集約化、国際化へと転換しつつある日本のエネルギー政策の中にあって原子力開発はその最も重要な政策の核をなすものであります。

４． 日本の原子力政策のあり方

原子力のあゆみは原子力平和利用の発足以来３０有余年を経て、今や軽水炉を中心とする原子力発電の経済的・技術的定着の時代を迎えています。経済的には、原子力のコストは発電源としてすでに石油・石炭火力を下回り、技術的安定性は、最近の急速な稼動率の上昇によっても明らかであります。事実、石油危機以降、

原子力は、石炭、天然ガスとともに石油代替の主要な役割を果たしたのであります。現在、原子力は世界の発電の約１６％、国によっては最高７０％、わが国においては約３０％を供給しております。このような情勢において、過去の技術開発の時代から原子力の新しい時代が到来したともいえます。その特徴として、

(1) 多くの先進国において原子力が主力電源としていわゆる電力の「原主油従」の時代を迎えつつあること、

(2) 経済性の定着とともに、各国の政治的、社会的環境によりそれぞれの国における原子力政策の多様化が起こりつつあること、

(3) 原子力の安全問題、核不拡散問題、また発展途上国における原子力開発等、原子力に関する国際的な新たな協力関係が求められつつあること、

を挙げることができる。

最近のソ連チェルノブイル事故を契機としてＩＡＥＡを中心とする国際的な原子力安全性に対する協力が急進展しているのも新たな国際的は協力関係のひとつの動機であります。

日本のエネルギー政策においては、原子力産業は、「長期計画」では基軸エネルギーとして位置づけられており、「原子力ビジョン」においては研究開発段階から経済原則の働く「通常の産業」の段階に達したと定義されております。いずれにせよ、わが国においては、今日原子力は、いままで最大の燃料源であった石油に置き換わる主要電源としての位置づけが確立され「原主油従」の時代に入ったのであります。将来エネルギーの電力化傾向が進むことを考えるならば、原子力エネルギーの重要性は一層大きなものとなります。その意味で、エネルギー政策で定義づれられているように原子力はもはや政府の政策的な計画と支援の下に進められる産業ではなく、経済性および社会との調和を軸とした民間・産業界主導の下に進められるべき産業に成長したということができます。すなわち将来の原子力開発規模は、経済性と「ニーズ適合性」による他エネルギーとの比較による最適化を基本とする市場原理と社会的情勢によって決められるべきであります。これが複合時代における原子力開発といえると思います。

軽水炉を中心とする原子力発電の民間主導による展開は、炉型戦略、核燃料サイクル、さらに運転保守技術等広範な原子力発電の炉技術と原子力のインフラストラクチャーとを包含するものであります。特に２０００年に向けての原子力産

業における核燃料産業と原子力発電の保守、点検、サービス産業等の割合が原子力発電炉供給産業とほぼ同等な比重を占める形で、大きく成長することを考える時、総合的な原子力産業の開発が民間の努力によって進められることが大きく期待されるのであります。

この点に関し、日本の原子力開発のあり方について第1に指摘したいことは、原子力産業は本質的には技術集約産業であり、これを維持・発展させるためにはわが国の原子力産業技術の維持・向上と人材の確保が最も重要な課題であるということであります。原子力が今後の基軸エネルギーであり、主要電源と申し上げましたが、具体的に将来の原子力発電の規模を予測してみますと、原子力産業の将来は必ずしもバラ色であるとは言えません。「原子力ビジョン」において、将来の原子力発電の割合を２０００年約４０％、２０１０年約５０％、２０３０年約６０％としての今後の原子力の伸びを試算した結果は、ケースによって異なりますが、市場として年間原子炉２～３基の伸びと予測しております。この数字は立地問題、原子炉の長寿命化、他のエネルギーとの競合、さらには電力の伸びなどを考えますと、これでも楽観的であるとの意見もあります。

いずれにせよ、原子力市場における競争は、大変きびしいものになることが予測されます。これはわが国だけの問題ではなく、世界的に産業の再編成が問題となっているわけであります。このような状況にあって、原子力技術の維持・向上の確保を行うことは、不可欠であるとはいえ、困難なことであります。このためには、企業間の積極的な技術交流と産業再編成が必要であると考えられます。これは国内の企業間のみならす、国際的な規模で進められつべきでありましょう。この場合、電気事業の側においても原子力産業への競争条件の導入と技術水準の向上のための技術交流を促進するような方策をとることが重要であると考えますす。

第2に、原子力産業が高度に技術集約的であり、巨大システム産業として技術革新の先導的役割を果たすものであることを考える時、より広範かつ長期的意味での技術開発戦略を考える必要があるということであります。すなわち、原子力産業は、「通常の産業」と定義されるにしても、技術集約的産業として、技術革新の中心をなすとすれば、原子力開発の展開は単に民間の問題としてではなく、産・学・官の密接な協力の下に進められなければならないといえます。その時に

あたっての政府の役割は、必然的に過去とは異なるものでありますが、例えば、原子力エネルギーの新たな可能性を開拓する先導的・創造的プロジェクト、さらに基盤技術、基礎技術の開発において果たすべき役割は、極めて大きいものがあいます。さらに安全性の確保、核不拡散、平和利用の担保など、原子力開発のための条件整備のための政府の役割は、今後ますます重要となると考えられます。

今日、産・学・官の協力は単に原子力のみならずわが国の一般的な課題でありますが、特に原子力においては産・学・官の協力における先導的役割を努めるべきであると考えます、そのためには、日本原子力研究所、動燃事業団、大学などを含めて産・学・官の研究開発体制の再検討が必要であります。

第3に、わが国の原子力における国際協力への画期的な変化が求められることであります。わが国経済の国際化と国際的責務の増大は、原子力においても国際協力におけるより積極的な姿勢を要求いたします。

わが国は、原子力開発の後発国として、今日までの国際協力はどちらかといえば、受動的な立場をとってきました。しかし、エネルギーとしての原子力の位置づけを強固なものとするための積極的な展開を進めるとすれば、国際社会の原子力に対する支持が不可欠であります。国際的責務と同時に、この点に関しても、わが国の国際協力への積極的な姿勢が求められるわけであります。勿論、単にわが国の原子力のためのみではなく、世界の原子力の確立、人類に対するエネルギー問題の課題の解決として原子力の国際協力が進められるべきであります。その意味で、先進工業国間の協力と同時に発展途上国との協力が強く求められる所以であります。

現在エネルギー産業におこっている大きな変革は、過去の資源によって制約される資源集約的産業から技術力によって資源の限界を越える技術集約的産業への移行であります。原子力産業は、その意味において将来のエネルギー産業の中核をなすものであるといえます。このような視点から、今後のわが国の原子力開発が進められるべきであると信ずる次第であります。

NUCLEAR ENERGY INDUSTRY IN BULGARIA - PRESENT STATE AND ITS DEVELOPMENT

by Prof. Nikola Todoriev, Corresponding Member of the Bulgarian Academy of Sciences, Minister, President of the Energetika Association

The energy crisis in the beginning of the 1970's led to significant changes in the policy and strategy of development of the world's energy sector and energy resources utilization. Irrespective of the effect of the natural, public-political, economic and other objectives and present-state factors specific to each country, these changes characterize general conclusions, estimates and tendencies in solving energy problems in the next 15 to 20 years.

Such is for example the conclusion about the cheap energy era passed for good and about the exceptional importance of the problem of effective utilization of energy resources as a strategic task from scientific, technical and economic point of view. The tendency of absolute energy consumption growth, depletion of the easily available and cheap energy supplies in the various regions and the higher cost-effectiveness of the measures for fuel and energy conservation as compared to the introducing of new primary energy resources is an objective fact. There is a general tendency of growing prices of energy equipment and increasing the relative share of capital investments in the energy sector.

Most of the nations have developed and are currently implementing long-range programs for discovering new supplies of energy resources and better utilization of the indigenous resources of coal, oil, natural gas and hydro power in order to decrease their dependence on the imports of energy feedstocks. The priority development of the electric energy sector and the relative increase of electric energy in the national energy balances is continuing.

These general conclusions and tendencies, determining the energy development of almost all nations, are fully applicable to Bulgaria's energy sector as well. The conditions of this development are further complicated by the limited indigenous energy resources. Bulgaria is poor on primary energy sources. The deposits of fossil fuels per capita of population are eight times smaller than the world's average figure. Bulgaria has insignificant deposits of effective fuels, oil and natural gas, and their total yield meets less than 1% of primary energy resources demand in the country. The hydro power potential is also below the average figure for the world. The main supplies are lignites with high admixtures content and calorific value 5-6 MJ/kg.

In these specific conditions Bulgaria had to develop its own energy sector in order to guarantee the necessary rates of development of the national economy and to meet the requirements of present-day living standards. Considering the available fuels and the necessity of importing two thirds of the energy resources we adopted a strategy of energy development through accelerated electrification and a higher degree of electricity participation in the fuel and energy balance. On this basis, the use of nuclear energy is the most perspective trend of development of the nation's electric power system.

Bulgaria's electric power system is presently characterized by its multi-component structure, a combination of thermal, nuclear and hydro power plants meeting an annual demand of about 5400 kWh/capita. For a total installed capacity in the power plants slightly above 10000 MW the share of thermal, hydro and nuclear power plants is respectively about 60%, 18% and 22%. Electricity generation is concentrated mainly in power plants comparatively big for our country, namely the thermal power plants Varna - 1260 MW, Maritsa East 2 - 1040 MW, Dimo Dichev - 840 MW etc. The hydro plants, where water is also used for irrigation, water supply etc, form part of river developments such as Belmeken-Sestrimo - 735 MW, Dospat-Vacha - 321 MW, Arda - 284 MW etc. Barely 4 to 5% of electricity is generated by power plants burning liquid fuel or natural gas.

Bulgaria has a well developed transmission system with a power pool at 400 kV. It is interconnected to all neighboring countries. The national electric power system is part of the electric power system of the CMEA member-nations.

In order to guarantee the reliable operation of the power system which includes big nuclear power units of the VVER-

1000 type we introduce powerful pumped-storage power plants. First of them is the 864 MW Chaira pumped-storage power project with Japanese turbines to be commissioned in 1989. The 750 kV transmission line interconnecting the power systems of Bulgaria and the USSR serves as emergency backup in case any of the nuclear power units fails.

An agreement was signed in 1966 between the governments of Bulgaria and the Soviet Union for cooperation in the construction and commissioning of Bulgaria's first nuclear power plant.

Site selection, near the town of Kozloduy on the Danube river bank, was based on a detailed feasibility report for the nuclear power plant.

The power plant was designed jointly by specialists of Atomelektroproekt, Moscow and Energoproekt, Sofia.

Process water is taken directly from the Danube by two-stage pumping in two successive pimp station. Water is carried to power plant by open channels. Water for the systems providing plant's nuclear and radiation safety is withdrawn from sprinkling basins.

The first units of Kozloduy nuclear power plant were designed based on the initial concept for safety adopted by the Soviet Union. Seismicity at site was adopted with intensity 4-5 by the Medvedev-Schponheuer-Karnik (MSK) scale. The Vranca

(Romania) earthquake of 4 March 1977 with intensity 8-9 by the MSK scale was also felt on the territory of Bulgaria.

Following the earthquake Bulgarian and Soviet experts made a detailed check of the then operational first and second units. All results confirmed the reliable operation of the equipment and the civil structures. A decision was made to continue further operation of the power plant at a rated power.

Considering the more stringent requirements toward seismic stability of the power plant Bulgarian and Soviet specialists proposed jointly measures to increase its seismic stability (units 1 through 4). A system for automatic antiseismic protection was developed and implemented. The basic idea of safety is aimed at providing protection of population and environment against radioactive effects resulting from radioactive discharges.

The design of the power plant incorporates a series of new technical features proposed by the Bulgarian design engineers. Thus, the main building is founded on a loess-cement bedding; main support structure of units 1 through 4 was built by slipforming in which case roof girders and panels were made as early as the initial stage; foundation pit of bank's pumphouse was drained by making an underground concrete screen; a special pier was built in the area of the power plant for unloading the large-sized and heavy equipment coming from the Soviet Union; a special container barge was designed and built in the Soviet Union for transportation of spent fuel from Kozloduy power plant to the respective reception point in the USSR and this is the first time in the world spent fuel has been transported by river.

At unit No 5 a new technology of execution of civil works and assembly of equipment was introduced. This technology provides for the use of special construction machines including a truck crane with lifting capacity 400 tons thus making possible the erection of the reactor, the steam generators, the pressurizer and the reactor cupola by the open method.

Time schedule of Kozloduy nuclear power plant construction:

- construction start, 6 April 1970
- reactor No 1 critical, 30 June 1974
- full power of unit No 1, 24 October 1974
- reactor No 2 critical, 22 August 1975
- full power of unit No 2, 5 November 1975
- construction start 2nd stage, October 1973
- full power of unit No 3, 27 January 1981
- full power of unit No 4, 17 June 1982
- construction start 3rd stage, 7 June 1980
- reactor No 5 critical, 5 November 1987
- commercial operation reactor No 5, 29 November 1987

It took 55 months from begin of construction to commissioning of unit No 1.Full power of unit No 1 was attained in

90 days, the respective figures for units Nos 2, 3 and 4 being 39 days, 42 days and 30 days.

The initial time for construction of unit No 5 (7 years and 5 months) was extended for various reasons.

Unit No 5 at Kozloduy nuclear power plant is the first unit with VVER-1000 reactor installed outside the Soviet Union on the basis of a multilateral international cooperation of 1979. In accordance with this agreement Bulgaria will specialize in the manufacturing of equipment for biological protection, special pumps, valves, transportation equipment etc. Bulgaria's participation in the manufacturing of equipment for nuclear power plants will increase in future.

The main pieces of equipment for the unit were supplied by all CMEA member-nations and Yugoslavia. The majority of special valves , hydraulic shock absorbers, power circuit breakers etc were imported from other industrially developed nations.

The great variety of equipment suppliers was the cause for some peculiarities in the start-up and adjustment works.

Coordination of the program for adjustment works and trial testing of equipment were considerably complicated and delayed. We had also difficulties in coordinating the activities between representatives of the equipment suppliers and the adjustment crews.

Delays in the supply of part of the equipment were also a reason for extending the deadlines. Some items of equipment were manufactured for the first time and showed some defects.

Another factor which influenced the extension of the construction time of unit No 5 was the introducing of some changes in the design.

In 1987 Kozloduy nuclear power plant produced 12435 thousand million kWh of electricity, or almost 30% of total electric energy produced in Bulgaria.

Kozloduy nuclear power plant is one of the most reliable and stable sources of electric energy in Bulgaria. The average annual utilizability of its installed capacity exceeds 7000 hours.

The economic indicators of operation of this nuclear power plant depend to a large extent on the effective use of the nuclear fuel in the core. In practice, the mean time between recharging depends not only on the desire to attain maximum burnup.

The experience from the operation of Kozloduy nuclear power plant thus far shows that for a variety of reasons, eg changes of load factors because of the need of maintenance and equipment refurbishing, impossibility to recharge during the autumn-winter maximum of power system loading etc, it is difficult to observe the design regime of operation and reactors recharging. This raised the problem of optimizing the regime of operation and recharging of reactors at Kozloduy nuclear power plant in order to meet the autumn-winter maximum of electric energy demand and to achieve maximum effectiveness of power plant operation, ie maximum production of electric energy within a calendar year.

In parallel with this we work on the problem of the most effective use of nuclear fuel.Design burnup of nuclear fuel has been exceeded thus saving significant amount of fuel. The power peaking factor of assemblies and in core has been lowered from 1.35 to 1.19 thus improving the conditions for safe operation of the core.

Nuclear energy development in Bulgaria is closely connected with a concentration of generating capacities. In 1989 the installed capacity in Kozloduy will reach 3760 MW. Unit No 6, also with a VVER-1000 reactor, is currently in construction.

Although nuclear energy is among the capital intensive sectors of the national economy it is for us the most perspective way of electricity generation and we, therefore, plan to increase continuously its relative share in total electricity production. According to plans of the Bulgarian government 40% of total electricity production in 1990 shall be provided by nuclear sources , the respective figure for the year 2000 being 50-55%. In accordance with the program for construction of nuclear power plants and nuclear heating plants of the CMEA member-nations until the year 2000, the installed capacity in the nuclear power plants in Bulgaria shall be 8760 MW by the year 2000.

On 20 March 1981 the Bulgarian government made a decision on the site of the second nuclear power plant Bélène, also on the Danube river. The installed capacity of this plant will be 4000 MW, or four reactors of the VVER-1000 type. Seismicity at site of power plant is taken with intensity 8, or the maximum design earthquake by the MSK scale. Bélène nuclear power plant will be built in two stages, or two units per stage. Construction works at the first two units have already begun.

In order to meet the increasing demand of low-potential heat in Bulgaria construction of a nuclear district heaing plant is planned to begin after 1995.

Kozloduy nuclear power plant also supplies heat for district heating purposes of the town of Kozloduy. The possibilities to supply heat from Kozloduy to the town of Mizia and from the future Bélène nuclear power plant to the towns of Bélène, Svishtov and Pleven is currently being investigated.

The successes in nuclear energy development in Bulgaria are undisputed. However, in order to realize the trend of development of that strategic production the now existing problams shall be solved in stages. The approach to them is determined by their importance, significance (national and international) and complexity. They shall be solved with priority, on a national level, without strict adherence to the sectorial and institutional interests. The strict requirements toward equipment in nuclear power plants require an adequate system of education, training and retraining of staff. A new approach toward the system of quality management is necessary. We must seek new ways and search for a new arrangement of the nuclear power plants taking into account the concentration of installed capacity at one site. Robotization of operations in nuclear power plants is regarded as a basic prerequisite for lowering the collective dose rate of maintenance crew.

World operational experience based on 3800 reactor-years without a single fatal radiation accident made us to believe that such an accident is impossible to happen. However, the Chernobyl accident led to a radical change of the situation. The risk of reactor accident with heavy consequences (core meltdown, reactor unsealing and radioactive discharge in the environment), although small for a single reactor, may become significant in the case of several reactors.

The further broadening and improvement of international cooperation and development of the socialist economic integration of the CMEA member-nations in the field of nuclear energy envisages the development of a new generation of reactors with greater safety and better technical and economic characteristics. The new designs shall take into consideration the present requirements and all possible technical aspects of reactor safety improvement.

Measures to improve nuclear power plants safety are taken by individual nations, however the role of international cooperation which must guarantee everywhere equally high standards of safety is constantly growing. Guided by the idea to create a world without dangers the Soviet Union proposes the setting up of a regime for safe development of nuclear energy. Bulgaria which has no equvalent alternative in the field of energy resources except nuclear energy fully supports this proposal and accepts as mandatory all safety standards of the International Atomic Energy Agency.

/MM

NUCLEAR ELECTRICITY IN THE UNITED STATES: PROVIDING ENERGY FOR THE NATION'S SECURITY AND WELL-BEING

Prepared for

Twenty-first Annual Conference of the
Japan Atomic Industrial Forum
Tokyo, Japan

by

Harold B. Finger

President and Chief Executive Officer
U.S. Council for Energy Awareness

April 13, 1988

NUCLEAR ELECTRICITY IN THE UNITED STATES:
PROVIDING ENERGY FOR THE NATION'S SECURITY AND WELL-BEING

Today I would like to report on the impressive success story of nuclear energy--its important contributions to the United States energy supply system, to our energy security, to our economy, and to American electric power consumers.

Nuclear energy in the United States has made major contributions since the small Shippingport prototype power plant began operating in 1957. Nuclear plants have contributed to cutting our imported oil dependency just when we most needed domestic energy supplies; they have kept our trade deficit from being even higher than it already is; they have provided electricity cost savings for the American consumer, and the electricity they generate has helped to improve our country's energy efficiency.

Recent legislative and regulatory actions, as well as research and development, are indicating that additional nuclear capacity can be available in the years ahead. The Congress has reaffirmed the Federal authority over health and safety related to nuclear energy; the unique legislation providing prompt liability insurance protection to the public in the unlikely event of a nuclear accident is being strengthened and extended; progress is being made on restructuring our nuclear regulatory organization and procedures; and our nuclear waste policy program has been amended so that a more directed and committed effort can be pursued to develop our first deep geologic disposal waste site, as well as a system for monitored retrievable storage. All of these actions reflect the public's recognition of the importance of nuclear energy. Congressional action supporting the new Japanese-U.S. agreement on nuclear trade and cooperation also reflects the broad U.S. recognition of the importance of nuclear energy worldwide. In addition, recent regulatory actions are reaffirming the health and safety of our current nuclear plants, as well as of those being completed.

The performance of our current plants is being improved. In fact, the conscious dedication of the entire industry to excellence in performance is clear in its individual plant operation and in the industrywide structures it has established to drive for excellence in all its activities. And worldwide organizations, like the important new World Association of Nuclear Operators, the International Atomic Energy Agency, and others--like OECD's International Energy Agency and the Nuclear Energy Agency--should help us all maintain high performance levels. Every one of our nuclear plant operators is dependent on excellence in the operation of all plants worldwide.

There is increasing discussion in the United States of the importance of advanced reactor concepts development. Some work is proceeding on evolutionary improvements of our light water reactors, on advanced light water reactors, on gas cooled reactors, on liquid metal cooled reactors. This is certainly encouraging for the long-term outlook of nuclear energy. But there is no question that the next generation of nuclear plants is already being ordered outside of the United States--for example, here in Japan, in Korea, in the United Kingdom. Those plants all use light water reactors--they are next-step evolutions and developments from our current reactors. We are especially pleased that

U.S. companies are involved in all of these international activities.

But problems and obstacles still exist in the United States. They are being addressed to reconfirm our long-term commitment to nuclear energy, but they are not yet all solved.

In spite of the fact that no referendum vote that has tried to shut down any nuclear plant has ever succeeded, antinuclear groups--though small in size--continue to make attempts to do just that. In fact, we will face several new state referenda in elections later this year. In spite of the fact that added electrical capacity is most urgently needed in their areas, political pressures are still keeping the already completed Seabrook and Shoreham nuclear plants in the northeast part of our country from operating. And our unique process of individual state regulation of electric rates has disallowed a major part of the cost of many nuclear power plants--and also of coal plants--from being included in electric rates. This has discouraged utility investment in long lead-time, high-capital cost baseload plants, even though the ultimate cost of their electricity would be low compared to the various oil and natural gas alternatives. And we, in the industry, still have the job of getting several of our plants that have not operated well and are out of service back into reliable, sound operation.

In brief, as in the entire industrialized world, nuclear electric power grew to maturity in the United States exactly when it was needed, when we were working to replace imported oil with our own domestic energy resources after the Arab oil crisis of 1973 and the other energy shocks of the 1970s. Since then the United States has become a much more energy efficient society--partly because of the increase in energy prices, but also because of our continued trend to increased electrification--our steady conversion to electricity.

But now, we see signs of a new imported oil crisis on the horizon and uncertainty in the structures for supplying our growing electricity demand. Unlike the situation in the 1970s, our electric power industry now faces major roadblocks to any new large baseload capacity, including nuclear power plants. So the U.S. industry is working to clear away these obstacles that have developed over the past decade, to pave the way for an even greater nuclear contribution to our electricity supply in the years ahead.

I'm pleased to report that progress is being made on those solutions, and that the American public recognizes the importance of nuclear energy.

Those are the main areas I would like to discuss with you today. So let me start with an overview of the U.S. energy situation today. Because America's public and political energy consciousness was generated by the oil embargo of 1973, I will be showing the changes since that time.

The United States Has Become More Energy Efficient

The United States has made impressive strides in using energy more efficiently since the 1973 embargo. Our total use of energy has remained essentially the same--it has increased only 2.3 percent, even though our population has grown by 18 percent since then, and our GNP has climbed by 40 percent. So we have in effect been squeezing 35 percent more work out of every BTU that we use. The savings is particularly clear in the sector of our economy that uses the most imported oil--transportation, which consumes nearly two-thirds of our total petroleum use. In 1973 our automobiles traveled an average of 13 miles per gallon; that has risen to over 18 miles per gallon. This amount of savings in only 15 years is certainly significant.

Along with the natural incentive that has resulted from higher energy prices, one of the added reasons for our energy efficiency improvement has been our continuing electrification. By moving from the direct burning of fuels to electricity, Americans and our industries have found that their energy costs can often be reduced--and in many cases, so can the total consumption of energy.

For example, when industries install electric arc furnaces to replace the direct burning of fuels, they are often not simply substituting one BTU for another; they are actually reducing their total energy consumption--even counting the energy lost in the generation of electric power. Similarly computer control technologies--which add only slightly to to a company's demand for electric power--can finely adjust heating and lighting to save sizable amounts of energy.

The United States Is Becoming Even More Electrified

These improvements in energy efficiency through the use of electricity have been made possible by the continuing electrification of our society. This trend has been particularly important since the 1973 embargo. The only form of energy that has increased in use since then has been electricity. The consumption of electric power has increased by more than 43 percent, while our use of non-electric forms of energy has declined by 11 percent. Last year our use of electric power rose by 4.5 percent, as our manufacturing activities became reinvigorated. Electric power now accounts for more than half of the energy used in the country, outside of transportation.

One of the clearest trends in energy use in all industrialized countries is the steadily growing reliance on electric power. Year after year in the United States, electricity has increased as a percentage of our total energy use. The generation of electricity accounted for 1/6 of our total energy use in 1950; 1/5 in 1960; 1/4 in 1970; today it represents more than 1/3 of our energy use.

Electricity Use Grows As Our Economy Grows

The growing importance of electric power has also underlined another fundamental lesson about our energy use patterns. Alone, among all forms of energy, electricity use remains closely connected with our economic growth. While electricity use increased 43 percent in the past 15 years, our Gross National Product (GNP) has gone up similarly, by a total of 40 percent. And let me remind you that this was during a period when our use of other forms of energy was declining. So our economic growth has been powered by kilowatts.

It has remained true since our energy use patterns began to change in the 1970s, just as it was before then, that every increase in our GNP has been accompanied by an increase in our consumption of electricity. There is no reason to believe that connection will change; in fact, the amount of electric power required for GNP growth could well increase, especially depending on industrial sector activity. The outlook for electric power in the United States--and consequently for nuclear energy--is a steadily growing demand, if we are fortunate to have an economy that continues expanding.

Coal and Nuclear Energy Supply Almost All Our Increased Electric Demand

Almost all of the 43 percent growth in our electric use since 1973 has been met by coal and nuclear electric generating plants. Coal and nuclear energy now supply nearly 75 percent of our electricity. The United States has been fortunate to have these two abundant energy resources which have made our continued electrification during this important time possible.

The largest increase in our use of domestic fuels since 1973 has been with coal. It now provides about 57 percent of our total electric power. Its contribution increased by 72 percent since 1973.

The rapid increase in nuclear electricity was also extremely important. In 1973 it was a distant fifth among sources of electric power generation. In 1980 it overtook oil; in 1983 it overtook natural gas; and in 1984 it passed our massive hydropower resources, to become second only to coal. It now provides almost 18 percent of our electricity.

The steady growth in our use of electricity fueled by coal and nuclear energy has helped us with both parts of the energy challenge we have faced since the 1970s: first, an improvement in the efficiency of our energy use; and second, an emphasis on using more domestic energy sources as a substitute for imported oil.

Electricity From Coal and Nuclear Energy Replaces Imported Oil

Increased use of electricity fueled by coal and uranium has cut our use of imported oil. Though our national strategy has been to increase our reliance on domestic energy sources over imported oil, the domestic production of oil and natural gas has never increased above their 1973 levels. U.S. production of crude oil has never matched its 1973 level of 19.5 quads, even with the addition of Prudhoe Bay in Alaska. Last year it amounted to only 17.5 quads. Domestic natural gas production also has never again reached the 1973 level, when it was 22.2 quads. Last year, it was only 16.5.

The production of coal has increased significantly since 1973, and all of the additional output has gone into the generation of electricity. The direct burning of coal in coke plants, other industrial facilities and general commercial and residential uses has declined from the 1973 level. That year 173 million short tons were used for those non-electric purposes; in 1986, only 119 million.

The increased use of coal and nuclear energy for our electricity has directly replaced significant amounts of oil and natural gas in power generation. Even as our total use of electricity increased by 43 percent, we have been able to reduce the amount of power generated by oil by nearly two-thirds--from 314 billion kilowatthours in 1973 to only 118 billion last year. It now provides only about 5 percent of our electricity. Similarly we have reduced the burning of natural gas to generate power by one-fourth, down to only 11 percent of our total electric power supply.

Even more important, the electricity generated by our increased use of coal- and nuclear-generated electricity has replaced sizable amounts of oil in many end-use applications throughout our society. Until 1974, for example, 61 percent of all the new homes built in the country were heated with oil or gas; over the past decade, half the new single-family homes have come equipped with electric heating, as well as more than two-thirds of the multiple-family housing. Because of such changes, the use of electricity in our residential and commercial sectors has nearly doubled since 1973, while the use of petroleum has dropped by almost one-half. Today two-thirds of all the energy we use in our residential and commercial sectors is involved in the generation of electric power.

As our industrial sector has cut back its total use of energy by 15 percent and its use of oil by 10 percent, it has increased its use of electricity by 20 percent. Electricity--in terms of the energy used to generate it--now accounts for 35 percent of all the energy used in our industrial sector.

Coal and uranium, then, have provided essentially all the growth that has taken place in U.S. energy production since 1973 and have replaced a significant amount of oil and natural gas. To say it another way, since the embargo our total use of energy has risen only 2.3 percent; our domestic production of energy has risen only 3.5 percent; our use of electricity has increased 43 percent; but our use of electricity generated by coal and nuclear energy has grown by more than 100 percent--more than doubled.

The Important Role of Nuclear Energy In Our Society

Nuclear energy is the second largest source of electricity in the United States, behind coal. We now have 109 licensed nuclear plants in 33 states. Those nuclear plants have a capacity of over 116,000 megawatts, and they provided 455 billion kilowatt-hours in 1987. That was almost as much electric power as our entire national electric power system was generating when nuclear energy was introduced with the

Shippingport nuclear electric generating station about 30 years ago. Almost every American receives part of his electricity from nuclear power plants, through our interconnected transmission system.

The expansion of U.S. nuclear capacity since the 1973 oil embargo has displaced more than three and a half billion barrels of imported oil, which would have raised our trade deficits by more than $106 billion. All of this has resulted from a capital investment of only $130 billion, and the savings will continue for years to come, for the operating lives of our nuclear plants. In addition, nuclear energy has saved consumers more than $65 billion compared to what they would otherwise have paid for the alternative sources of electric generation that would have been available.

So nuclear energy provides a major part of our electricity; it has cut our use of imported oil; it has cut our trade deficit; it has cut America's electric bill. All of those are strong positives and there have been no counterbalancing negatives for our country and our electricity users to subtract from those benefits.

No Room for Complacency--The Continuing Drive for Excellence

In spite of these national benefits offered by our nuclear electric plants, the drive to assure excellence in all nuclear energy activities continues with even increasing industry emphasis. This special effort started in earnest as a result of the many lessons the United States learned from Three Mile Island. Engineering changes and regulatory changes, rearrangement and redesign of control rooms, changes in operator training and increased number of operating shifts all were the result.

But in addition and at least as important are the organizations the industry established after TMI. Most significant has been the establishment of the Institute for Nuclear Power Operations. INPO continues to examine the operation of all our nuclear plants and identifies any aspects that are not up to its high standards of excellence. Its evaluations are important to all utilities and all utilities work to achieve INPO's approval. And, of course, the Federal Nuclear Regulatory Commission provides strong oversight of all nuclear operations to assure a Federal involvement in and responsibility over health and safety aspects.

Ultimately, the industry's most important initiative will be its drive for excellence in the operation of our nuclear power plants. Over the past several years it became clear that not all U.S. nuclear plants were being operated at the level of excellence that must be our standard. Therefore, the industry recommitted itself to uniform excellence, and has taken a number of steps to bring that about. The Institute of Nuclear Power Operations has continued to strengthen its efforts to promote excellence and the highest margin of safety in nuclear power plants throughout the country. A new National Academy for Nuclear Training has been established to strengthen the training and accreditation of key workers throughout the nuclear industry. The Academy sets standards for training programs and accredits those utility programs as the standards are met.

The industrywide drive for excellence also led to the reorganization of the national nuclear associations last year. The Nuclear Management and Resources Council is centralizing the utility industry's operational and technical regulatory issues. The American Nuclear Energy

Council remains the industry's primary government affairs arm. And our organization, the U.S. Council for Energy Awareness, provides the industry's national communications and public information on energy issues with emphasis on electricity provided by nuclear energy. We examine technical issues on peaceful uses of nuclear energy and consider international nuclear activities.

Collectively these efforts are making a difference. An example of some of the changes made after Three Mile Island is the increase in the number of operating shifts so substantial time is made available for training and refresher programs along with operation shift requalification. In 1979, at the time of TMI there were only 10 training simulators available; today there are 66 training simulators configured identically with the control rooms of plants they simulate.

Progress can be measured in a number of ways, but probably the most telling may be the performance indicators of nuclear power operation as reported by INPO. For the past seven years many of the key indicators have continued to show a steady, marked improvement. Unplanned automatic scrams have dropped steadily from an average of 7.4 in 1980 to less than 3 in 1987. The lost-time accident rate, as reflected in the number of worker injuries involving days away from work for every 200,000 man-hours worked, has improved from a rate of 1.36 in 1980 to 0.34 in 1987. Radiation exposure among plant workers and the volume of low-level radioactive waste generated at nuclear plants have dropped substantially. For many of these categories, our performance has already exceeded the industrywide goals that were established for 1990. In addition, very importantly, the availability of plants has increased. That increase is the equivalent of bringing two additional plants on line. Further progress is still being made.

This growing level of excellence in operation combined with the benefits I indicated earlier and the remarkable public safety record that our industry has maintained should help us assure the availability of nuclear energy for the future.

Broad Public Acceptance of Nuclear Energy

The American public shows broad, realistic and increasingly mature acceptance of nuclear energy. Recent opinion polls have turned up a strong awareness of the importance of and need for more nuclear electricity in the years ahead. Almost 80 percent of the American public believe that nuclear energy will be important in meeting our electricity needs in the years ahead, with 53 percent saying it will be very important. And more than three-fourths of the people--76 percent--believe that the need for nuclear energy will increase in the years ahead, compared to only 17 percent who disagree--a margin of more than 4 to 1. About 70 percent believe that nuclear energy is a good or realistic choice for large-scale use.

Even though more people oppose building more nuclear plants than are in favor, we believe this reflects a lack of awareness that we need more electric capacity. Almost half the people asked say they would reserve judgement about building more plants until they had more information.

In effect, the American public is counting on the availability of nuclear energy when it is needed.

I am convinced that the recent actions of our Congress reflect these realistic public attitudes on nuclear energy.

They reflect the broad recognition of the importance of and need for more nuclear energy in all segments of our population. The favorable actions of our Congress continue a long string of support. Their recent actions include approval by the Senate of the Japan-United States agreement, the rejection of the proposal to return authority for determining suitability of emergency procedures for Seabrook and Shoreham to the individual states, the Senate's extension of our Price-Anderson nuclear liability legislation, the approval of an arrangement to examine the suitability of a single waste site in Nevada and its development if suitable, and the Senate's recent passage of legislation that will strengthen our uranium enrichment capability.

WITH ALL THIS GOOD NEWS, WHAT ARE THE PROBLEMS?

I've painted an upbeat--a positive--picture. It's a picture made up totally of hard facts. But it does not present the entire picture. Our U.S. energy outlook is not good. And little is being done to solve our onrushing energy problems and to eliminate their cause.

Electric Power Reliability Problems Loom Ahead

Ironically, even though we have seen how important electricity is to our long-term strategy of reducing our dependence on imported oil, the United States is rapidly approaching a time when it must have added capacity to meet our needs reliably.

Year after year, the demand for electricity is growing faster than new supplies are being added. Though many critics of electric utilities and of nuclear energy predicted that demand growth would fall to zero in the

1980s, it has in fact increased substantially since the end of our recession early in the decade. Just since 1982 our use of electricity has grown by nearly 10 percent. Last year alone it grew by over 4.5 percent, the greatest increase in a decade. Today it is almost 7 percent higher than a year ago.

By comparison, utilities have been adding new capacity at a slower rate--less than 3 percent a year. Based on the shrinking amount of new capacity under construction, additions over the next 10 years could support a growth rate of only 2.2 percent a year with any degree of reliability--less than half of what we have recently been experiencing.

A significant reason for this low capital investment by our utilities is the direct result of the discouragement caused by the Public Utility Commissions of our individual states. Those PUC's, which determine allowable electric rates have, in many cases, disallowed large portions of the construction cost of completed nuclear and, also, coal plants from being included in rates. So utilities and their stockholders have been penalized for past investments and frequently for national economic and other conditions over which they had no control. Having been burned once, they are reluctant to expose themselves now.

Another question mark about our electric power capability is the make-up of our national system. It is rapidly aging. Our average generating station is nearly 19 years old; by 1995, it will be 26 years. Aggressive life-extension programs for older plants are underway, but we will still see some erosion of efficiency, with a string of power plants that will have to move from operation, to stand-by, to retirement.

In addition, a sizable amount of our national capacity--28 percent--is still fueled by oil and natural gas. Unless we add to our coal and nuclear capability, future growth in demand will require utilities to use that oil and gas capacity more fully--not only for peaking service. This will result not only in a greater dependence on imported oil, but that greater dependence will also drive up the price of those fuels and, as a result, the cost of the electricity supply.

For the nation as a whole, electric power reliability problems may be only a few years away. But for some regions, they are more immediate. Our New England states are the leading example. Because of that region's remarkable economic recovery, the use of electricity in that region has been growing much faster than the rest of the country. The New England Power Pool had to invoke emergency procedures 24 times last year, including three voltage reductions. Analyses of the outlook for electric power have concluded that New England's capacity for generating electricity may not be adequate to meet its demand by the early 1990s--which, of course, is only a couple of years away. Yet, as is the case nationally, utilities are not beginning any new baseload power plants--and two completed nuclear units in the Northeast, Shoreham and Seabrook, are sitting idle, because of political opposition. New England may be a harbinger of the future of the entire country: the next energy crises may be an <u>electric</u> crises.

Use of Oil Imports is Increasing and So Are the U.S. Energy Trade Deficits

The most serious question about our electric power situation is the country's current drift back to reliance on imported oil. The sudden OPEC price cuts in early 1986 made

Americans even more complacent about energy than they were. We have been happy to return to relatively inexpensive imports. So our use of foreign oil has been rising rapidly; it is now up to 40 percent of our total oil consumption and growing. Our bill for imported oil last year was $42 billion a year and climbing. It now amounts to 25 percent of our record trade deficit. With current trends, many experts are predicting that we will be importing half our oil as early as 1990, and perhaps as much as two-thirds by the middle of the next decade. This could lead to an imported oil bill as high as $150 billion--almost as high as our entire merchandise trade deficit today.

That level of dependence on imports would represent a serious threat to our economy, and even to our national security. The United States already has ships and sailors in the Persian Gulf, guarding tankers that are bringing oil out of the Middle East; the national security threat has become tangible. A solution to the next imported oil crisis may not be available--if we do not have the momentum of a growing electric power program like the one that proved so crucial in the 1970s.

<u>Momentum for New Non-Oil Fired Capacity Does Not Now Exist</u>

With all the disincentives utilities face in considering any long lead time capacity additions requiring high investment, the outlook is for short-term decisions that will make the United States increasingly subject to foreign oil dependence. No program for significant capacity addition exists today in spite of continuing electric demand growth. Utilities will fulfill their duty to serve--to assure needed electricity supply--by operating existing oil-fired capacity for longer periods (mid-range and baseload service); by buying power from neighboring utilities who may have adequate supply; by buying power from neighboring nations (like Canada); by buying new, short lead-time and low capital-cost combustion turbines; by inviting competitive proposals from power plants that are built and operated by independent power producers. All of these approaches, with the exception of Canadian imports, imply increased dependence on foreign oil, at least in the short term.

Nuclear energy was able to make the important contributions after the 1973 Arab oil embargo that I've described only because there was a strong momentum behind its expansion when the embargo struck. It was encouraged by strong bipartisan government commitment and by the need for electric capacity to meet our rapidly growing economy.

In 1973--before the "energy crisis", only 30 nuclear plants were operating with a total capacity of 16,000 megawatts. They provided only 4.5 percent of the country's electricity. But utilities were involved in a major construction program to meet the electric power demand needed to fuel our booming economic growth, which national economists were forecasting would continue well into the future. Fifty-six nuclear plants were under construction, with a total capacity of 53,000 megawatts. Orders for new nuclear power plants had been building steadily since the end of the 1960s: 7 in 1969, 14 in 1970, 21 in 1971, 38 in 1972 and 41 in 1973.

That momentum before the embargo made it possible for nuclear energy to increase its contribution so greatly afterward: 12 new units came into operation in 1973, 14 in 1974, and a total of 87 through today. The growth in the contribution from nuclear energy could have been even greater, but the slowdown in the economy and the resulting slowdown in electric power demand growth led utilities to cancel many generating plants that they were planning, both coal and nuclear.

I am personally convinced that the time is not far off when our nation will regret not having some of those plants available to meet our growing electrical needs.

Nuclear energy also offered another important advantage in many areas of the country: a way to diversify the fuel base. Utilities were seeing signs of fuel problems even before the 1973 embargo: in the winters of 1970-72 and 1972-73, both the Northeast and the Midwest suffered shortages of natural gas that reduced the electric power available in New York, Chicago and other large cities. Factories were closed, store hours were cut back, schools had their hours reduced. In the winter of 1972-73 the delivery of natural gas was interrupted even in Texas. This taught utilities that they needed to have a more diversified fuel base. In the early 1970s, therefore, nuclear plants were ordered by utilities in Texas, which had relied on natural gas for 91 percent of its electricity; Louisiana, which used gas for 88 percent of its power; Connecticut, which burned oil for 79 percent of its power; New Jersey, which used oil for 71 percent, and other areas that were excessively dependent on a single fuel. All of those states have successfully diversified from that predominance of a single electric generating fuel.

As these nuclear plants began operating after the embargo, they played a much more important role than had been envisioned. As I've indicated earlier, the 87 nuclear plants that have been completed since then helped the United States meet the most serious energy crisis in its history, by adding to the country's supply of electricity as an important element in our effort to cut back our reliance on imported oil.

But there is no such construction program momentum today. So the solutions we will turn to in the short term will aggravate the problem we see bearing down on us. And I believe it is clear that we will indeed face serious electrical and imported oil problems within the next several years if our economy continues to grow.

The Ultimate Return to Nuclear Electric Additions

As our society continues to become more electrified, as the electricity cost of the small scale, and short lead time power plants begin to add up, as our dependence on imported oil grows and, especially when its price again increases, the bargain and benefits of our nuclear electric capacity will become ever more apparent. And the success of nuclear energy throughout the world will accelerate that realization.

We will then again turn to nuclear energy. Recent analyses has shown that nuclear power plants can be built in the U.S. for $1.5 billion and be economically competitive with oil priced as low as $9 a barrel. The time between plant order and operation, will be much shorter than was the case for our most recently completed plants. But even during that shortened time, I believe the United States will indeed have serious energy problems and will be scrambling to supply electricity every way that's possible. We'll suffer serious short term problems while working to return to a long term gain.

I'm convinced that our electric power system will react as it should. That reaction will undoubtedly be based on an increase in the nation's baseload capacity, fueled by the two sources we can count on for the decades to come--coal and nuclear energy.

The Challenge to the Nuclear Industry

We have a responsibility to work to assure that our Nation proceeds to this logical position. We must continue to work toward growing acceptance of nuclear energy as a major source of the increased electrical capacity we will certainly need. And we must work toward increased acceptance of nuclear electric power plants in areas that most urgently need capacity and where nuclear energy offers electricity cost and energy security benefits.

That continues to mean that we never let up on our drive for excellence. Excellence in operations must continue to be the conscious target of all operators. Excellence in communications to the public of the need for electrical capacity, of the benefits of nuclear energy, and of the excellence being achieved in operations is also essential. And excellence in communication with decision-makers at all levels of government is also required to assure that sound policy, legislation, and regulation is established and implemented.

As I have indicated, we believe we have made significant progress in these matters in the United States, but the job is never complete. Worldwide communication on these matters is essential. Communication in all forms is needed, including forums like this one and more intimate meetings as well as worldwide organizations. The World Association of Nuclear Operators will provide the opportunity for quick exchange of operating experience. The International Council that we have established in our organization, reporting to our Board of Directors, can certainly help to exchange knowledge on effective means of communicating with the public through our various media. And broad public communication is essential.

I look forward to working closely with you to help assure that all of us achieve the solid performance on which each of us is so dependent. I want to emphasize that this is, indeed, a worldwide activity that requires close cooperation and collaboration if each of us is to succeed.

セッション2

アジアにおける原子力協力の展開

アジアにおける原子力地域協力の展開

国際原子力機関（ＩＡＥＡ）事務局次長

ノラムリイ・ビン・ムスリム

アジアにおける原子力協力の展望

原子力委員会委員

中江　要介

＜パネル討論＞

中国原子力工業省外事局副局長

劉　雪紅

インドネシア原子力庁長官

D．アヒムサ

韓国エネルギー研究所長

韓　弼淳

フィリピン原子力研究所長

Q．O．ナバロ

国際原子力機関（ＩＡＥＡ）事務局次長

ノラムリイ・ビン・ムスリム

科学技術庁長官官房審議官

井田　勝久

㈳海外電力調査会専務理事

武田　康

The Development of Regional Co-operation in Asia and the Pacific

by
Noramly bin Muslim
Deputy Director General
and Head of the Department
of Technical Co-operation

INTERNATIONAL ATOMIC ENERGY AGENCY

Vienna, Austria

Executive Summary

Co-operation in the nuclear field in Asia dates back to 1962 with the development of the India-Philippines-Agency IPA project. The project involved the supply of a neutron diffractometer by India for installation in the 1 MW Philippines reactor. By the end of the project, a number of countries including India, Indonesia and the Republic of Korea were involved.

In view of the success of the IPA project, the IAEA decided to extend the scope, and include more countries in a wider set of projects. The Regional Co-operative Agreement (RCA) came into force on 12 June 1972. Projects incorporated within RCA were very diverse and included (a) Neutron Scattering, (b) Food Irradiation, (c) Nuclear Instrument Maintenance, (d) Improvement of Domestic Buffalo Production. An important initiative was taken in 1976, when RCA Member States requested the IAEA to seek support from UNDP for a large project on the applications of radiation and radioisotopes to industry. This project which was initiated in 1982, after an extensive pre-project planning stage and has now entered a second phase. It has played a very significant role in the development of RCA, at one time accounting for over 70 percent of the budget.

Within RCA maximum use is made of regional resources. From about 1979, Japan and Australia have been funding a range of project activities as a tangible evidence of their commitment to regional development. In a farsighted move, India began supporting RCA as a donor in 1983. This was followed in 1986 by the Republic of Korea.

The willingness of developing countries to accept responsibilities as donors provides a sound basis for the promotion of Technical Co-operation between Developing Countries (TCDC) within RCA. Increasing use will be made of

the excellent institutes and facilities within the region as co-operation enters a more mature phase. Centres of excellence, in part supported by RCA project activities are evolving and will continue to be supported. Such centres hosting for instance secondary standard dosimetry laboratories, nitrogen-15 measurement equipment, or isotope hydrology facilities should be encouraged to serve countries still lacking these capabilities. A number of such offers have been received through RCA. Still more can be done to further the local production of radioisotopes and radiopharmaceuticals.

Concurrent with these practical moves towards regional self-sufficiency is a broadening and refining of the programme. Member States, through their Meetings of Representatives are acutely aware that needs and priorities change. For instance, in the 1988 TC component of the RCA programme are projects in the fields of the "Radioimmunoassay of Thyroid Related Hormones", "Energy and Nuclear Power Planning" and the "Radiation Sterilization of Human Tissue Grafts. In addition, a Japanese initiative has led to the major new project "Strengthening of Radiation Protection Infrastructure".

RCA is widely regarded as one of the few successful examples of regional technical co-operation. To some extent it has influenced the development of the ARCAL co-operative programme in Latin America, and possible future arrangements in Africa.

I. INTRODUCTION

The Asian and Pacific region comprises about half of the world's population and is extremly diverse. Countries vary greatly in size in per capita income, culture, geography and climate. The region has, however, been experiencing relatively rapid economic growth over the past decade.

UNDP predicts that there is a strong potential for continued vigorous economic development through at least the remainder of the century. It further recognizes that the transfer of technology is particularly significant under these circumstances. Because of the differences in the level of development within the region, there are substantial opportunities for potential transferers as well as recipients of technology. Regional projects are a natural medium for such technical cooperation. Particular emphasis is being placed on technical co-operation between developing countries (TCDC).

Technology cannot be transferred without human resources development (HRD). HRD is more than training, as it also involves man-power planning and the efficient management and deployment of available skills and capabilities. In his statement to the Forty-third Session of ESCAP, the chief delegate of Japan, His Excellency Mr. Keiwa Okunda said [1]:

"Japan depended in very great measure on its human resources for modernization. Our experience has left us firmly convinced of the importance of HRD in the economic and social development process. Japan has therefore consistently placed special emphasis on HRD as the foundation of nation building when assisting the efforts of developing countries and has maintained its positive co-operation in this field".

These three norms of the technical co-operation viz

- technology transfer
- human resources development (HRD)
- technical co-operation between developing countries (TCDC)

form the basis of the IAEA's regional programme.

In the following sections the history of the Agency's regional programme, its scope, and ideas to further develop it will be outlined.

II. HISTORY OF THE IAEA's REGIONAL PROGRAMME FOR TECHNICAL CO-OPERATION IN ASIA

The development of a sound basis for regional co-operation is not a rapid process. Co-operation in the nuclear field in Asia dates back to the India-Philippines-Agency (IPA) project (1963-1972). The project involved the supply of a neutron diffractometer by India for installation in the 1MW Philippine reactor. By the end of the project, a number of countries from India to the Republic of Korea were involved. The long term impact of this project was that it showed [2]:

(i) it is possible to train researchers from countries with very different cultural traditions and educational systems in new technologies which could form the basis of national Research and Development programmes; and

(ii) it is possible to build sophisticated equipment such as the filter detector spectrometer within the means and expertise of regional centres when co-operation is present.

In view of the success of the IPA project, the IAEA decided to extend the scope and include more countries in a wider set of programmes. The Regional Co-operative Agreement (RCA) came into force on 12 June 1972 [3]. Support came largely from the countries themselves and has resulted in bringing about a good deal of cohesion within the region in dealing with problems of common interest. The early programme was diverse, and included

- neutron diffraction and its applications
- food irradiation
- nuclear instrument maintenance
- isotope hydrology and sedimentology; and
- improvement of domestic buffalo production.

RCA activities were traditionally reviewed by annual meetings of Representatives of Member States at the time of the General Conference. In 1978, the first RCA Working Group Meeting was conducted in the region. It was held in Kuala Lumpur, hosted by PUSPATI and chaired by Professor Kakihana, then Deputy Director General Department of Research and Isotopes. These meetings were crucial for the development and maintenance of links between institutes in the region and the future development of nuclear co-operation.

In 1976, as a direct result of an initiative from RCA Member States, UNDP was approached to support a large scale Regional Industrial Project. Following extensive evaluation by UNDP and a Preparatory Assistance Project, the first phase of the project funded at a level of $5.5 Million commenced in 1982. A second phase was approved in 1987. The importance to RCA of this project cannot be over estimated. At one time it amounted to over 70% of the RCA budget, and has been a major, constant contributary factor to RCA activity.

From about 1979, Japan and Australia have been financially supporting RCA to an ever increasing extent. In 1983, India, itself a developing country began contributing to RCA as a donor. This farsighted example was followed by the Republic of Korea in 1986. In 1988, extra budgetary contributions, including UNDP will amount to 65% of the $2.81 Million operating budget. Details are presented in Figure 1. The spread of the resource base provides an excellent framework for further planning, and in particular, for the development of TCDC.

III. RCA PROGRAMME

The RCA programme currently involves projects spanning the fields of

- medicine
- agriculture

- industry
- energy and nuclear power planning
- basic nuclear science.

Individual projects are listed in Table 1. Some details are presented in a recent issue of the IAEA Bulletin [4]. To illustrate the RCA mechanism, reference will be made to the new project, "Strengthening Radiation Protection". This project was formally proposed by Japan at the Ninth RCA Working Group Meeting, Colombo, March 1987. After some general proposals were presented to Member States a project formulation meeting was called in Tokyo, in November 1987 to analyse the needs of the region and to prepare a detailed project proposal. The project will comprise a number of components including Regional Training Courses, Regional Workshops and Co-ordinated Research Programmes. Apart from the formulation meeting, the first three activities are:

(i) Regional Training Course: Development of Infrastructures for Ensuring Radiation Protection, Sydney, April 1988 (Australian funded).

(ii) Regional Workshop: Personnel and Environmental Dosimetry Intercomparison Study, Tokyo, October-November 1988 (funded by Japan).

(iii) Co-ordinated Research Programme: Setting of Reference Man for non-Caucasians - Compilation of Physiological and Social Parameters. (funded by Japan).

In addition, the Government of India has offered to make facilities available to support the programme.

IV. DEVELOPMENT OF REGIONAL CO-OPERATION

1. A basis for planning

In his address to the First ASEAN Science and Technology Week [5], Professor Kakihana identified four steps required by many Asian countries in achieving development aims:

(i) the establishment of a good balance between the demand and supply of food;

(ii) the fostering of agro industries and some process industries;

(iii) the building up of selected advanced industries; leading to

(iv) the evolution of an industrial structure similar to that of the advanced countries.

On the whole, the IAEA's programme of Technical Assistance reflects the fact that many Asian countries are in the second and third stages of development.

As indicated, the Agency's regional projects are designed to achieve specific development aims, and, at the same time, to contribute to the general processes of technology transfer, human resources development (HRD) and technical co-operation between developing countries (TCDC).

The long term effectiveness of the programme will depend on the extent to which the region's development aims can be furthered through the afore mentioned processes.

2. The immediate future

2.1 Technology transfer

Considerations leading to a decision to introduce a new technology are complex and cannot be attributed unequivocally to a particular project. In the examples cited later, key decisions were taken during the time frame of the projects and involved personnel who took part in the human resources development programme.

A good example concerns the application of nucleonic control systems to the paper industry. A training/demonstration facility was established at the Siam Kraft Paper Corporation's factory near Bangkok. Training courses were arranged annually. To date a number of installations have been commissioned in the region including 10 in Thailand. The next logical stage is the extension of this activity to simpler, less expensive installations tailored for small paper mills of which there are about 250 in the region. This exciting concept which is being developed by a Japanese expert envisages the involvement of engineers from the paper industry in the design, and an electronics company from the developing countries in the manufacture.

Nucleonic control systems have also been applied to the copper industry. A demonstration facility has been established at the Philex Mining Corporation, Baguio City, Philippines. The technology is now being used, for instance, by the Mamut Copper Mine, Malaysia. A major project involving the application of nucleonic systems in the coal industry is in an advanced planning stage.

Irradiation facilites have been, or will soon be commissioned in Bangladesh, Malaysia, Pakistan, Philippines and Thailand for the sterilization of medical products and /or food irradiation. Particular mention should be made of the Thai Company, Gammatron which was established in 1984, as a direct result of the project for the manufacture and sterilization of medical products. Future activities will be concerned with improving the standards of manufacturing practice. In the case of food irradiation, a great deal of scientific and technical work has been undertaken. The next stage involves assisting Member States to ensure proper process control and to facilitate the acceptance of food irradiation in trade.

Of the many other examples of technology transfer which could be quoted, reference will be made only to the radiation vulcanization of natural rubber latex. Activities in this field are accelerating. For instance, the Indonesian Family Planning Board has decided (subject to Government approval) to start commercial production of surgical gloves using irradiated latex. Again, Malaysia is to make a major investment in research and development in this field. Serious interest is also being shown by the Republic of Korea, Thailand and Sri Lanka. The future involves investigating the potential of electron beam technology.

2.2 Human resources development

Human resources development is a wide concept involving the identification of manpower requirements, increase skill levels through training and the deployment and management of these resources. It is a dynamic process. This is well illustrated in Figure 2 where the development of three different types of training is shown: regional training courses, executive management seminars and national training courses.

Regional training courses are still the principal method of introducing new technologies to scientists and engineers. However, during the early stages of the project it became apparent that for effective transfer of a new technology it was necessary to ensure that senior decision makers were also aware of its potential advantage to their operations. Executive Management Seminars were therefore introduced and have become increasingly popular.

As a technology spreads, the demand for training increases and can no longer be met by regional training activities in which one or two participants from each country are selected. The Agency has therefore started supporting national training courses by the provision of one or two specialist lecturers. This is a cost effective way of reaching a large number of people.

The organizing of national training courses under the auspices of a Regional project may appear to involve an inherrent contradiction. However, under RCA the pattern of courses are determined by the regional meeting of national project counterparts. In addition, maximum use is made of regional lecturers. In 1987, of the 30 lecturers supported by the Agency, 22 were from the region, including 7 from developing countries. This of course excludes the majority of instructors who were from the host country. A conscious effort will be made to further increase the assignment of lecturers from developing countries, itself a very effective avenue of HRD.

In the new Nucleonic Control Systems (NCS) Coal Project another innovation is to be tried. One specialist lecturer from Australia supported by a small Thai staff will instruct a small group of participants (maximum 6) in the applications of nuclear techniques to the coal industry. More personalized attention will be possible. Courses will be conducted twice a year.

2.3 Technical Co-operation between Developing Countries (TCDC)

The Buenos Aires Plan of Action, 1978 [6] which was endorsed by a United Nations General Assembly Resolution stated that one of the principal aims of TCDC is to "promote and strengthen collective self reliance, the pooling and sharing of their technical resources and the development of their complementary capacities". It adds - that while the main flow of technical co-operation would be between two or more developing countries, the support of developed countries within the region and of interregional institutions may be necessary.

Many delegations to the 1985 High-level Committee of Review of Technical Co-operation between Developing Countries expressed disappointment that despite the extensive efforts over the years since 1978, there was still much to be desired in terms of the enormous potential for such co-operation [7]. Four factors for the implementation of TCDC are required.

a) political will amongst the countries involved;
b) establishment of certain necessary mechanisms;
c) readiness to share resources of all types;
d) clear and agreed identification of concrete areas for co-operation.

All of these preconditions for TCDC have been established within RCA. Central to (a) and (d) is the rapport established and the agreements reached at the bi-annual Meetings of Representatives of RCA Member States.

The readiness to share resources is clearly shown in Figure 1, where six separate sources of funding, including two developing countries are identified. This graph does not show the very substantial in-kind resources made available by all countries for the implementation of the regional programme. They at least match the cash contributions.

In addition, every effort is made to use regional experts. This is particularly well illustrated with the NDT sub-project of the Regional Industrial Project. In the period 1986-1988 there has been a substantial reduction in the number of experts recruited from outside the Region and a large increase in those from the developing countries. The trends are shown in Figure 3. The increased use of both physical and human resources from developing countries is clear evidence of the viability of TCDC in Asia.

Although significant achievements have been reported there is still much to be done. Perhaps the next step is to encourage the development of bi-lateral relations between specific institutions in developing countries. The "resource" institute could provide expertise for project support and offer fellowships for training. Some catalytic funding would be necessary.

As mentioned above, the successful evolution of TCDC requires an element of political will. It leads to an interchange of personnel and skills on the basis of a partnership between those who need and those who are able to help. This in itself helps to create an even better environment for further co-operation.

3. The longer term

The strength of the Agency's regional programme will ultimately depend on the effectiveness with which it is possible to match the modalities of technical co-operation (technology transfer, HRD, TCDC) with current development aims (fostering of agro-and process industries, and the building up of selected advanced industries). A partnership is required between the developing countries, donor countries and other Agencies and Associations concerned with multilateral technology transfer.

Over the past 15 years, an essential infrastructure has developed under the RCA umbrella. RCA is gathering a strength which cannot simply be explained by the cumulative effect of the success of individual projects. A tradition is being developed which extends back to the early 1970's. Central to this tradition are the bi-annual meetings of Representatives of RCA Member States. Many of the delegates have been working together for many years and understand the development problems and opportunities in each others countries rather well. As a result, these meetings provide the Agency with a consistent pattern of advice on the programme.

The consistency of this advice tends to strengthen the RCA tradition and to ensure a sound long-term basis for incorporating nuclear science and technology into the region's long-term development plans.

Tokyo, 14 April 1988
2nd Session
JAPAN INDUSTRIAL FORUM
Annual Conference

References

[1] Statement by H.E. Keiwa Okuda, Member of the House of Representatives and Head of the Delegation of Japan to the 43rd Session of ESCAP, Bangkok 21 April 1987.

[2] R. Ramana, former Chairman, Indian Atomic Energy Commission, private communication.

[3] Regional Co-operation Agreement for Research, Development and Training related to Nuclear Science and Technology 1972, IAEA/INFCIRC 167.

[4] M. Ridwan and P.L.Airey Regional Co-operation for Technical Progress IAEA Bulletin 29 (1) pp 8-14,1987.

[5] H. Kakihana, The Philosophy of Science and Technology Co-operation in Asia, Presented at First Asean Science and Technology Week, Kuala Lumpur 29 April 1986.

[6] Buenos Aires Plan of Action for Promoting and Implementing Technical Co-operation among Developing Countries. UNDP New York, Division of Information 1979.

[7] Report on the High-level Committee of Review of Technical Co-operation among Developing Countries. UN General Assembly, Official Records: Forthieth Session Supplement No.39 (A/40/39) UN, New York 1985.

TABLE 1: RCA PROJECTS 1988

Field	Project	(1) Funding
Agriculture	Asian Regional Co-operative Project on Food Irradiation (Phase II)	Australia
	Use of Nuclear Techniques to Improve Domestic Buffalo Production in Asia - Phase II	IAEA Regular Budget
Medical and Biological	Quantitative Evaluation of Nuclear Medical Procedures for Diagnosis of Liver Diseases	Japan
	Improvement of Cancer Therapy in Asian Countries	Japan
	Aerosol Inhalation Imaging for the Diagnosis of Respiratory Diseases in Developing Countries	India
	Development of Tc-99m Generators Using Low Power Research Reactors	IAEA Regular Budget
	Radiation Sterilization for Tissue Grafts	Technical Assistance Fund
	Radioimmunoassay of Thyroid Related Hormones	Technical Assistance Fund
	Nuclear Techniques for Toxic Elements in Foodstuffs	IAEA Regular Budget
	Care and Maintenance of Nuclear Medical Instruments	IAEA Regular Budget Technical Assistance Fund
	Immuno-diagnosis of Tuberculosis	IAEA Regular Budget
	Use of Computers in Technetium-99 imaging	Australia

Field	Project	Funding
Industry	Regional UNDP Project for Asia and the Pacific (RCA) on Industrial Applications of Isotopes and Radiation Technology	UNDP Technical Assistance Fund Japan Australia
	Sub-projects: - Tracer Technology in Industry - Non-Destructive Testing - Radiation Technology - Nucleonic Control Systems	
Radiation Protection	Strengthening of Radiation Protection	Japan Australia
General	Basic Science Using Research Reactors	India
	Energy and Nuclear Power Planning	Technical Assistance Fund

(1)
In addition, annual Workshops/Training Courses are being funded by the Republic of Korea.

FIGURE 1

SOURCES OF RCA PROJECT SUPPORT: 1988

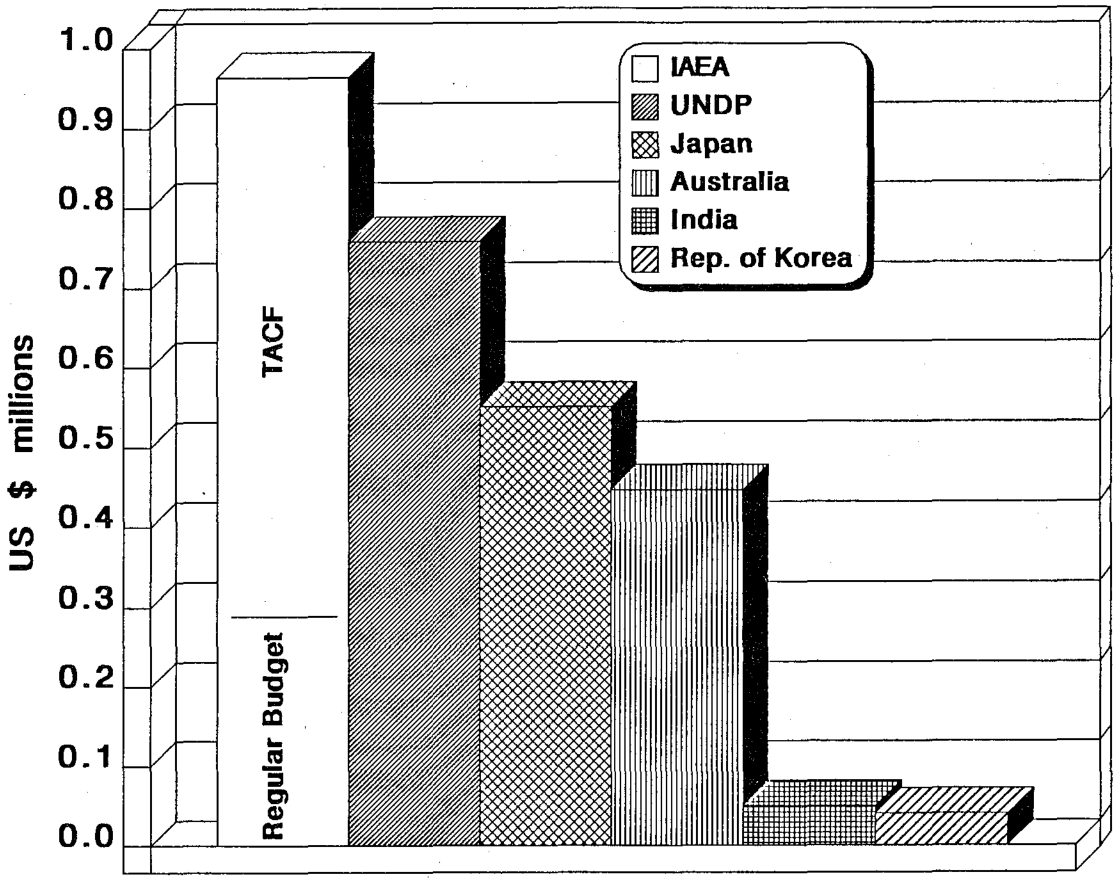


FIGURE 2

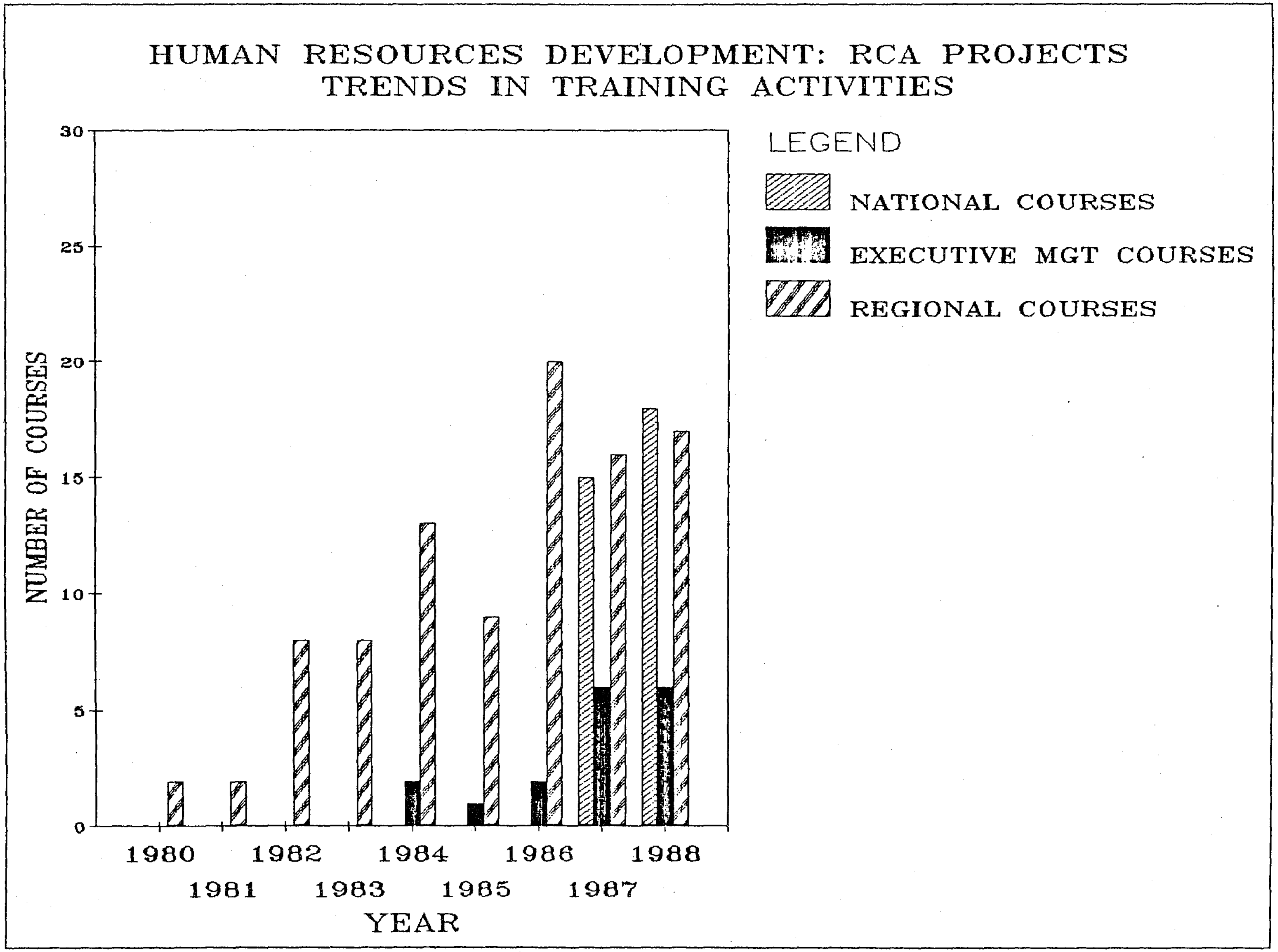
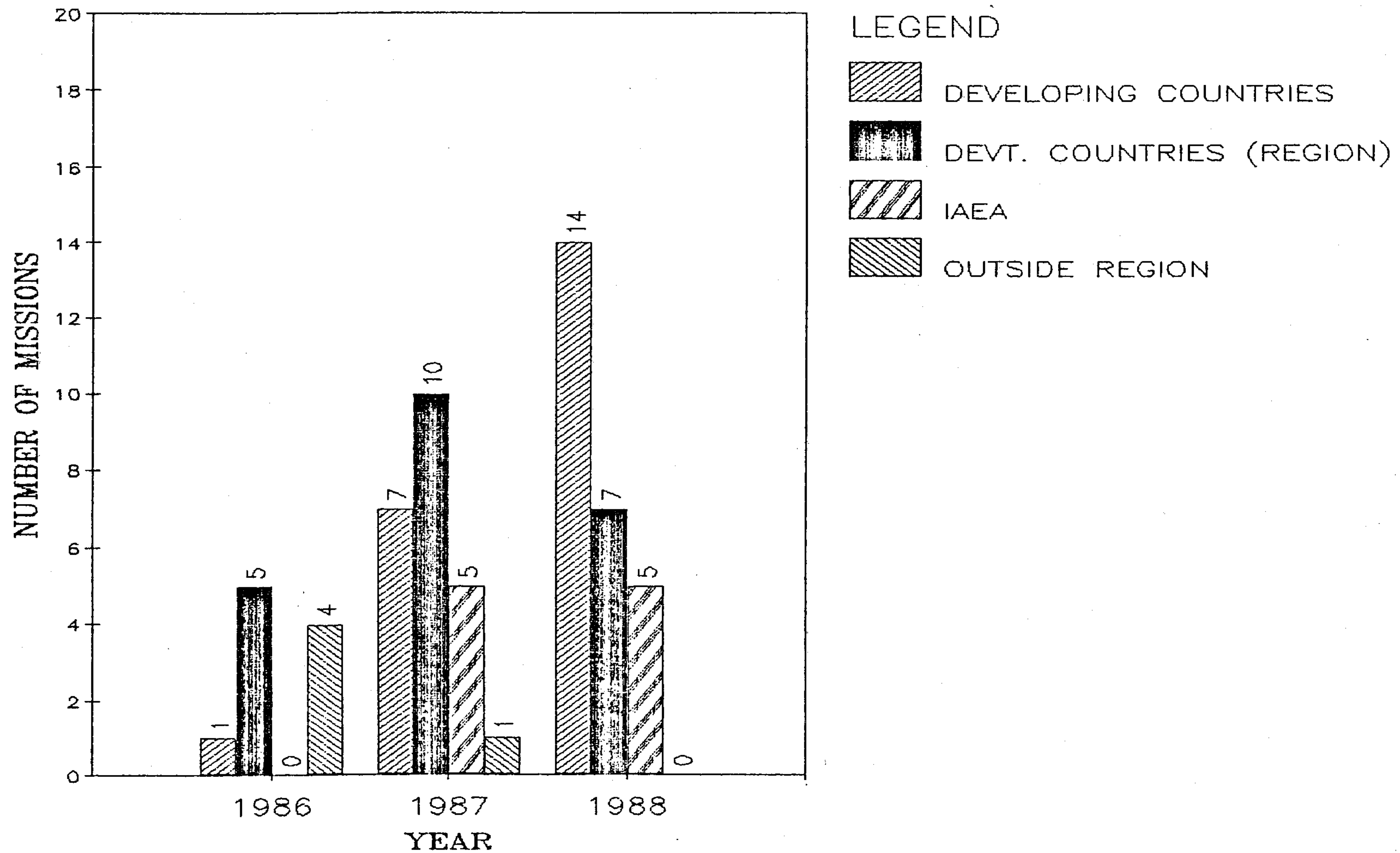

HUMAN RESOURCES DEVELOPMENT: RCA PROJECTS
TRENDS IN TRAINING ACTIVITIES
NUMBER OF COURSES
30
25
20
15
10
5
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
YEAR
LEGEND
NATIONAL COURSES
EXECUTIVE MGT COURSES
REGIONAL COURSES

FIGURE 3
RECRUITMENT OF EXPERTS, NDT SUB-PROJECT RAS/86/073



「アジアにおける原子力協力の展望」

原子力委員会委員
中 江 要 介

1．冒頭挨拶

本日、本セッションにおきまして、「アジアにおける原子力協力」について私の意見を述べることができる機会を得ましたことを光栄に存じます。

2．序

まず、本題に入る前に、アジアにおける国際協力一般について、私の見解を簡潔に申し述べておきたいと思います。

個人的なことですが、私は１９７１年から１９７８年までの８年間、外務省でアジア関係の事務を所管しておりました。その間、いろいろの問題がありましたが、画期的なこととして、日本の対アジア外交についての基本的な政策が、－おそらく戦後初めてのことと思いますが、－ 当時の福田首相の口から、マニラで公にされたことが想起されます。１９７７年８月のことで、一般に「福田ドクトリン」と呼ばれています。

この「福田ドクトリン」は歴代内閣によって踏襲され、今後共変わることはないと信じますが、それは、三つの原則から成っています。

第一は、日本はいかに経済力が大きくなっても、決して「軍事大国にはならない」ということです。

第二は、アジア諸国との間では、物質的な関係に偏らず、「心と心の触れ合い」を重視していくべきだ、ということです。

第三は、イデオロギーや政治・経済体制の違いを越えて「平和共存」の関係を目指すべきだ、ということです。

これらの諸原則は、これから申し述べる「アジアにおける原子力協力」の問題についての我が国の考え方や施策に忠実に反映されています。即ち、我が国が原子力の利用を厳格に「平和目的」に限定していること、人材交流を重視していること、原子力問題を世界的規模において取り上げ、国際協力を重視していること、などはその好例であります。

3．原子力を巡る環境の変化

そこで本題に入りますが、近年原子力を巡る環境は大きく変化しております。第一には、エネルギー需要の伸びが鈍化しつつあり、世界的にエネルギー需給は、緩

和基調にあります。また、化石燃料の価格も低下し、各エネルギー間での競合関係は一段と厳しさを増してきております。第二には、１９８６年4月に発生したソ連チェルノブイル原子力発電所の事故によって、原子力施設の安全確保の重要性が強く再認識されました。

4．原子力発電への期待

原子力発電は、エネルギーの安全確保の観点から石炭及び天然ガスとともに石油代替エネルギーの中核的役割を担うとともに、世界的なエネルギー需要の緩和に貢献している。またそれにより、限られた化石エネルギーを有効利用できるようになる。さらに、酸性雨、大気中の二酸化炭素の濃度上昇というような環境問題に対する影響が小さいといった特徴を有しています。このため、我が国はもとより、世界的にも原子力の平和利用が着実に推進されることが期待されているところであります。

5．新長期計画の策定

以上のような観点から、日本の原子力委員会におきましては、昭和５７年6月に策定された原子力開発利用長期計画を見直し、昨年6月２２日に新しい長期計画を策定しました。新長期計画は、２１世紀に向けての原子力政策の展開という長期的な視点を踏まえて、今後２０００年までの原子力の研究、開発及び利用に関する指針の大綱を明示し、また基本的な施策とその推進についての考え方を明らかにしております。

6．新長期計画の基本方針

新長期計画においては、先程述べました原子力発電の特長に着目して原子力開発利用を今後とも着実に推進していくこととしておりますが、その際基本方針として、「平和利用の堅持」と「安全確保」を大前提としています。すなわち、我が国の原子力基本法や核不拡散に関する条約の精神にのっとり、世界の核不拡散体制の維持・強化に貢献していくとともに、我が国の原子力開発利用を平和目的に限って推進することとしています。また、安全確保についても、現状に満足することなく、技術の向上、従事者の教育訓練、安全確保対策の一層の整備・充実など関係者の不断の努力により、安全確保に万全を期すこととしております。

7．新長期計画の３つの基本目標

以上の２つの基本方針を大前提として、新長期計画では、次の３つの基本目標を掲げております。

（1）第1は、「基軸エネルギーとしての確立」であります。原子力は最適なエネルギー構造を構成する重要なエネルギーであり、準国産エネルギーとしての役割を担い得るものでありますので、これを我が国のエネルギー供給構造の脆弱性の克服に貢献する「基軸エネルギー」として位置付け、その安全性、信頼性、経済性等の質の向上を重視して開発を進めていくということであります。

（2）第2は、「創造的科学技術の育成」であります。原子力については今後開拓すべき面が多く残されており、またその研究開発は広範な科学技術の水準向上の牽引力ともなりますので、今後は創造型研究開発を指向し、ニーズの多様化・高度化に対応していくとともに他の科学技術分野との連携・交流に努めることにより、次世代の創造的科学技術の育成を図っていくべきだとの考えであります。

（3）第3は、「国際社会への貢献」であります。従来の長期計画においては国際協力の役割については多くを論じていなかったのですが、今回の長期計画から3つの基本目標の1つとして大きく取り上げられることとなりました。そこで、この点について少し詳しく説明したいと思います。

8．国際社会への貢献

（1）今日、我が国は世界のＧＮＰの1割を占め、世界有数の技術を有するまでに発展したことから、世界の経済発展・活性化への貢献、エネルギー問題を始めとする人類共通の課題の克服への積極的対応、世界の科学技術レベルの向上への寄与など主要先進国として積極的に国際社会に貢献する責任が生じています。

（2）また、大型プロジェクトの開発研究に関しては、これに充てる資金・人材などの研究開発資源の制約が顕著となってきているため、国際協力を通じてこれらの資源を有効に活用することにより国レベルの制約を克服していくことの重要性が強く認識されてきています。

（3）さらに、我が国の原子力発電は、非常に高い設備稼動率を達成し、原子力発電技術の高い安全性、信頼性が世界的にも評価されつつあります。

これらの理由から我が国としては「平和の目的に限り、安全の確保を旨とし、進んで国際協力に資する」との我が国原子力基本法の基本方針にのっとり、今後、欧米の主要先進国とともに原子力分野における牽引車として積極的に国際社会に貢献する方針であります。

9．主体的・能動的国際対応

このため、原子力委員会としては、次の3点を国際社会への貢献に当っての基本

目標とし、所要の国内措置を講じつつ、我が国の国際対応を主体的・能動的に推進することと致しました。

（1）第1点は、「世界共通の利益の積極的追求」、すなわち、原子力開発利用を進めていく上で当面する諸課題に対処していくに止どまらず、長期的視点に立って創造型研究開発を推進し、新しい技術や知識を生み出してそれを世界の原子力平和利用のために提供していくことにより、世界共通の利益を追求するということであります。

（2）第2点は「各国研究開発資源の効率的活用」、すなわち、世界的規模での低成長時代の到来、研究開発プロジェクトの大型化等の情勢の変化により、各国とも資金、人材等の研究開発資源について制約が顕著になっている現状に鑑み、我が国としては、各国が共通して推進している大型の研究開発プロジェクトにおいて国際協力の可能性を追求し、研究開発資源の国際的な効率化を進めるということであります。

（3）第3点は、「適切な国際環境整備への主体的貢献」、すなわち、我が国として世界の核不拡散体制の健全な維持・強化に貢献していくこと、我が国における安全確保の実績と経験を国際社会に提供し、国際的な原子力の安全の確保に貢献していくこと等により原子力平和利用推進のための国際環境の整備に努めるということであります。

以上の3つの基本目標にのっとり、原子力委員会では、近隣アジア諸国を始めとする諸外国との国際協力を進める問題については、これを「2国間協力」と「近隣地域対応」の2つに分けて検討を行い、次の結論を得たのであります。

10．二国間協力

まず「2国間協力」について説明します。その基本的な考え方は、相手国の国情を勘案しつつ、研究基盤、技術基盤の整備に重点を置き、相手国の原子力開発利用計画の初期の段階から原子力開発のレベルに応じ、そのレベルが円滑に向上するように協力を進めていくということであります。その際、原子力開発のレベルが比較的高い国については、協力促進の観点から核不拡散及び安全確保を前提とした形で協力の枠組を整備するとともに、相手国においても国力相応の努力が図られることが重要です。また、協力の成果が相手国に確実に根付くよう、資機材の移転等の後の利用計画への助言、トレーニングの実施など利用面でのアフターケアーないしフォローアップについても十分配慮すべきだと考えております。

これらの基本的考え方を受けて次のような具体的方策を提案しています。

イ．人材交流については、相手国の協力ニーズの把握に努めつつ、研究者・技術者交流、原子力アドバイザーや十分な経験を有する者の活用を含め、人材交流の促

進を図ること。また、

ロ．放射線・ＲＩ利用については、国際原子力機関(ＩＡＥＡ)、アジア原子力地域協力協定(ＲＣＡ)などの活用及び二国間協力の充実により、医療、農業、工業等の面での放射線利用技術の向上及び実生活、産業振興への反映に対する積極的貢献を行うこと。

ハ．研究炉の利用については、効率的な研究開発の実施及び研究施設の有効利用に対する助言・指導の強化を図ること。さらに

ニ．原子力発電については、その進捗状況に応じフィージビリティ調査、安全規制、運転管理等に必要な情報の提供、技術者・管理者、運転・保守員の養成・訓練等の協力を行うとともに、国際分業に配慮しつつ原子力産業の国際的展開を図ること。

以上のような基本的考え方及び具体的方策を受けて、日本政府としては１９８８年度には、主として次のような諸施策の強化を予定しております。

a．まず、「人材交流」ですが、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いるところです。このため、各国からの要請に基づく既存の個別研修員の受入れ、専門家派遣に加えて１９８５年度から原子力研究交流制度が実施されており(過去３年間の受入れ研究者数１２３名、派遣研究者数６３名)、各国からも高く評価されていると聞いておりますが、１９８８年度は、外国人研究者の受入れについては、前年度を２．２％上回る約７０名の受入れが予定されております。また、我が国研究者の派遣についても前年度の１１％増の３０名の派遣が予定されております。次に、

b．「集団研修」につきましては、研究者、技術者を対象とした既存の原子力基礎実験セミナー、原子力発電セミナー等に加え、１９８７年から原子力関係の行政官を対象とした原子力政策、開発利用、国際協力分野に関する原子力関係管理者セミナー及び原子力安全規制分野に関する安全規制行政セミナーが開始されました。

原子力の開発利用の推進にとって、総合的な計画の策定・実施及び安全規制体制の整備は何にも増して重要であり、その中核となる関係行政官等の養成は、本地域内各国に共通の最優先課題と考えます。その意味で、今後より多くの行政官や研究管理者の受入れが期待されるところであります。

c．近年、近隣アジアの国々における原子力の開発・利用の進展に伴い、人材派遣の要請が高まっているところですが、相手国の多様なニーズに応えて、原子力アドバイザーとして十分な経験を有する適切な人材を速やかに派遣することを可能とするため、１９８８年度から原子力研究者派遣斡旋制度が創設されることになっ

ています。

11．近隣地域対応

次に「近隣地域対応」について説明します。その基本的考え方は次のとおりです。我が国と地理的、経済的に密接な関係にある近隣アジア地域は、原子力分野においては、放射線・ＲＩ利用、研究炉利用、原子力発電システムの導入、安全確保・緊急時対応等の面で多くの共通課題を持っております。これらの共通課題の解決に当たっては、本地域の限られた財政的・人的資源を最も効果的かつ効率的に使用するため、我が国を含めた地域ぐるみの協力を行うことが有効です。これを実現するため、解決すべき課題、解決に当たっての協力分担等について、地域としてのコンセンサスを得るとともに、我が国としても協力分担に応じて積極的に地域協力を進め、本地域全体の原子力技術レベルの向上を図り、もって本地域の経済・福祉の向上に貢献したいということであります。

この基本的考え方を受けて次のような具体的方策を提案しております。

（イ）近隣地域の代表者が参加する国際的な検討の場を設けるなどして、これらの国々のニーズを的確に把握し、計画策定段階からの協力を行うとともに、

（ロ）安全確保対策での協力の推進、地域特性に十分配慮した先端技術による画期的な原子炉システムの共同研究開発(共同設計等)についての検討、放射線・研究炉利用等に関する地域協力体制について検討を行うということであります。

これらの基本的考え方及び具体的方策を受けて日本政府は、これらの課題を検討するために

a．本年度から、「検討委員会」を開催することとしております。

b．また、事前の予備調査として調査団を今年２月から２週間、韓国、インドネシア、マレーシア、タイに派遣して各国の原子力プロジェクトの概要や日本に対する協力の要望などについて調査を実施しましたが、現在その報告書を作成しているところです。

さらに、

c．今年度中に、同様の調査団を中国及び韓国に派遣するとともに、近隣アジア諸国の原子力政策担当者を招へいして意見交換を行いたいと考えております。

12．まとめ

以上、昨年６月に改定された長期計画のうち国際協力に関する部分について、近隣アジア地域に重点をおきつつ説明するとともに、それを受けての１９８８年度の日本政府の具体的措置について簡単に説明してまいりました。

原子力の開発利用というのは、各国の外交政策や産業政策において大きなウェートを占めるものであります。従って、その国際協力を進めるに当たっては、各国間の相互理解と協力にとどまらず、各国国内における理解と協力も不可欠であることを強調しておきたいと思います。

以上、冒頭に申し上げましたいわゆる「福田ドクトリン」に集約されている日本政府の対アジア外交基本政策の下で、日本政府がアジア地域において原子力協力をいかに力強く、具体的に推進しているか、また、今後、いかなる方向に努力してまいるか、について私の所見を述べました。本日お集まりの皆様方の間で、この意見を参考として、実のある意見交換や協議を行っていただければ幸いであります。ご静聴有難うございました。

THE COOPERATION IN PEACEFUL USES OF NUCLEAR ENERGY BETWEEN CHINA AND THE OTHER ASIAN COUNTRIES

Liu Xuehong
Deputy Director-General
Bureau of Foreign Affairs
Ministry of Nuclear Industry, PRC

Mr. Chairman, Distinguished Delegates,

I am honoured to have the opportunity to participate in the 21st JAIF Annual Conference, and to address this panel on Nuclear Energy Cooperation in Asia.

Today, I will be discussing the topic entitled "the Cooperation in Peaceful Uses of Nuclear Energy between China and the other Asian Countries."

1. INTRODUCTION

It is well known that Asia, compared with other regions in the world, has scored spectacular achievements in rapid development of economy and likewise, the scenarios in nuclear field have been also encouraging over the past decade. There are 56 nuclear power reactors currently in safe operation. 22 plants are under construction, out of which 3 units are in China; Nuclear technology, radiation processing technique and radioisotopes have found extensive applications in both developed and developing countries in the region; Industrial infrastructure for manufacturing equipment of nuclear power plant is also taking in shape; Certain countries and areas are now actively working whereabouts in nuclear fuel cycle; And there exists a considerable size of experimental facilities for research and development ranging from fast breeder reactor, nuclear fusion to basic research on nuclear physics and radiochemistry etc., wherein significant achievements have been obtained. It is recognized as whole therefore that the Asian region possesses the experiences, technologies and capabilities in nuclear power, nuclear fuel cycle, application of nuclear techniques and research & development on nuclear science in general.

However, unbalanced development, as is the case of economic situation, prevails in various countries and areas in the region. For example, Japan has become one of the most globally advanced in nuclear power, while some developing countries whose nuclear power development is in the initial stage, have just phased in nuclear technologies for gradual applications. Thus, where the difference in both economy and technology is concerned, the cooperation among the Asian countries appears to be of greater importance. I would like to touch upon the considerations of China to the perspective cooperation within this region.

On the one hand, such a cooperation could help China to have a command of technologies and experiences related to nuclear power. Being a developing country, China lacks seriously in power supply. Hence, the government of the People's Republic has decided to develop nuclear power. Well in this context, we need to learn from foreign experiences combined with our existing technologies in designing, constructing, commissioning and operating nuclear power plant so as to achieve step by step the objective of self-reliance. In this connection, we can find out many such examples in the region.

On the other hand, China is able to positively contribute its bit to the international cooperation in Asia. 30 years or so have been witnessed in nuclear development in China, during which definite experiences have been accumulated in nuclear fuel cycle, research & development and applications of nuclear technologies with technical team and sizeable industrial and research facilities being built up. All of them could be provided to Asian countries.

The cooperation among us is imbued with better adaptability and acceptability, due to the approximation in geography, history and culture in the Asian region. Thus we hope the cooperation could promote the development of nuclear power in China, and while are prepared to share knowledges and experiences with Asian countries with the view to facilitating the cooperation in peaceful uses of nuclear energy, bringing its benefit to the Asian peoples.

2. POTENTIAL AREAS OF COOPERATION BETWEEN CHINA AND OTHER ASIAN COUNTRIES

Over the past decade since the policy of opening to the outside world was adopted, China has actively learnt from foreign advanced technologies and experiences and established cooperative relations with the European as well as the Asian countries, specially with Japan, in the area of peaceful uses of nuclear energy. Such a cooperation is characterized by seeking, through governmental, non-governmental or commercial channels, to conduct manpower training, organize technical tours or scientific lecturings and purchase equipment, aiming at overcoming difficulties in nuclear power development in China. The Ministry of Nuclear Industry has built up good cooperative relations, on bilateral basis, with the Japan Science and Technology Agency, Japan Atomic Industrial Forum and Japan Electric Power Information Center, as well as the commercial contacts with Mitsubishi and Hitachi, et al. The scenario in the cooperation is satisfactory.

At present, we wish to further continue the cooperation in the following areas:

A. Quality Management in Design, Construction and Commission of Nuclear Power Plant

The reactor safety has become mostly concerned after the Soviet nuclear accident at Chernobyl. Many countries including China have formulated and upgraded their comprehensive safety regulations However, a strict quality management system needs to be set up in order to be in compliance with regulatory requirements. On the one hand, we gather experiences and draw lessons through constructing Qinshan and Daya Bay Nuclear Power Plants respectively, on the other hand, we desire to use the matured and effective methodology of Japan and other countries for reference so as to avoid mistakes and improve safety of nuclear power plant.

B. Training of Operators and Maintenance Staff for Nuclear Power Plant

Having realized that safe operation without any accidents in the 30 odd years of life time after completion of a nuclear power plant by standards really depends upon the qualified operating and maintenance staff, China has started to build a simulator center for nuclear power plant at Institute of Nuclear Energy Technology of Qinghua University and a simulator in Qinshan Nuclear Power Plant for the purpose of ensuring operators being accorded necessary training prior to start-up of the plants. Furthermore, only such technical leaders as operating supervisors and maintenance chief shall be trained abroad, can they be granted with operating license. Therefore, we are concious of the need to acquire experiences in managing and operating simulator center and the need to bring up mainstay aborad.

C. Treatment and Disposal of Radioactive Wastes

In China, significant volume of high, medium and low level radwastes has been produced over the past 30 years. Despite of experimental work being carried out respectively on glass, bitumen and cement solidification, treating and disposing capability in industrial scale is still hardly created. As a result, the question to remedy the situation has become increasely pressing and requisite. As far as the final disposal of radwastes is concerned, geological and geochemical research work is now being carried out. We hope to use the experiences of our neighbouring countries for reference by launching technical and industrial cooperation in the area of radwastes solidification and conducting exchange of information and personnel in this field.

D. Building Nuclear Power Plant in the Form of BOT

In implementing its nuclear power programme, China, as a developing country, is being faced with shortage of domestic funds as well as foreign exchange. Therefore, it might be a valuable attempt to nuclear power cooperation that developed countries would construct nuclear power plants in China by joint ventures using Chinese and foreign investment or by exclusively foreign investment and seek for possible ways of compensation, which, we believe, could be the perspective avenues to accelerating nuclear power development in developing countries. In this connection, we are ready to explore such ways for compensation trade with foreign partners as:

— direct or indirect compensation trade, namely making compensation with nuclear products as for yellow cake, low enriched uranium, etc. or with goods produced by the electricity generated from this nuclear power plant;
— establishment of nuclear power joint venture company, manufacturing jointly nuclear power plant of international competitiveness for export to third countries by low cost of machining and cheap availability of manpower in China.

— participation with shares paid by electricity generated in the nuclear power plant in producing such power-consuming chemical and metallurgical products at selling as ferro-silicon, aluminum and alkalichloride, etc.

3. PERSPECTIVE CONTRIBUTIONS BY CHINA IN THE REGIONAL COOPERATION

As stated by Vice Minister Chen Zhaobo in his introduction of China's status in nuclear industry, China is prepared to share the experiences and technologies so accumulated and built up over the past 30 years with those countries who like to do so. Since our experiences have been gained in the state whose economy is not yet highly developed, they are more suited to and easily absorbed by some countries and areas of the region in light of their situations similar to China, which has been recongnized in the seminars on application of radioisotopes and nuclear techniques held within the framework of RCA in China.

We consider it meaningful to share the experiences together with the other Asian countries in the following areas:

A. Uranium Prospecting and Exploration

To date, a complete uranium geology works comprising exploration, research & development and education have been carried out in the Ministry of Nuclear Industry. Ground and airborn survey has so far covered 3.4 million square kilometers, where many types of uranium deposits were discovered, notablly classified according to their host rocks into the following 4 types as for granite, volcanite, sandstone and carbonaceous-siliceouspelitic rocks. There are now 7 uranium geology research institutes, more than 10 thousands professional staff and various advanced methods and technologies for exploration as well as for conducting chemical and physical analysis of rocks and minerals.

B. Usage of Research Reactor

With 10 units of heavy water, swimming pool type and high-flux research reactors in operation totalling 120 reactor-years, China has conducted various research work on reactor physics, thermal-hydraulics, materials, fuel elements and non-destruction testing, etc. as well as production of radioisotopes. The number of scientists and engineers committed to these operations totals roughly about 5,000. It is known that the high-flux research reactor is characterized with high flux of both thermal and fast neutrons, the quality of irradiated materials and the specific ratio of isotopes produced in the reactor are duly increased.

C. Research on Particle Accelerator Technology

Particle accelerator is an important tool wherewith to do research on nuclear physics, elementary particles and to develop nuclear industry. Ever since 1957 when China built its first 2.5 MeV proton Van de Graaff, the scientific institutions, industrial enterprises and unversities have set up 103 units of accelerators, including the 6 × 2 MeV Van de Graaff, the 6 ~ 25 MeV electron-cyclotron accelerator, the 100 MeV electron linear accelerator and the 35 MeV proton linear accelerator, etc. The HI ~ 13 Tandem Van de Graaff introduced from the United States went into operation in 1986 at the Beijing Institute of Atomic Energy of MNI with accelerated energy being increased from 26 MeV of light ion to 4.3 MeV of silicon ion. With these equipments, the Chinese scientists and engineers have done a great deal of fundamental research work yielding great achievements in this regard.

D. Application of Isotopes and Nuclear Techniques

A sound foundation for a sizable development, production and application of isotopes and nuclear techniques has been laid down in China. For routine supply, there are nearly 800 types of isotopic products being available in the market and more than 2000 domestic clients are now making use of radioisotopes. At present, professional staff doing the business accounts for over 10 thousands. Isotopic techniques and other nuclear technologies thus have been extensively applied in various sectors of agriculture, medicine, petroleum and coal industry, metallurgy, water conservancy, building materials and chemical engineering and in the fields of physics, chemistry, biology, archaeology and environmental protection.

In line with the principle of equality and mutual benefit, the cooperation in the stated four areas could be launched by adopting the different forms as follows:

- accept training of personnel in China or send Chinese experts abroad for scientific lecturing;
- hold technical seminars on bilateral or regional bases;
- use the China's facilities to carry out joint research projects;
- provide expert service; and
- cooperate in certain joint projects such as in uranium exploration and in the utilization of radiation facilities, research reactors, etc.

4. THE PROPOSED PATTERNS OF COOPERATION

In view of the current situation prevailing in the cooperation in the region, we hereby propose to further expand the cooperative activities.

A. The scope of the cooperation within the framework of RCA under the auspices of the IAEA could be further enlarged. Up to now, a fairly number of training courses on application of radioisotopes and nuclear techniques have been held effectively under the RCA programme. In this context, it is proposed that the activities in nuclear safety, operation and management of nuclear power plant, nuclear fuel cycle and treatment and disposal of radwastes could also be incorporated into the programme.

B. Japan is one of the regionally most advanced countries in nuclear technology and also one of the most developed countries in economy in the world. It is therefore expected that Japan could make greater contributions to the cooperation in the field of peaceful uses of nuclear energy among the Asian countries. Since the Scientists Exchange Programme in Nuclear Energy Research between Japan and the Neighbouring Countries which is sponsored by the Science and Technology Agency enjoys appreciation in China, it is hoped that the Programme could be expanded from exchange of personnel to engagement in joint research projects by using some existing facilities in China to pursue experiments whereas the manpower is provided by China and the experimental results are shared mutually by both sides.

C. In the light of conditions and requirements of the Asian countries, we consider it appropriate to establish an Asian International Programme for the purpose of jointly developing some long-term projects of high cost. For instance, the installations that have been already completed in one state, like Tokamak Facility, the Tandem Accelerator and the High-Flux Reactor in China, could be used jointly by other states, where the parties bear the operating costs while scientific results are shared among the participants, thus helping to reduce operating costs of utilities and obtain fruits at smaller cost. In particular, academic thinking can be expedited and livened up through such practices.

D. We endorse the establishment of both nuclear power training center and nuclear power operating information center in Asia with the view to further strengthening nuclear power cooperation in the region. We hope that these activities could make progress. In the mean time, we wish to see the expansion of the training center's workscope which includes not only the training of operators at simulators, but also the on-the-job training for designers and builders at sites of nuclear power plants under construction so as to facilitate the Asian countries in constructing nuclear power plants by self reliance and in safe conduct of power reactors.

In short, strengthening the cooperation in the field of peaceful uses of nuclear energy depends upon not only the willingness of one state, but also the desire of the cooperating parties. We shall strive, within our power, for the realization step by step of all possible cooperative projects in line with the spirit of equality and mutual benefit.

Thank you!

ENHANCING THE PRODUCTIVITY OF RESEARCH AND DEVELOPMENT COOPERATION IN THE PEACEFUL UTILIZATION OF NUCLEAR ENERGY

Djali Ahimsa *)
BATAN - INDONESIA

It is indeed a great honour for me to be invited to attend the 21st JAIF Annual Conference and to be given an opportunity to speak before the panel on cooperation in this region in the field of nuclear energy development and utilization.

Japan through JAIF is to be commended for its continuous efforts for cooperation in the peaceful utilization of nuclear energy. It is my hope that this role is continued, expanded and deepened in the near future.

The Indonesian nuclear program is based upon the state philosophy and basic law and is aimed at realizing a just and prosperous society in a united and democratic nation and at the same time to contribute in the strengthening of world's peace.

Selfreliance is one of the basic strategies in the development and implementation of the nuclear program. This means that we must develop strong scientific and technological manpower, research and development infrastructure, management and organization. It should be stressed of course that selfreliance does not preclude mutually fruitful cooperation with developing and develop nations in the peaceful uses of atomic energy.

*) Director General - National Atomic Energy Agency - BATAN

The last 30 years the world has witnessed convincing progress in the development and utilization of nuclear science and technology both in advanced nations as well as in developing nations. At the present time, nuclear energy supplies a substantional portion of electricity generation in the world, on the other hand the application of radioisotopes and radiation has made great contribution in various sectors such as : health, agriculture, hydrology, public works, industry and environmental research. In other words, nuclear energy is unavoidable due to its great usefulness for the society and its already proven safety.

I will now touch on some aspects about cooperation, its frameworks and modes. In a world characterized by increasing interdependence and also increasing crises in energy economy, it is always invigorating to discuss and to realize cooperation in nuclear energy field. It should be stessed however that this cooperation should be effective and productive not just symbolic.

If this cooperation is to be effective, various factors both technical and non-technical should be considered. In the first place we must try to enhance and deepen mutual understanding on each other's program.

Good knowledge on resources, expertise and research infrastructure in participating countries is a necessity and of important. Developing countries with limited resources should, if possible, avoid duplications of facilities available in other countries. Well coordinated effort on cooperation could increase the efficiency of existing facilities in these countries.

Another important aspect in enhancing cooperation are personal contacts between scientists, engineers andother officials of the region through conferences and seminars which are held. This is important in developing conducive environment for cooperation, to increase exchange of information and to expedite the execution of the joint program toward successful results.

As mentioned earlier certain framework should established as the basis to create a successful cooperation. The Regional Cooperative Agreement (RCA) under the auspieces of International Atomic Energy Agency is one of such frame works already axist and operates successfully.
This RCA framework has benefitted developing countries in Asia and the Pacifics especially in the field of radioisotopes and radiation applications. Through continous effort and understanding of the participating countries RCA programs is contineously expanding.

Other framework should be pursued actively such as establishing of bilateral cooperation between develop and developing countries and among the developing countries itself to exchange its experience in development their nuclear program.

It is to be noted that since 1985 Japan as an advanced country has been very active in promoting cooperation with Asian countries and bridging communication among the developing countries for our mutual benefits. It is hoped that Japan and other advanced countries can continue to act in this capacity so that the cooperations among the developing nations in nuclear energy can produce concrete result.

The last point that I would like to mention in relation to the cooperation modes is the creation of cultural environment that could contributs to a smooth and fruitful cooperation. In this respect I believe good personal contacts among scientists, engineers and officials in the region through meetings and regional seminars can achieve such purpose. This forum will facilitate exchange of ideas and information at the technical level and also discuss common programs informally.

Indonesian will offer its ready build research centres at Serpong to be used as one of the site for cooperation in the development of nuclear program among developing countries. Participation of advance countries would enhance the creasibility of such cooperation.

I will not discuss any specific topic or field for cooperation, but to give you some broad picture of our program and facilities available for cooperation. (See annexes).

It may also be interesting to mention possible fields of cooperation. Nuclear safety is one issue that we have to look into to boost healthy development of nuclear energy.

With new developments that we have seen lately it is also very important to exchange experience in regulatory practice and quality assurance program.

For developing countries assistance in reviewing of energy demand and supply planning is very important.

To increase the result of research in developing countries joint research programs are very efficient and effective to reach our mutual goals. For while exchange of scientists, engineers and specialists will smoothen this cooperation.

ANNEXES

MAIN FACILITIES AVAILABLE AT SERPONG NUCLEAR COMPLEX

A. Reactor Installation

The reactor is based on the concept of an H2O swimming pool reactor with beryllium reflector. The core design of the reactor provides experimenter with two significant features :

- the core and the beryllium reflector with its large volume vertical irradiation channels, and
- an optium arrangement of beam tubes, located within the high thermal neutron flux field (2.1 - 2.6 x 10^{14} n/cm^2/s) with energy less than 0.625 eV.

The reactor is designed for a thermal output of 30 MW and a peak value of thermal flux in Central Irradiation Position 5.38 x 10^{14} n/cm^2/s.

The Reactor Facility includes : Pneumatic Transfer System, In pile loop, Neutron Beam Tube, Vertical Irradiation Channel.

1. Pneumatic Transfer System

Several irradiation positions in the reflector are charged and discharged via one pneumatic transfer system and four hydraulic transfer system. The pneumatic transfer system with the required track switches ends in a hot cell allocated to the reactor and equiped with lead-glass windows and hand manipulators. The hot cell provided for handling the samples has an area of approximately 2x4 m^2.

2. In-pile-loop

The in-pile facilities will perform the irradiation experiments for testing of specific properties and functions of subassembly of part assembly of fuel bundle for PWR, PHWR and MTR and for testing of materials for the reactor structure.

The PWR/PHWR in-pile loops are high pressure (150 bar) and high temperatur (250-320 C water temp) loops and capable for fuel testing with PHWR bundle of 12-6 rods and 500 mm long and with PWR bundle of 21 rods and 500 mm long. The Material Testing Reactor in pile loop will allow irradiation of fuel samples of MTR type in one irradiation position of the reactor.

3. Neutron Beam Tubes

Inside the reactor pool, horizontal beam tubes and vertical irradiation channels are provided for irradiation experiments. Two horizontal beam tubes arranged tangentially to the core and four horizontal beam tubes arranged radially to the core. The beam tubes are made of ALMg3 and have inner diameter of 150 mm. The beam tube noses are conducted into the interior of the beryllium block reflector up to core vicinity and have geometries optimized with regard to neutron physics. (The neutron flux is about 2.1 - 2.6 x 10^{14} n/cm^2/s with the neutron energy less than 0.625 e V). They are arranged on 3 levels, on core centre level and on level 200 mm above and below this.

4. Vertical Irradiation Channels

Vertical irradiation channels are provided in incore and out of core irradiation positions. The essential irradiation channels are as follows : 3 vertical in core irradiation channels with area 77 x 81 mm, 1 vertical in core irradiation channel with area 154 x 162 mm, several vertical irradiation channels in the beryllium reflector with and without pneumatic transfer system with area 77 x 81 mm. Three out of core positions in the region of the beryllium reflector elements are connected via the Pneumatic Transfer System with the hot cells arranged to the reactor. The capsules facility will allow irradiation experiments with UO_2 fuel pellets/pin of about 10 cm length and 12 mm diameter and steel or zircaloy specimen to test creeps behavior under irradiation.

This facility will allow control of the temperature and the load of the specimen under creep test for a maximum tensile load of about 100kg and a maximum temperature of 900 C.

The reactor also provides a power ramp test facility for power ramping of single fuel rod and power cycling under PWR and PHWR operating conditions. The neutron radiography facility is used for non destructive testing, in particular for testing of fuel rod. It also can be used for the examination of hydrogenous object.

The reactor is equiped with the Silicon Doping Facility to produce high grade semiconductor materials.

B. Fuel Element Production Installation (FEPI)

The purpose of the FEPI is to produce MTR-type fuel elements using either U_3O_8 or UAL_x fuel to saatisfy the demand of the Multipurpose Reseaaarch Reactor for refueling. In the Facility there are two production lines, one being alternate to the other, i.e. : the U_3O_8-fuel element and UAL_x-fuel element production lines. It is possible to utilize the plant for research and development. It is planned that the R&D program will cover the following activities :

- Fuel modelling
- development of new alternate fuels
- improvement of fuel element performance in the reactors
- and other relevant activities

C. Engineering and Safety Installation (ESI)

Construction of the Engineering and Safety Installation (ESI) will be completed in 1989. This laboratory is a materials fabricating and testing facility for components found in pressurized water reactor (PWR) and pressurized heavy water reactor (PHWR). THe ESI has a primary loop, a general loop, a test rig, non-destructive testing and destructive testing equipments, and in-pile facilities. The ESI facilities will carry out a variety of thermohydraulic tests and experiments on materials, structures and equipments of interest for Nuclear Power Plants.

In the future the ESI will help acquire the technology of research and power reactors, nuclear power plant components and nuclear safety.

D. Radiometallurgy Installation (RMI)

Construction of the Radiometallurgy Installation (RMI) will be completed in 1990. The RMI allows the performance of various Post Irradiation Examination on different types of reactor fuel and components. Destructive and non-destructive examinations are carried out in series of adequately shielded hot cells. The RMI also contains various non shielded laboratories, maintenance and storage facilities and support facilities.

The RMI will be used for research on structural materials of fuel element i.e. zircalloy, Al, Si, burnable poison and commencing post-irradiation examinations of reactor components in cooperation with Reactor Installation.
In the future the RMI, in cooperation with the Fuel Element Production Installation (FEPI) and the Experiment Fuel Element Installation (EFEI) will have acquired the technology of power reactor fuel element and advanced fuel element fabrication.

E. Radioisotopes Production Facilities

One of the supporting facilities in Center for the Preparation of the Nuclear Industry in Serpong is Radioisotopes Installation (RII), which has been designed for Producing radioisotopes and radiopharmaceuticals needed in industry, hydrology, agriculture, and medical purposes. In addition to the 30 MW pool type reactor, various laboratories is being installed to support the process. These include uranium assay, non uranium analysis instrument, wet preparation, incubator and particle count, QA counting, bioassay, and animal laboratories.

Radioisotopes and radiopharmaceuticals are produced in two separate sections of the plant. The radioisotopes-portion of the plant will produce three types of fission - product radioisotopes and 21 types of activation product radioisotopes as listed in Table 1, while the radiopharmaceuticals portion of the plant will produce several types of nonradioactive pharmaceuticals and one type of radioactive pharmaceutical, shown in Table 2. The annual production capability is up to 30,000 cold kits. Molybdenum-99 produced at the radioisotopes portion, is used in the radiopharmaceutical portion as ^{99}Tc -----> ^{99}Tc isotope generator, and from that ^{99m} - containing pharmaceutical. The production of ^{99} Mo -----> ^{99m}Tc generators will be 12.000 unit per year. The total ^{99} Mo activity in each generator at time of shipment will be within a range of 0,83 Ci to 4,14Ci (in lead pigs).

At the Center we will also install a CS - 30 Cyclotron with the capability of producing the specified external beam currents for 26 Mev proton, 15 Mev deuteron, 38 Mev He_3 and 30 Mev He_4. A chemical processing system is available to produce the commercial quantities of short lived radioisotopes such as Tl-201 and Ga-67 from the suitable targets in the ion-beam. The installation will be finished in middle of 1989, while the firs goal of our radioisotope production is the medical radiopharmaceuticals ^{201}Tl - chloride and ^{67}Ga - citrate.

Table 1

RADIOISOTOPE PRODUCTION

Radioisotope	Production Rate (Ci/yr)	Target Description	Approx. Target Qty(../yr)	Approx. Target Qty(gm/yr
Co-60 Source	25,000	Co metal wire	52	500
Ir-192 Source	10,000	Ir metal wire	52	1,000
Mo-99 Activation	1,000	Mo O_3	52	1,000
P-32	500	Sulphur	12	1,500
I-131	500	TeO_2	26	1,500
I-125	75	40% enriched Xe-124 gas	N/A	100 mL/Yr @ STP
S-35	52	KCL	6	200
Mo-99 (F.P)	10,000	UO_2 (93% U-235)	52	250 maximum
Xe-133 (F.P)	3,000	Same target as Mo-99 (F.P)	-	-
I-133 (F.P)	100	Same target as Mo-99 (F.P)	-	-
Cr-51	1	Cr metal (enriched)	12	0,010
Fe-59	0.1	Fe_2O_3(enriched)	1	0,010
Sr-85	0.1	$SrCO_3$(enriched)	1	0,020
Hg-203	0.1	HgO (enriched)	1	0,025
Se-75	1	Se (enriched)	1	0,020
Sn-113	0.1	Sn (enriched)	1	0,020
Yb-169	0.1	Yb_2O_3(enriched)	1	0,045
Na-24	50,000	Na_2CO_3	104	2000
Cl-36	0.1	KCL	1	100
Ca-45	0.1	$CaCO_3$	1	0,060
Ni-63	0.1	NiO (enriched)	1	0,15
Fe-55	1	Fe_2O_3	1	0,040
Mn-54	0.1	Fe_2O_3	1	10
Sn-119m	0.002	Sn (enriched)	1	0,010

Table 2

PHARMACEUTICAL PRODUCTION

Pharmaceutical	Pharmaceutical Description
DPTA	Diethylenetriamine Pentaacetic Acid Kit
HSA	Human Serum Albumin Kit
MAA	Macro-Aggregated Albumin Kit
HIDA	Hydroxyde-Idio-Amine Kit
HEDSPA	Hydroxy Ethylidene Disodium Phosphonate Kit
TSC	Technetium-99m Sulfur Colloid Kit
ASC	Antimony Sulfur Colloid Kit

"Significance of the Development of Nuclear Energy in Korea and Possible Ways of the Regional Cooperation in this Field".

Mr. Chairman,

Ladies and Gentlemen,

It is my great honor and privilege to present views on " Significance of the Development of Nuclear Energy in Korea and Possible Ways of the Regional Cooperation in this Field", as a panel member at the twenty-first Annual Conference of JAIF.

Firstly, I would like to briefly mention about nuclear power development program in Korea.

---- Slide 1 ----

As shown in the first slide, there are now seven nuclear power plants in operation, which shares over 50% of electricity generation, and two nuclear units are under commissioning stage, and two other nuclear units are in design stage.

--- slide2 ---

Three 600 MWe class nuclear power plants were constructed on the turn-key approach in the early 1970s, which can be catagorized as a first generation nuclear power projects. Some domestic companies had participated in construction works as sub-contractors to foreign suppliers.

Six 900 MWe class nuclear units, which can be classified as the second generation nuclear projects, have been carried out under the framework of the component approach. In due course, mostly architect engineering technology and eqnipment manufacturing technology have been developed to certain level. Local participation rate in architect engineering and hardware manufacturing through the second generation nuclear project was little over 40 percent.

It is realized, however, that software related technologies including nuclear steam supply system design technology are hard to be promoted without having indigenous research and development endeavors and without the involvement of highly educated manpower. Last year, mainly by the virtue of succeaful experience in indigenous development of PHWR fuel technology, Korea decided to carry out 1,000 MWe nuclear power projects through which self-reliance in nuclear power technology is to be achieved. For performing the third generation nuclear power projects, all nuclear related domestic organizations including nuclear research institute have been participating in the project according to their respective functions, as shown in the next slide.

... slide 3 ----

For example, Koear Electric Power Corporation (KEPCO) is responsible for the overall project management. Korea Advanced Energy Research Intitute is doing for NSSS system design and fuel design, while Korea Heavy Industries and Construction Company is carrying out hardware manufacturing and component design works.

The purpose of functional identification of each organization is to eliminate unnecessary duplication of investment and to have critical manpower in each designated field in order to effectively achieve self-reliance in nuclear power technology by the year 2000.

Now I would like to share with you some experiences in nuclear power technology development. At the beginning of the 1980s, KAERI changed its main goal from nuclear technology development to nuclear power technology development in order to actively participate in nuclear power projects, through which self-reliance in nuclear power technology can be effectively achieved.

...slide 4....

At the beginning of the 1980s, KAERI decided to develop its own capability for design and manufacturing CANDU fuel, using a pilot fabrication plant which has operated since 1978. After three years of R D efforts, KAERI was successful developing indigenous CANDU fuel technology with an extensive support of AECL of Canada. The full core of KNU-3 has been loaded solely with KAERI-made fuel from July, 1987, which will annually save several million US dollars of nuclear fuel import cost. To this end, KAERI recently expanded its pilot scale fabrication plant to the capacity of a semi-commercial scale plant. When it expanded the capacity of its fabrication plant, KAERI also tried to indigenously develop some of the machines and equipment in connection with plant expansion, with small and medium-size manufacturing companies.

By doing so, it is believed that the capability and quality of domestic industries have been improved and several million dollars of investment have been saved.

For PWR type fuel design, KAERI concluded a technology transfer contract with KWU of the Federal Republic of Germany in August 1985. Starting in 1989 all the fuel assemblies required for Korean PWR NPPs will be designed by KAERI and be manufactured by KNFC (Korea Nuclear Fuel Company), which has a plant capacity of 200ton per annum.

We expect annually over fifty million dollars of reduction in foreign dependence, through this project from 1989. It is realized that as the technical capability of KAERI is built up, technical collaboration with foregin R&D institutions should also be increased.

Now, I would like to briefly mention about, "Possible Ways of the Regional Cooperation in Nuclear Energy Fields."

--- slide 5 ----

Korea has long been one of technology recipient countries of the IAEA, since she became a Member State in 1957. Many cooperation activities with the Agency have been carried out through manpower training and expert services. Korea became one of donor countries of the Agency from 1987.

---- slide 6 -----

In addition, my country has made efforts to strengthen relationship particularly with the Asian and the Pacific Countries to share our experiences and technologies for the peaceful uses of nuclear energy especially through the RCA (Regional Cooperative Agreement). Since Korea became a member of the RCA, my country firmly believes that the RCA carries an important vehicle to accomplish regional cooperation through collaboration particularly among member countries. In line with this spirit, irradiation facility of the KAERI has been used for the regional training course as it was selected a Centre of Excellence of UNDP/RCA project. In addition, Korea hosted the RCA Regional Workshop on photon, Electron and Neutron Dosimetry in Radiotheraphy in June, 1987. It also plans soon to host the IAEA Inter-regional Training Course on Nuclear Power Project Planning and Implementation.

Regional cooperation has been so far emphasized in the fields of application of radiation and radio-isotopes to food irradiation and medical uses. However, in the long-run, nuclear power generation projects, which are currently limited in such east Asian countries as Japan, China, and Korea, need to be more widely carried out in the Region.

For the countries planning to have nuclear power program, Korea, which is now in the threshold stage of self-reliance in nuclear power technology, can share the experiences mainly in the following areas such as feasibility study on introduction of nuclear power program, nuclear fuel design and manufacturing, nuclear safety, and rad-waste management. We all know that there is no border of countries, as far as possible damage of nuclear accident is concerned, as we experienced in TMI accident, and Chernobyl accident which were occurred in well advanced nuclear power countries. Therefore, we need more strong regional and international cooperation in the field of nuclear safety enhancement and effective measures for public acceptance of the nuclear power. At present, nuclear cooperation has been implemented within the framework of multilateral agreement between concerned countries through IAEA/RCA. For more effective cooperation in the region, these agreements are desirable to be applied more widely in the region in the near future. In any case, however, it should be kept in mind that the agreement be provided under the principle of nuclear non-proliferation regime and on the basis of mutual benefits and respects of sovereignty.

Mr. Chairman:

Now, I would like to conclude my presentation with hope to strengthen the regional cooperation in the field of nuclear energy.

In this connection, I sincerely hope the leadership of the Japanese nuclear industry will be taken place, particularly through the arrangement of the JAIF.

Thank you very much.

NUCLEAR POWER PLANTS IN KOREA

- o Units In Operation
  - 6 PWRs And 1 CANDU
  - Installed Capacity : 5,716 MWe

- o Units Under Construction
  - 2 PWRs Of 950 MWe
  - COD : '88 and '89

- o Units In Design
  - 2 PWRs Of 950 MWe
  - COD : '95 and '96

KAERI

CONTRACT APPROACH TO NPP CONSTRUCTION

- o Up To Mid '70s : Turn-key Base
  - Domestic Constructors Participated As Subcontractor.
  - 3 x 600 MWe Units (2 PWRs and 1 CANDU)

- o Late '70s : Component Approach
  - Domestic Companies Participated As Subcontractor For A/E And Equipment Manufacturing.
  - 6 x 950 MWe Units (6 PWRs)

- o From '80s : Self-Reliance In Technology
  - Maximum Utilization Of Domestic Institutions
  - From Korean Nuclear Units 11 & 12 (2 x 950 MWe, PWRs)

KAERI

DIVISION OF ROLES IN NUCLEAR POWER TECHNOLOGY DEVELOPMENT

ROLE	INSTITUTION
Project Management	KEPCO
Plant Design	KOPEC
NSSS Design	KAERI
Fuel Design	KAERI
Hardware Manufacturing	KHIC
PWR Fuel Fabrication	KNFC

KEPCO : Korea Electric Power Cooperation
KOPEC : Korea Power Engineering Company Incooperation
KAERI : Korea Advanced Energy Research Institute
KHIC : Korea Heavy Industries & Construction Company Limited
KNFC : Korea Nuclear Fuel Company

KAERI

SELF-RELIANCE IN NUCLEAR FUEL FABRICATION

o CANDU Fuel
  - KAERI Succeeded In Commercialization Of CANDU Fuel Fabrication With KAERI-Developed Technology In Early '80s.
  - Whole Core (100 ton/yr) Of Wolsung Unit 1 Is Supplied With KAERI's Fabricated Fuel From July, 1987.

o PWR Fuel
  - KAERI Is Performing Reloading Fuel Design Jointly With KWU.
  - 200 ton/yr Will Be Supplied From KNFC's Commercial Fabrication Plant From '89.

KAERI

KOREA'S COOPERATION WITH IAEA

- o General Status
  - IAEA Member State From 1957
  - Member Of The Board Of Governors For 1988-89
  - Donor Country From 1987

- o Cooperation With IAEA
  - Manpower Training, Expert Utilization, etc.
  - Openning RCA Training Courses
  - Hosting International Conferences

KAERI

PARTICIPATION OF KOREA IN RCA PROJECT

o Irradiation Facility At KAERI
  - Selected As Center Of Excellence Of UNDP/RCA Project
  - Has Been Used For RCA Regional Training Courses

o Korea's Participation In RCA Projects
  - Participated In 17 Projects
  - On-going UNDP/RCA Industrial Projects Using RI
    - Tracer Technology
    - Non-Destructive Testing
    - Radiation Processing

KAERI

POSSIBLE AREAS FOR REGIONAL COOPERATION

o The Present Cooperation Is Mainly Related To Application Of Radiation. Nuclear Power Generation Projects Should Be Carried Out More Widely In The Region.

o Cooperation Fields Possible For Korea Are As Follows.
  - Manpower Training
  - Feasibility Study On NPP Introduction
  - Nuclear Fuel Design And Manufacturing
  - Rad-Waste Management

KAERI

Cooperation Among Asian Countries in the Utilization of Nuclear Energy

by

Quirino O. Navarro
Director
Philippine Nuclear Research Institute
Quezon City, Philippines

During the panel discussion on regional cooperation at the 15th Japan Conference on Radioisotopes, it was my privilege to speak on a number of factors which influence the extent of cooperation among countries in the region. These included: national priorities, culture of the people, stage of a country's development, existence and identification of centers of excellence, fields of interest of local scientists, management of contributed resources, commitments of donors, and the role of the IAEA and multilateral agreements in promoting, cooperative programs. These factors still remain valid.

The success of the first phase of the UNDP/RCA Industrial Projects augur well for expansion into other projects along industrial, agricultural, medical and even business applications. Cooperation can be enhanced farther through the strengthening of bilateral and multilateral agreements which are facilitative of the transfer of relevant technologies and supportive of exchanges of information, expertise and scholars.

In the last few years, significant events occurred in the field of nuclear energy which will significantly have an impact on areas of common interest and the people's perception of nuclear energy applications which should form bases for collaborative efforts within the Asian region. These are: the Chernobyl accident, the agreement between the superpowers on partial reduction of nuclear armaments; and on the part of the Philippines, the government's decision to "mothball" the first Philippine Nuclear Power Plant and the ratification of the Philippine Constitution which has a provision for a "nuclear weapon free" policy.

The countries of the region, although distant from the site of the Chernobyl accident, were recipients of radioactive contaminants in varying intensities through trade activities and atmospheric movements. These transboundary effects point to the need for information and laboratory networks for early detection, mitigation and mutual assistance in cases of major nuclear incidents which may occur in the future. The non-operation of the nuclear power plant in the Philippines resulted in a temporary "excess" of nuclear expertise which could be shared with other countries, and the requisite preservation program for this plant provides valuable insights into nuclear power programs and energy planning of Third World countries. Currently proposed national legislation which are aimed at supporting a nuclear-weapon free policy would be of interest to neighboring countries.

The experiences gained in several decades of cooperation among countries in Asia, through bilateral and multilateral arrangements, if properly evaluated, could provide a consensus on the best approach to enhancing cooperation among these countries with the end in view of an Asian nuclear community attuned to the needs of the twenty-first century.

Mr. Chairman:

A famous Asian once said: "A picture is worth a thousand words". Allow me to follow his dictum and share with all of you this picture (Figure 1).

The utilization of nuclear energy in all its forms brings with it both benefits and harm. In most ways our geopolitical system behaves like a physical system in its interaction with the prevailing environment in which people find themselves. In both constructive and destructive utilization of nuclear energy, we have taken a first step.

To paraphrase an old philosopher's adage:"A journey of a thousand li begins with the first step", is enlightening. We have done so and it is hoped that the next steps will be arrived at by this panel with the objective of collective cooperation among Asian nations and peoples, rather than by calamitous competition among them in the exploitation of current developments in nuclear energy utilization.

Thank you, Mr. Chairman.

---

*Paper presented at the 21st Annual Conference, Japan Atomic Industrial Forum, 13-15 April 1988. Tokyo, Japan.

BIG BANG

Universe

Star

Earth

Thorium Uranium (Neptunium) Actinium

NATURAL RADIOACTIVITY

Ra

$^{27}Al(\alpha,n)^{30}P$

Ra + Be

U (n,f) fp

n ----- n'

^{6}Li + ^{2}H

$E = Mc^2$

NUCLEAR TECHNOLOGY

H-bomb A-bomb Radioisotopes Power

?

Effect on
Man and Environment

$$-\,(\underline{E}\,/\,\underline{M})^{\frac{1}{2}} = \underline{C} = +\,(\underline{E}\,/\,\underline{M})^{\frac{1}{2}}$$

Contaminated Clean

Competitive Cooperative

Figure 1

QON-04-14-88-Jaif

近隣諸国との原子力協力の展開（原子力発電分野）
（キーノート要旨）

（社）海外電力調査会　専務理事
武　田　　康

１、近隣諸国の原子力開発と協力ニーズ

アジア近隣諸国では、近年産業の発展、生活環境の向上を反映して、電力需要は高い伸びを示している。　各国とも電力需要の将来予測と資源の実情に応じた長期の見通しを立てているが、そのなかで原子力発電の開発に対するニーズは次第に高まっている。

原子力発電の開発を進めるについては、各国とも人材の養成、技術の修得、資金の調達、産業基盤の整備など、過去３０年を通じて我が国が経験したのと同様な課題を、自らの力で、また国際協力を通じて克服していくことが必要である。

２、我が国の協力の進め方

我が国は、海外から原子力発電技術を導入しつつ官民一体となって安全性、信頼性の向上に努めてきた結果、現在世界的に見て規模・技術とも極めて高い水準に達している。

この原子力発電の導入から定着に至る３０年の経験は、これから本格的に原子力発電の開発に取り組もうとする近隣諸国にとって貴重な教訓を含んでいると考えられる。

我が国としては、自らの経験が有効に生かされるよう、近隣諸国のニーズに積極的に対応していきたいと考えている。　具体的には、各国ごとの国状を勘案し、真のニーズを踏まえながら、各国の原子力発電が適切・円滑に進められるように協力を進めていきたい。

３、我が国の協力体制

１９８６年3月通産省の総合エネルギー調査会によって基本的な原子力発電技術協力のあり方についての報告書がまとめられ、その後の協力の指針となっている。

そのなかで国は、協力が円滑に実施されるよう、対外的には全体の窓口となるとともに国内の総合的な取纏めを行ない、具体的協力の進め方について方針を示すこととなっている。

また民間における協力については、各国からのアクセスが容易にできるとともに多様な協力ニーズを的確に把握し、対応できる調整力のある窓口機関を必要としている。　この趣旨にそって海外電力調査会は、主として電気事業者が担当する協力についての窓口となっている。

４、電気事業者の協力活動

我が国の原子力発電開発は、国の平和利用の促進という基本政策の下に、電気事業者が中心となりメーカ、工事業者との密接な連携のもとで、自主技術の向上を図りながら、安全の確保と信頼性の向上に努めてきた。　そのなかで電気事業者は、開発・導入計画、建設現場の施工管理、発電所の運転・保守まで一貫して人材の育成と技術の蓄積を行なってきた。

我が国の電気事業者としては、この人材・技術・経験の蓄積を生かして、近隣諸国における技術的・人的基盤の整備・充実を支援することに重点を置いて協力を進めている。

具体的には、次の通りである。

(1) ＪＩＣＡ集団研修原子力発電コース（１９８６年開設）
(2) 原子力発電所の計画、建設、運転・保守の各段階における人材育成
　（専門家の派遣、専門家・研修生の受入れ）
(3) その他各国で開催されるセミナー等への専門家派遣

これらについて、過去２年半の実績（電力中心のもの）を示すと、次の通りである。

(1) ＪＩＣＡ集団研修　－－　３回実施、延１８名受入れ
(2) 専門家の派遣　－－－－１２件（３３名）を派遣
(3) 専門家等の受入れ　－－１２件（４１名）を受入れ

５、電気事業者による協力の実施体制

電気事業者による原子力発電分野の協力は、９電力会社・日本原子力発電会社がその蓄積と人材を結集し、海外電力調査会を窓口として実施している。

窓口の海外電力調査会には、１９８５年８月に各電力会社等をメンバーとする原子力技術協力委員会（委員長大石関西電力常務、副委員長佐々木東京電力原子力業務部長）が設けられ、委員会での検討を経て、協力計画の立案とその具体化に当たっている。

この委員会は１１電力会社および政府機関からのメンバーにより構成され、また原産会議、メーカー等関係機関メンバーが参加しており、多様な国際協力についての相互連絡の機能も持っている

６、おわりに

以上我が国の電気事業者が行なっている原子力発電分野の国際協力の現状を述べたが、今後協力の実を挙げていくためには、近隣諸国との相互の深い理解と信頼のうえに立って協力しあうことが重要である。

我が国電気事業者による協力の窓口担当者として、我が国電気事業者による協力内容、実施体制等について各国の一層の理解を得、我が国が蓄積してきた原子力発電についての経験をより一層利用していただけるように努力したい。

以　上

Cooperation with Neighbouring Countries in the field of Nuclear Power Generation (Keynote)

Ko Takeda
Executive Managing Director
Japan Electric Power Information Center, Inc.

1. Nuclear Power Development in the Neighbouring Countries and the Needs for International Cooperation

In our neighbouring countries, there has been remarkable increase of electric power demand, as a result of recent effort for industrial development and improvement of living standard. Each of the neighbouring countries has established long-term rolling-plan on power resources development, taking into account its own national enegy policy, available resources and estimated future power demand. And nuclear power generation seems one of the most important concern in their future development plans.

In order to proceed the development of nuclear power generation, it will become necessary to promote man-power development, to master sophisticated nucliar technology, and to provide enough ammount of funds and adequate industrial infra-structure, based on self effort and through international cooporation.

These challenging problems, our electric power supply industry has been trying to overcome them with long range view-point recent 30 years.

2. Japan's Approach toward International Cooperation

Jpanese electric power industry introduced nuclear power technology from U.K. and U.S. at the initial stage of its nuclear business, and the joint effort of the government and the private sector since those days, particularly that of improvement of safety and reliability, has enabled us to take an higher place among the advanced nuclear countries in terms of operating plant capacity and the level of technology.

This 30 years experience of our nuclear power development, from initial introduction through nowadays, would be full of valuable lessons for those countries intending to introduce nuclear power generation and proceed its development program.

Our electricity supply industry is ready to respond to the needs of neighbouring countries in the field of nuclear power development through an effective transfer of those lessons.

Taking into acount the fact that each of neighbouring countries are in the different stage of nuclear power development and they have respective needs for corporation, we like to proceed our corporative activities, so as to enable them to promote their nuclear power development in an efficient and timely way.

3. Role of the Government and Private Sector in Japan

In March 1986, the Sub-Committee on Nuclear Energy of the Advisory Committee for Energy published it's report on the technical cooperation in the field of nuclear power generation with neighbouring countries. The report provide guidelines to various sectors relating international cooperation.

The report recommends to the government to act as overall liaison agent to foreign countries concerned, to take over the cordinative management of every cooperative activities by domestic parties, and to establish the scheme for proceeding international cooperation, so as to secure the steady progress of cooperative activity.

Regarding to the private sector, the report recommends to set up a proper liaison agent, to which every foreign parties may feel easy to make contact, The report also recommends the liaison agent shall be capable to collect various needs of foreign parties and to take countermeasures to those needs with the full support by domestic parties concerned.

Following this recommendation, Jpapn Electric Power Information Center Inc. (JEPIC) has been acting as a liaison agent representing Japanese electric power companies.

4. Cooperative Activities of Japanese Electric Power Companies

Nuclear power development in Japan has been carried out mainly by the electric utilities, under national basic policy to promote peaceful use of nuclear energy and with close collaboration with plant manufacturers and general contractors.

And we tried to promote the self-reliant technology as well as higher level plant safety and reliability.

In this respect, the electric utilities have been trying to have enough qualified man-power and necessary technology and experiences covering every stage of nuclear power development including planning, construction and operaion stage.

Using this man-power, technology and experiences, our electric utilities are proceeding their cooperation with neighbouring countries. placing major emphasis on the support to their effort for establishment and enhancement of technical and human resources.

The measures for cooperation are as follows:
(1) JICA's Training Course on Nuclear Power Generation (Since 1986)
(2) Support for manpower deveropment through dispaching of experts and accepting of experts and trainees. in the field of planning, construction, operation and maintenance stage.
(3) Other measures such as dispaching experts to seminars held in neibouring countries

Following figures are the result of cooperation by our electric power utilities for the period of these two and a half years.
(1) JICA Training Cource: 3 times, total 18 trainees
(2) Dispaching of experts: twelve times, total 33 experts
(3) Accepting of experts: twelve times, total 41 experts

(note) Adding to these figures above, dozens of experts were sent to neighbouring countries under schemes of JAIF and other organization.

5. The structure of the cooperation activities by electric utilities

International cooperation in the field of nuclear power generation has been proceeded by 9 electric power companies and Japan Atomic Power Co. Inc. with their highly established technology and qualified manpower.

In order to promote the cooperative works effectively, the Cooperation Committee for Nuclear Technology (Mr.Oishi,Managing Director of Kansai Electric Power Company, Inc. as Chairman and Mr.Sasaki, General manager, Nuclear Power Administration Department, Tokyo Electric Power Company,Inc. as Vice-Chairman) was organized in JEPIC in August 1986. With consultation of this Committee, JEPIC, the liaison organization, set up corporative program and carried out it's program.

The Comittee consists of members from eleven major electric companies and governmental sectors and associate members from relating organizations such as JAIF and manufacturers, and has a part of coordinative function among various sectors relating international cooperation.

6.Conclusion

This paper briefly describes current status of international cooperation activities by our electric power utilities. To make cooperative work more effective and fruitful, it is important to establish more close bilateral relationship based on mutual understanding and reliance..

As the liaison agent, JEPIC will contribute for more effective transfer of our experiences to neighbouring countries, with better understandings on our measures and schemes of cooperation by all of parties

(End)

午　餐　会

通商産業大臣所感

通商産業大臣所感
田村　　元

特別講演：東西文明の接点

京都大学名誉教授
会田雄次

第二十一回　（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

一（はじめに）

通商産業政務次官の浦野烋興でございます。

本日は、第二十一回、原子力産業会議年次大会、午餐会の席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、利用に長年携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。第二十一回年次大会が、このように盛大に開かれることとなりましたことを、心からお祝い申し上げます。

一（安全確保対策）

さて、私ども通商産業省は、原子力発電所の設計、建設、運転等の各段階において、厳格な安全規制を実施しているところでございますが、最近の状況を振り返ってみますと、昨年冬頃から本年にかけて、不

幸にして原子力発電所が故障、トラブル等で停止をするケースが二、三生じました。

こうした事態の発生は、それ自体誠に遺憾と申し上げざるを得ませんが、トラブル等がごく軽微であったにもかかわらず、原子炉を停止することとなりましたのは、「いかなる小さなトラブルでも、安全を最優先し、原因を徹底的に究明し、早期に対策を講じる。」という安全第一の考え方を貫いた上でのことと承知しております。今後、この一連の事態を、原子力発電の安全に対する認識を新たにする機会と真摯に受けとめ、関係諸方面の共知を結集し、故障、トラブルを未然に防止するための努力を一層進めていくことが重要であります。

また、通商産業省といたしましては、去る三月二十四日に「第2回セイフティ21推進委員会」を開催し、一昨年より進めてまいりました、原子力発電安全確保対策の一層の充実を目指した総合的な施策である、通称「セイフティ21」計画を推進していくことを再確認したところであります。

さらに、来る5月は「原子力発電安全月間」であり、原子力発電実務功労者の表彰、講演会の開催等を通じ、原子力関係者の安全に対する意識の高揚等を図り、原子力発電の安全性をより確実なものとしてまいりたいと考えております。

三 （P・A・対策の充実）

ところで、昨今の我が国国内における原子力発電を巡る動向の中でも、特に著しい動きを見せているのは、都市部を中心とする、新しいメディアを活用した一部反対運動の活発化であります。

このような動きの多くは、原子力発電の安全性、必要性、経済性などの基本的な問題について、正しい理解が得られていない人々がいることに端を発しているものと思われます。

これらの新しい動きに対応し、広く国民一般による原子力発電への確かなる理解と合意を得ていくためには、従来にもまして強力かつ柔軟な広報体制の整備と、広報活動の積極的な推進を図っていくことが重要であると私は考えます。

このため、通商産業省といたしましては、広報活動の抜本的な拡充を図ってまいる所存であり、本日御出席の皆様方を始めとする関係者の御支援と御協力をお願いする次第であります。

四 （国際協力の推進）

さて、今後の原子力発電のさらなる発展のためには、安全対策や広報の充実などの他にも、多くの課題がございますが、最近、特に重要性を加えている課題の一つに国際協力の推進があげられます。

ソ連チェルノブイル事故後の、原子力を巡る国際的な動向の中でも、最も重要な動きは、国際原子力機関（ＩＡＥＡ）や、経済協力開発機構・原子力機関（ＯＥＣＤ／ＮＥＡ）等を中心とした国際的な協調と協力への動きであると私は考えております。

通商産業省といたしましても、これらの国際機関の活動等に対する積極的な参画を通じて、原子力発電の安全規制や関連技術開発等の分野での情報交換等、様々な分野での多国間協力や、二国間協定に基づく協力を推進していく所存であります。

五　（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ましたが、これらの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、多くの人々の理解と、関係者の間での密接な協力が必要不可欠であります。このため、本日御列席の皆様を始めとする、内外の関係者の皆様の御協力を重ねてお願いする次第でございます。

最後になりましたが、有澤前会長の御姿を、本日、この場に拝見することができないことは、痛恨の極

みでございます。有澤前会長がたどられた原子力の分野での足跡は、まさに我が国原子力の歴史そのものと言っても過言ではなく、今日、原子力が石油代替エネルギーの中核としての位置付けを得ていることは、まさに会長の御尽力の賜物であると申せましょう。原子力を巡る多くの課題を、一歩ずつ、着実に解決していかなければならないこの時期に、有澤会長を失ったことは、大きな痛手と言わざるを得ません。

通商産業省といたしましても、会長の御遺徳をいつまでも忘れることなく、今後とも皆様の御協力の下、原子力発電の開発と利用を着実に進めてまいる所存でございます。

終りに際し、年次大会をかくも盛大に開催されました日本原子力産業会議の皆様の御労苦に深甚の敬意を表しますとともに、皆様の御発展を心からお祈り申し上げまして、私の挨拶とさせて頂きます。

セッション3
今日の原子力技術

西ドイツの乾式キャスク貯蔵開発の経緯と現状

西ドイツ核燃料再処理会社（DWK）専務取締役
W．ストラスブルク

カナダにおける使用済燃料処分の概念

カナダ原子力公社（AECL）副社長
W．T．ハンコックス

フランスのウラン濃縮技術開発の現状

フランス原子力庁（CEA）ウラン濃縮研究・物理科学部長
P．レニー

日本のウラン濃縮技術

東京工業大学名誉教授
高 島 洋 一

高速増殖炉の革新技術

動力炉・核燃料開発事業団理事
澤 井 定

核融合実験炉への道

日本原子力研究所特別研究員
苫米地 顕

先端技術と放射線利用

東 京 大 学 教 授
田 畑 米 穂

History and Actual Status of Dry Cask Storage Development in West Germany

---

Dr. Wolfgang Straßburg
Member of the Executive Board
Deutsche Gesellschaft
für Wiederaufarbeitung von Kernbrennstoff mbH (DWK),
Hamburger Allee 4,
FRG 3000 Hannover 1

I. "Entsorgungskonzept"

With the introduction of the so-called "Entsorgungskonzept" ("Entsorgung means the German term for all back-end fuel cycle activities starting from unloading used fuel from the reactor up to the disposal of all kinds of wastes arising from nuclear energy production) by the German Federal Government in 1974, pressure was increased on the utilities to take a greater initiative in the area of the back-end of the nuclear fuel cycle. It was the time, when the chemical industry had manifested that it was no longer interested in taking the enterprenerial lead in the field of reprocessing.

The "Entsorgungskonzept" is characterized by a division of responsibility between the operators of nuclear installations and the Federal State which is responsible for final disposal of all radioactive wastes in geologic formations. The utilities shall take care for all the other steps of the back-end of the nuclear fuel cycle.

In 1976, an amendment of the Atomic Law required that for new power stations operating licences should only be given, if wastes and fuel elements would be recycled or disposed of in a safe way. Priority was given by the law to recycling of the still valuable Uranium and Plutonium shares in the used fuel.

So DWK decided in 1976 to elaborate a more detailed concept of a nuclear fuel park. This meant that all the facilities for storage, reprocessing and fuel fabrication should be concentrated and this preferentially directly at the site of a final disposal repository, for which in Germany a salt dome was considered to be the best solution.

The concept to concentrate all facilities of the back-end of the fuel cycle at one unique site could not be realized due to political reasons; with the only exception, to build the facilities on separated sites the heads of the Federal and State Governments confirmed in 1979 the need to enlarge interim storage capacities, to expeditiously construct a commercial reprocessing plant, and to characterize the site of the repository at Gorleben.

Simultaneously, investigations of alternative disposal techniques, such as direct disposal of spent fuel without reprocessing, was requested to enable a decision to be made as to whether decisive safety related advantages would result from direct disposal. In 1985, on the basis of an evaluation of the scientific findings, the Federal Government found that there were no decisive reasons for dispensing with reprocessing.

In particular, the Federal Government concluded:

- that the need for fast implementation of a reprocessing plant remains;

- that the question posed by the heads of the State and the Federal Governments in 1979 as to whether decisive safety related advantages could result from direct disposal rather than reprocessing had to be answered with "no";

- that, in the light of today's state of the art, it would not permit the application of direct disposal techniques to demonstrate the required evidence of back-end provisions for LWRs; that, in principle, direct disposal was technically feasible but requires further R&D-work; that only in addition to reprocessing the development of direct disposal techniques should be continued, that international developments should be taken into consideration;

- that it would continue to apply direct disposal techniques for spent fuel where reprocessing is economically not justified.

II. Dry Cask Storage Development

Due to the results before-mentioned the Dry Cask Storage Development in West Germany has two objectives in subsequent and overlapping phases:

- development of casks suitable for interim storage of spent fuel;

- development of casks suitable for final storage and in addition for interim storage, if required.

Development started when it became clear to everybody that storage capacities would be needed in order to cope with the shortage of reprocessing capacity. The only available reprocessing facility in La Hague could not cope with a high demand and the new contracts proposed by COGEMA and BNFL made it evident that a long negotiation period would be necessary prior to signature.

Many ideas came up in order to build up storage capacity on a short term. The most logical one was compact racking within the power station pools. However, this was not possible; either for licensing or for simple static reasons within some of the elder power stations.

Another idea was to build a cask fleet corresponding to the total capacity of the biggest power reactor and to argue with the authorities in the direction that a fast transportable fleet could be considered as the emergency unloading capacity for all the German reactors. The consequence could have been that immediately in all reactors the three thirds of a spare unloading capacity could have been used for storage purposes giving a relief in storage capacity for at least three years.

However, this idea, though quiet practical and acceptable, did not find the necessary positive reaction of the authorities. So the next alternative envisaged was to build greater storage capacities based on dry storage casks.

This development had been initiated by Gesellschaft für Nuclear-Service mbH (GNS), a subsidiary of DWK. It was based on the casting process for the cask bodies for many evident reasons. One was that the fabrication of the big transport casks like TN 12 (forged steel) had taken a considerable time-span of almost three or more years; and it was reasoned that casks on a greater scale should be built within less than one year.

Furthermore, the forging capacities in Germany for such heavy rolls of steel were limited. The casting technology, however, could assure that greater numbers of casks could be produced within acceptable time-spans.

1. Safety Reasons and Tests

So, by the end of 1977, DWK decided to give a development contract to GNS based on the CASTOR-technology. The reference material within this contract was cast nodular iron.

In order to keep competition alive, a similar contract was given to Transnuklear, based on the cast steel technology.

Testing of the first prototype (a half scale model) started in May 1978. In total, about a dozen drop tests were made and almost exclusively at the low temperature of minus 40^{o} C and some of these test even without shock-absorbers in order to cope immediately with the objection that cast nodular iron could exhibit brittle behaviour at lower temperature.

In autumn of the same year already, the first full scale prototype CASTOR Ia was subjected to drop tests and in April 1979 even a drop test with an artificial, however, blunt flaw.

The shift from the mere transport function to an immobile storage module gave rise to safety requests of the authorities which had not been applied in the past to transport casks. Some examples were:

- The reference concept for storage implies the casks standing vertically within a hall. The authorities questionned the capability of the casks to withstand a vertical drop of an aircraft at high speed into the cask.

  The matter of concern was at that time not the question of leak tightness, but more the fear that the cask could open up like a tulip in the case of a high-speed central impact of a military plane. So this accident situation was simulated on a military test-site by propelling a simulated turbine shaft of a phantom fighter at a speed close to sonic velocity and vertically onto the center of the cask lid system.

Additonal tests were made using the lateral impact of configuration.

All tests showed that the cask would not experience any major damage and that it would even survive a subsequent kerosene fire without inacceptable radioactivity releases.

- Another matter to be examined was the question of the consequences of sabotage. It is not my purpose, to report on these results in detail, but I can summarize that the tests have shown that the reference material cast nodular iron had very favourable properties with respect to this incident.

- As the storage time to be considered in the licensing procedure was 40 years, the authorities requested proof, not only with respect to the long-term leak tightness of the seals, but also with respect to the eventual welds. Here, the advantage of the reference design - a cast body without any welds - became clear. The cast body is homogeneous and so in very simple tests, the adequacy of the design with respect to eventual permeation of Tritium across the walls could be verified.

2. AFR-Storages

When these results were available to DWK, the basis for a shift in storage strategy was broad enough and in 1979 the reference storage concept comprising a big AFR-pool (Away-From-Reactor) facility at Ahaus with a capacity of 1500 tHM was switched to a cask storage facility.

On year later, the licence application for a second AFR interim storage facility located at Gorleben was filed. As construction of the facility was completed in 1984 this facility is used as the reference case and will be commissioned recently.

The storage facility is run by the Brennelementlager Gorleben GmbH (BLG), a wholly-owned subsidiary of DWK-Hannover. The number of people employed totals about 60. In addition to the interim storage facility, a storage hall for low level radioactive waste as well as infrastructure buildings are situated at the site on an area of 11 ha.

The storage hall of an interim fuel storage facility is constructed in a modular design and can be modified in terms of capacity on demand. For the Gorleben site a capacity has been chosen of 1500 tHM, which means space for 420 casks.

The Gorleben facility, including its infrastructure, has been constructed at an expense of approximatively DM 60 million in just less than two years. The relatively short construction period compared to a wet storage facility as well as low initial cost are a distinct advantage of this concept.

Transport and storage casks containing fuel elements are taken from the nuclear power plants to a station near Gorleben by rail, loaded onto heavy trucks and delivered by road. The storage hall for fuel element transport and storage casks consists of a cask delivery area and storage area. The arriving casks are prepared for interim storage in the delivery area. These preparations include mainly leakage tests on the lid system and radiological control on the cask surface as well as fitting of a pressure switch for the storage cask monitoring system. In the storage area the casks, weighing up to 120 t, are placed in predetermined storage positions by way of a bridge crane and connected to the storage cask monitoring system. The storage positions are arranged in such a way as to allow the movement of any cask without disturbing the others.

The storage hall is provided with air intake inlets, through which the outside air enters in natural convention, passing by the casks, thus cooling them. The heated air escapes through air outlets in the roof. The removal of decay heat by natural convection and radiation has been optimised in calculations and practical tests. It has been proven that heat removal up to a maximum of 9 mW is guaranteed even under the most unfavourable conditions, so that the permissible maximum temperature of the fuel rods are not exceeded.

As the surface dose rate is limited to 200 uSv/h (20mrem/h) for storage casks, which is lower than the rate permissible for transport casks by a factor of 10, the local dose rate on the site and in the vicinity is also much lower than the legal limits. These favourable boundary conditions, created according to the Radiation Minimisation Recommendations, result in the fact that, mathematically, even with storage facilities filled to capacity, the radiation exposure of the personnel is kept far lower than the legal limits prescribed in the Federal Republic of Germany.

In 1983, storage licence was granted in accordance with article 6 of the German Atomic Law. It authorises the interim storage of used fuel elements from light water reactors for a period of 40 years in casks of the CASTOR type. Additional licensing procedures for interim storage of fuel elements in differenct types of casks are in progress.

The granting of the storage licence was preceeded by extensive expert examination based on the safety report and a number of additionally produced detailed documents. Althoug not provided for in law, the public has been given the opportunity to read the safety report and a public hearing has taken place.

3. Evident Advantages

Let us resume the evident advantages of the new storage concept which justified this decision at that time and which remain still in favour today:

- double purpose transport and storage capability;
- modular increase of the required storage capacity thus negligible interest during construction;
- no secondary wastes during operation;
- completely passive cooling by natural convection;
- zero release due to the no-weld, double-lid system with pressure survey;
- optimum resistance even to aircraft impact and insensitivity to major earth-quake loads;
- practically no technical limitation of the lifetime;
- easy decommissioning;
- and another very important advantage: the casting process allows high serial production rates within limited time frames.

The sum of all these facts leads to an additonal, very convincing one: lower overall storage cost.

As these arguments remain still valid today, DWK has based its other storage projects - the entrance storage facility of the Wackersdorf reprocessing plant too - on the same technological solution.

Furthermore, for the return of vitrified high level waste from COGEMA and BNFL, the storage and transport in casks seem too to be the acceptable reference solution. Therefore, DWK has initiated the fabrication of a prototype - CASTOR HAW 21 - already in 1984 and performed an extensive testing programme demonstrating the feasibility of the cask concept.

4. Experiences and Demonstrations

In order to gain experiences with cask storage, fuel scale demonstration programmes of complete irradiated fuel assemblies being stored in different types of GNS and TN shipping/storage casks have been carried out since 1982. The objectives of the demonstrations were to verify cask design parameters, to gain operational experience in cask handling and to expand the data base on dry storage fuel performance.

The irradiated fuel assemblies were loaded into the casks in the storage pools of the German reactors, e.g. Würgassen, Stade and Biblis. The cask drying operations, which are required to reduce cover gas moisture, were carried out successfully. Fuel is stored in Helium gas at less than 1 atm pressure. The peak cladding temperatures decreased rapidly from about 400° C to about 200° C over the 2-years storage period, showing a substantial longitudinal and axial temperature gradient. The radiation levels are in the expected range.

The programme results could be summarized as follows:

- In-pool loading and unloading of shipping/storage casks have been successfully demonstrated.

- Cask design parameters have been verified in practice.

- Radiation levels to operators are extremely low.

- No rods have failed due to dry storage even for a wide temperature range and range of cladding metallurgical conditions.

Even under the hypothetical assumption of a 100% rod failure the German cask concept and its barrier system constitutes a safe containment. However, with regard to the fuel unloading procedure, the question of fuel integrity and fission gas release fraction might be of interest, e.g. for operation of a fuel receiving station in a reprocessing plant.

Full scale dry storage demonstrations with different types of casks, hot cell tests with failed and unfailed fuel rods, and fuel behaviour modelling have been conducted in the FRG, using PWR and BWR Zircaloy clad fuel.

Irridiated fuel has been placed in and retrieved from various CASTOR casks and from a TN 1300 cask.

Dry storage tests and demonstrations have invloved 3000 fuel rods, which have been monitored during dry storage with maximum cladding temperatures ranging from 250 to 450° C. There is no evidence that any rods exposed to inert gases have failed during dry storage. Even under conditions more severe than in the casks, the fuel shows no cladding failures.

Dry storage under cask conditions with maximum insertion temperatures in the range of 400° C does not expect to cause

- a significant creep deformation above 1%
- cladding oxidation
- conditions that induce SCC or flaw propagation.

Thus, peak cladding temperatures up to about 450° C (depending on the character of the fuel) are predicted to be acceptable for inert gas storage.

In parallel to these demonstrations in 1983, another CASTOR was loaded in Würenlingen, Switzerland, with the full core of a research reactor. This was the first commercial used fuel storage demonstration based on dry cask technology.

In parallel, the French company NERSA, owner and operatur of the Super Phenix reactor, became interested in the cask solution as an emergency option for storage purposes and ordered and tested a prototype successfully in 1982/1983.

One cask was delivered and loaded in the Russian power station Woronesch in 1984. Other demonstrations were made in Germany with high temperature reactor fuel elements, and in the United States, the first storage demonstration started at the Idaho National Laboratory in 1985. Here, already a new generation of storage casks could be used: the CASTOR V for 21 PWR-fuel elements.

5. Optimizing the Cost

With an upper limit of the cladding temperature during storage of 390° C it is evident that the capacity of the casks and thus the cost for storage can only be optimized if the cooling time prior to dry storage is rather long, e.g. 4 to 7 years. Under these circumstances it could be shown for used fuel in the United States, were sufficient up-front fuel storage is available, that casks with capacities of 21 PWR-fuel elements and in some extreme cases also with 28 or 33 fuel elements could be realized.

So, the Virginia Electric Power Company initiated the operation of its Surry storage facility based on this technology in 1986. At this time, a total of 9 casks has been ordered, delivered and more than 6 casks are loaded today.

III. Final Disposal Cask Development

In my introductory remarks reference has been made to the decision by the Federal Government in January 1985 with regard to future development of direct disposal. It was stated that, in addition to the construction of a reprocessing plant, spent fuel disposal without reprocessing should be developed to a technical maturity for those fuel elements for which reprocessing is neither technically feasible nor economically justifiable, even from the viewpoint of political economy.

The successful development of the dry cask storage technology gave an impetus to the development of final disposal casks which in addition to the CASTOR family now is called POLLUX cask system.

The design criteria for a reference cask for final disposal in a salt repository were developed within an R&D programme of the German Ministry of

Research and Technology (BMFT) during 1979 - 1985. Since actual geological conditions will only be sufficiently known after exploration of the final disposal repository it is important to achieve a high technical flexibility in the present disposal cask design.

1. POLLUX Cask System

For this reason the POLLUX cask system developed by DWK comprises:

- the POLLUX cask for disposal in drifts and
- the POLLUX canister for disposal in boreholes.

POLLUX casks are independent packages for direct disposal which at the same time meet all the IAEA requirements for transport as well as for storage of spent fuel. By variation of dimensions lid systems and built-in equipment (internals) the POLLUX cask can be adapted to the requirement of the different radioactive materials to be handled.

The present POLLUX canister is designed for final disposal in boreholes together with vitrified high-level waste of the reprocessing plant. The transport and an optional interim storage, however, can only be done in transport/storage casks, e.g. CASTOR HAW 21, providing the necessary shielding function.

The POLLUX cask is designed according to the double shell principle, the inner steel shell providing temporary gas tightness by means of screwed-in lid and long term containment after welding in a secondary lid. The outer shell, which is fabricated in steel or ductile cast iron, assures shielding of gamma- and neutron radiation under transport, storage and corresponding accidental conditions as well as mechanical protection under operational and type B(U) test conditions.

The present criteria for corrosion protection of the steel containment with water intrusion in the final disposal repository are met with Plasma Hot Wire Surfacing of Hastelloy C4.

Loading of the cask and closing of the screwed-in lid is done in remote control mode in a Hot Cell, whereas closing of the steel containment by welding techniques can be done in direct access.

The mechanical safety of a cask system for radioactive material can be proved according to IAEA regulations by testing of a model cask, testing of a prototype or analytical calculations. For the POLLUX cask the mechanical safety for normal and faulted loads is evaluated by analytical methods.

The double shell principle of the POLLUX cask permits the application of established standards and approved technical rules for material and fabrication. The evaluated safety margin shown by analytical methods for normal and faulted operation established a comfortable inherent safety. The result with such an engineering procedure for the POLLUX cask assures provision against failure.

2. Pilot Plant for Fuel Conditioning

Development and testing of the described final disposal casks requires a pilot plant for fuel conditioning. The atomic licence application was submitted by DWK to the licensing authority on 6 May 1986. The site selected is at Gorleben, and is located directly adjacent to the 1500 tU AFR interim storage facility described before.

The pilot plant is designed as a multipurpose facility, in which the conditioning and encapsulation technology for different forms of radioactive material will be demonstrated.

The facility's main tasks are:

- conditioning and encapsulation of spent fuel, so that the resulting package, e.g. POLLUX, is suitable for final storage and in addition meets the requirements for interim storage.

In addition, the pilot plant should fulfill the following tasks:

- unloading of radioactive waste containers, e.g. vitrified high active waste concentrates from transport casks into storage casks suitable for interim and/or final storage;

- encapsulation of radioactive waste in a form suitable for final storage;

- maintenance of transport and storage casks;

- loading of storage casks with consolidated spent fuel.

Owing to the pilot function of the facility, the throughput is limited to 35 t U/a, which is sufficient for execution of the development programme.

The safety report was submitted to the licensing authority in March 1987 and the public hearing is expected to take place in May 1988. A first construction licence is likely to be issued in 1989 and hot operation could start in 1994.

IV. Conclusion

This overview shows that dry cask technology for interim storage has reached maturity in West Germany and is available for application.

Final disposal cask development is under way and will have to be harmonized with repository conditions, so that applications can be envisaged at the end of this century.

THE CANADIAN CONCEPT FOR USED NUCLEAR FUEL DISPOSAL

William T. Hancox
Vice-President, Waste Management
Atomic Energy of Canada Limited Research Company
Pinawa, Manitoba

Paper presented to the
21st Annual Conference of the
Japanese Atomic Industrial Forum
Tokyo, 1988 April 14

ABSTRACT

AECL's assessment of nuclear fuel waste disposal deep in plutonic rock of the Canadian Precambrian Shield is now well advanced. A comprehensive understanding has evolved of the chemical and physical processes controlling the containment of radionuclides in used fuel. The following conclusions have been reached:

- Containers with outer shells of titanium and copper can be expected to isolate used fuel from contact with groundwater for at least 500 years, the period during which the hazard is greatest.

- Uranium oxide fuel can be expected to dissolve at a rate less than 10^{-8} per day, resulting in uranium concentrations less than 10^{-8} mol/L. This is consistent with observations of uranium oxide deposits in the earth's crust.

- Movement of dissolved radionuclides away from the containers can be delayed for thousands of years by placing a compacted bentonite-clay layer between the container and the rock mass.

- The granite plutons of interest consist of relatively large rock volumes of low permeability separated by relatively thin fracture zones. The fracture zones have a much higher hydraulic conductivity than the background rock and, thus, control the groundwater flow within the rock mass.

Field studies are continuing that will validate groundwater flow models at the regional scale. Construction of an underground research laboratory is nearing completion in a previously undisturbed granite pluton.

INTRODUCTION

Since 1978, AECL has been assessing the concept of disposing of nuclear fuel wastes deep in plutonic rock of the Canadian Precambrian Shield, and developing and demonstrating the associated technologies. Our concept is based on the use of a multi-barrier system in which the plutonic rock mass is supplemented by engineered systems. Consideration of specific sites will occur only after the concept has been judged acceptable.

The decision to focus the assessment on disposal in plutonic rock arose from a 1977 study led by Professor F.K. Hare of the University of Toronto [Aitken et al. 1977]. The rationale for the focus is as follows. The Canadian Shield has been relatively stable for at least 600 million years, and most of the Shield has not had major orogenic activity for 2.5 billion years. Therefore, it is reasonable to infer that the region would remain stable for the required lifetime of a disposal vault. Also, regional topographic gradients in the Shield are low, about 1 m/km. As a result, the natural driving force for groundwater flow deep in the rock should be weak. Further, it is believed that there are large volumes of plutonic rock with extremely low porosity and permeability. These would serve to limit access of groundwater to the waste, thereby slowing its deterioration and inhibiting movement of radionuclides through the rock. Also, minerals in plutonic rock are known to react with many of the radionuclides in nuclear fuel waste, further retarding their movement.

Since the physical and chemical processes that might lead to release of radionuclides, and to their transport back to the surface, would evolve over thousands of years, it is not possible to provide a direct physical demonstration of the concept's safety. Our approach is to base the demonstration of safety on long-term predictions using mathematical models that represent the various components of the disposal system, including the waste material and the plutonic rock mass. The research program was designed to provide a comprehensive understanding of the underlying physical and chemical processes, to develop appropriate models and to validate them against carefully integrated laboratory and field experiments.

The research program is now well advanced and a comprehensive understanding of the performance of the various barriers has evolved [Dormuth 1987]. This paper describes our reference design for the disposal of used CANDU fuel and highlights our current understanding of the performance of the system components, including the used-fuel container, the used fuel, the clay buffer surrounding each container, and the plutonic rock mass. The status of our underground research laboratory is also described.

DISPOSAL CONCEPT

Characteristics of Used CANDU Fuel

A typical CANDU fuel bundle is shown in Figure 1. The uranium dioxide fuel is in the form of ceramic pellets that are sealed inside zirconium alloy tubes to form individual fuel rods.

Table 1 compares the compositions of a typical bundle before irradiation and one-half year after removal from the reactor. Note that, at 0.23%, the post-irradiation concentration of uranium-235 is comparable to that of enrichment tails. Also, the plutonium concentration, at less than 0.4%, is about 2.5 times less than that for used LWR fuel. Thus, there is little economic incentive to reprocess used CANDU fuel.

TABLE 1: CANDU FUEL BUNDLE COMPOSITION (g)

CONSTITUENT	NEW	USED*
Uranium-238	18,865	18,725
Uranium-235	134	44
Other Uranium Isotopes	1	15
Plutonium		71
Other Actinides		1
Iodine		1
Cesium		11
Technetium		4
Other Fission Products		128
	19,000	19,000

* Assuming a burnup of 650 GJ/kg and a cooling time of 0.5 years.

When first removed from the reactor, the used-fuel bundles are intensely radioactive. One year after removal, the intensity of the radiation has decreased by a factor of 100 (the dose rate at 30 cm is 30 Sv/h) and the heat generation rate has decreased to 60 W. In ten years, the radiation intensity has decreased by a factor of 1,000 and the heat generation rate to 4 W.

Although the hazard from penetrating gamma radiation is relatively small after about 500 years (1 mSv/h at 30 cm), the long-lived radionuclides iodine-129, cesium-135, technetium-99 and plutonium-239 remain toxic for hundreds of thousands of years. These radionuclides are the most important radionuclides from a disposal view point. However, they are contained within the uranium oxide grains and will be released only if the grains are dissolved.

Prior to disposal, the used-fuel bundles would be sealed in corrosion-resistant containers. Figure 2 shows a conceptual design for a thin-walled, particulate-filled container for 72 CANDU fuel bundles. Prototype containers of this design, with a 5-mm thick titanium alloy outer shell, have withstood external pressures up to 10 MPa at 150 C, meeting the primary structural requirements for disposal in a vault at a depth of 1,000 m [Teper 1985].

Disposal Facility Reference Design

The reference layout of a single-level disposal vault is shown in Figure 3, as well as details of a typical disposal room [Baumgartner, Simmons 1987]. The vault would consist of 480 disposal rooms (220 m long, 8 m wide and 5.5 m high) and would have a plan area of about 4 km^2. It would be excavated at a depth between 500 m and 1,000 m, depending on the characteristics of the host rock mass. There would be sufficient capacity to dispose of about 190,000 Mg of used CANDU fuel (about 135,000 containers).

The used-fuel containers would be lowered through a vertical shaft, transported to the disposal rooms, and placed in holes (1.2 m in diameter and 5 m deep) bored into the floor of the rooms. Prior to receiving the waste containers, the holes would be filled with a mixture of sodium-bentonite clay and sand, mechanically compacted and then rebored to provide a central hole (700 mm in diameter and 4.2 m deep). The 250-mm thick clay-sand buffer would act as a diffusion barrier to the movement of groundwater, inhibiting the transport of radionuclides away from the container. The clearance space between the container and the buffer would be filled with sand.

When filled with containers, each room would be backfilled and sealed. The backfilling would be done in two stages: first, the lower portion of the room would be filled with a mixture of clay and crushed granite, which would then be mechanically compacted; second, the remaining space would be filled pneumatically with a mixture of granite aggregate and bentonite. To close the vault, the access tunnels would be backfilled in a manner similar to the disposal rooms, and the access and ventilation shafts would be fitted with a series of bentonite/concrete seals separated by a backfill mixture of compacted clay and crushed-granite.

BARRIER PERFORMANCE

The Used-Fuel Container

Container integrity will be determined primarily by the corrosion resistance of the outer-shell material. We have focussed our research on titanium alloys, our current reference material, and copper.

Our studies on titanium alloys [Ikeda, Clarke 1986] demonstrate their very low uniform corrosion rate (less than 1 μm/a) under the conditions expected in the disposal vault; that is, groundwater at less than 150 C with a high chloride content (less than 0.97 mol/L). The low corrosion rate is a result of a protective, passive oxide film. Breakdown of this film can make titanium susceptible to localized corrosion processes, such as crevice corrosion. Using an electrochemical approach, which forces crevice corrosion to initiate, we have demonstrated that both grade 12 and grade 2 titanium are capable of preventing the propagation of crevices by re-establishing their protective oxide films. Thus, a 5-mm thick titanium outer shell would be sufficient to provide an effective barrier to radionuclide release for at least 500 years.

If copper is used for the outer shell, only uniform corrosion is expected to play a role. We have studied the dissolution of copper metal in chloride solutions and in the presence of compacted bentonite buffers [King, Litke 1986]. The experiments show that the corrosion rate is limited by the rate at which dissolved metal species are transported away from the corroding surface. We conclude that a 25-mm thick outer shell of copper would provide an effective barrier to the release of radionuclides for at least 5,000 years.

The Uranium Oxide Fuel

Once groundwater breaches the container shell, the zirconium alloy fuel sheaths are not expected to provide significant protection. Because of the high chloride content of the deep groundwater, the zirconium may be attacked by crevice corrosion.

However, the uranium oxide is expected to provide highly effective containment of radionuclides [Johnson et al. 1988]. Our research demonstrates that there are three principal mechanisms by which radionuclides are released:

1. about 2% of the iodine and cesium are released rapidly once the zirconium alloy fuel sheath is breached.
2. an additional 6% of the iodine and cesium are slowly released by preferential dissolution at the grain boundaries.
3. the remaining 92% of the fission products and actinides trapped within the uranium oxide grains are released extremely slowly as the grains dissolve.

Under the reducing conditions expected in a disposal vault, experiments with used fuel show that uranium concentrations in groundwater would range from 10^{-7} mol/L to 10^{-9} mol/L depending on the salinity of the groundwater. Dissolution rates are observed to be less than 10^{-8} per day.

The stability of uranium oxide in groundwater has been confirmed by studies at the Cigar Lake uranium deposit in northern Saskatchewan [Cramer 1986]. The deposit, shown in Figure 4, is situated at a depth of 430 m at the interface between the host sandstone formation and the underlying basement rock of the Archean Shield. The ore body contains about 170,000 Mg of high-grade ore and is lens-shaped (2,000 m long, 100 m across, and 20 m thick at mid-length). It is surrounded by a clay-rich layer that ranges in thickness from 5 m to 30 m. An iron oxide/hydroxide-rich zone forms the contact between the high-grade ore and the clay layer.

The ore body consists mainly of individual grains of uraninite mixed with clay minerals; the average concentration of uraninite is 12%, with local concentrations as high as 60%. Since the ore body was formed about 1.3 billion years ago, there have been several episodes of groundwater interaction with the ore body. Despite this interaction, there has been no significant movement of uranium. Water samples taken only 5 m from the ore body have such a low uranium concentration (10^{-8} mol/L) that they are suitable for drinking.

Although the groundwater flowing toward the deposit is oxidizing in nature, oxygen is removed by iron minerals and organic materials within the ore body and the surrounding clay layer. The iron is oxidized more easily than uranium and acts as a scavenger for oxidizing species. Examinations of samples from the ore body show that the oxidation state of the uraninite grains is less than U_3O_7 [Sunder et al. 1988]. Compositions less than U_3O_7 are consistent with the observed reducing condition of groundwater samples from the ore zone and with laboratory observations of the behaviour of uranium oxide fuel.

The bentonite-clay buffer surrounding each container

The principal function of the buffer is to inhibit the movement of radionuclides away from the container. Our research shows that radionuclide movement in compacted bentonite-sand mixtures would occur only by diffusion [Cheung 1987]. Buffer thicknesses of 250 mm yield breakthrough times of thousands of years for the critical long-lived radionuclides; for example, under the expected groundwater conditions the diffusion properties of the reference buffer are such that the breakthrough time would be about 3,000 years for technetium, 5,000 years for iodine, and 140,000 years for plutonium.

The granite rock mass

Field research areas have been established at three locations in the Precambrian Canadian Shield: in the Atikokan and East Bull Lake regions of northern Ontario, and in the Whiteshell region of southeastern Manitoba. Since 1978, these research areas have been extensively characterized from a geotechnical perspective, and monitoring of the groundwater flow system in each area is continuing via instrumented networks of boreholes [Whitaker 1987].

The Whiteshell Research Area is shown in Figure 5, and is the main focus of our field studies. This region contains the Whiteshell Nuclear Research Establishment and AECL's Underground Research Laboratory (URL). The region is situated on the Lac du Bonnet Batholith, a large granite pluton similar to many found in the Canadian Shield. There is a moderate topographic slope across the region of about 50 m from the southeast to the northwest and the water table closely follows the topography. The Winnipeg River system provides a well-defined hydrological boundary for most of the study area.

Hydrogeology of Granite Rock Masses

A detailed understanding of the hydrogeology of a candidate rock mass is essential to assess its acceptability. Our methodology for gaining this understanding is derived from a structured process which integrates the various geoscience disciplines. The steps are as follows:

1. The geological features of the rock mass that control the groundwater flow, and the associated physical, chemical and hydrological characteristics, are determined from field investigations.

2. These geological features and their characteristics are interpreted to establish a conceptual model of the groundwater flow system.

3. Based on the conceptual model, a detailed three-dimensional mathematical model of the flow system is used to predict changes caused by natural and artificial perturbations of the rock mass and flow system.

4. Comparisons are made between predicted and measured responses to test the conceptual and mathematical models, and to refine them so that, together, they provide a realistic representation of the actual groundwater flow system.

As an illustration, a description follows of the methodology as it was applied to the characterization of the site for the URL [Davison 1985].

Over 130 boreholes were drilled into the shallow overburden deposits and into the underlying granite to depths up to 1100 m. Fractures were characterized in the boreholes using a number of techniques: by detailed core-logging methods, by in-hole television camera equipment, and by a variety of standard and innovative borehole geophysical logging techniques. Hydraulic conductivity measurements were made at selected intervals in individual boreholes. In addition, interference tests were done in which water was either injected or withdrawn from one borehole, while groundwater pressures were measured in isolated intervals in neighboring boreholes. These tests provided an understanding of the hydraulic conductivity of the portion of the rock mass between the boreholes.

Analysis of the information obtained from the field studies identified three major low-dipping fracture zones, shown in Figure 6, dipping at about 20 degrees to the horizontal. The upper and lower zones are relatively uniform and have thicknesses of a few metres. In contrast, the middle fracture zone has a complex geometry with a number of off-branching limbs. At the surface of the batholith, the fracture zones coincide with major topographic lineaments that have been studied by geological mapping and surface geophysical surveys.

The major fracture zones control the movement of groundwater and, within the zones, there is a wide variation in hydraulic conductivity. Regions of high and low conductivity were determined by continuous monitoring of the hydraulic pressure in isolated intervals in the network of boreholes during interference tests. Outside the fracture zones, the rock is relatively unfractured, except for a network of near-vertical fractures that extends from the surface to depths of about 250 m. Other widely spaced vertical fracture zones exist that extend to depths of 400 m. These vertical fractures and fracture zones are oriented roughly parallel to the direction of the maximum principal stress in the rock mass.

These results, which are consistent with the observations in the other field research areas, indicate that the groundwater flow characteristics of the plutonic intrusives of interest can be conceptualized as relatively large rock volumes of low permeability separated by relatively thin fracture zones. The hydraulic conductivity of the fracture zones is usually much greater than the conductivity of the background rock and, thus, the fracture zones control the groundwater flow within the rock mass.

This conceptual groundwater flow model is described mathematically by a finite-element computer model called MOTIF [Guvanasen 1985]. It represents the relatively unfractured background rock by an equivalent porous medium, composed of three-dimensional continuum elements. The high conductivity zones are represented by special planar elements, which are embedded in the background porous medium. The flow within these planes is dominant along their axes. The three-dimensional flow field within this assembly of blocks and planar elements is described by porous medium flow equations.

To test these models, predictions were made of the rate of groundwater flow into the shaft opening and of the changes in hydraulic head in the groundwater flow system that would be caused by the excavation of the URL shaft [Davison 1986]. These predictions were then compared to the responses measured at 171 isolated intervals in the network of boreholes used to characterize the rock mass as the excavation proceeded.

Figure 7 shows the measured and predicted rate of groundwater flow into the URL shaft during excavation. The first inflow occurred when several water-bearing near-vertical fractures intersected the shaft walls and the rate of inflow increased as the excavation passed through the upper fracture zone. Notice that the inflows predicted by the MOTIF computer model are generally a factor of three greater than the measured inflows. As predicted, the maximum inflow occurred as the upper fracture zone was penetrated. Subsequently, the predicted rate of inflow gradually declined to a constant value, consistent with the measured inflow.

Figure 8 shows a comparison between measured and predicted histories of hydraulic head at one of the monitoring locations in the upper fracture zone. The onset of the sharp drop in hydraulic head corresponds to the onset of groundwater inflow to the shaft opening. The agreement between prediction and experiment is generally good. The deviations during the period 1985 March to 1986 April are attributed to seasonal variations in groundwater recharge, which could not be included in the mathematical model. This agreement is typical of that attained at most monitoring locations used in the comparisons, and gives us confidence that the methodology is sound.

The continuing field research is directed at determining the hydrogeological features that affect the groundwater flow within the entire Whiteshell Research Area, to a depth of at least 1,000 m [Davison et al. 1987]. Drilling of a regional network of deep boreholes has begun and will provide the basis for extending the existing conceptual model for the rock mass surrounding the URL. We plan to continue to monitor the groundwater chemistry and hydraulic head fluctuations within the boreholes, and to extend the network by further drilling at strategic locations within the area. When completed, we hope to have sufficient information to establish a three-dimensional conceptual and mathematical model for the groundwater flow system within the entire study area to a depth of 1,000 m, and to have tested the model against field measurements.

Underground Research Laboratory

Construction of the URL is now at an advanced stage. It is being constructed in a part of the Whiteshell Research Area which had not been previously disturbed. The excellent outcrop in the area facilitated the geological characterization of the site. The location of the access shaft and underground laboratory rooms was based on knowledge of the underlying geological structure and groundwater flow system derived from the extensive characterization program described in the preceding section. The excavation of the shafts and rooms has confirmed and supplemented the information obtained from the borehole investigations.

The present state of underground development at the URL is shown in Figure 9. The excavations include a 3 m by 4 m rectangular access shaft and a 2 m diameter ventilation shaft, both 250 m deep, and laboratory rooms excavated at a depth of 240 m. Excavation is underway to extend the access shaft to a depth of 455 m as part of an agreement with the U.S. Department of Energy. The excavation has reached a depth of 380 m and is scheduled to reach 455 m during 1988 July. Geotechnical characterization of the shaft is expected to be completed by 1989 September. The rock mass around the shaft at the 455-m level will also be characterized to select sites for experiments.

To date, work at the URL has provided unique information on the response of the rock mass and its groundwater flow system to the excavation. During the shaft excavation, geomechanical and hydrogeological instrument arrays were installed (at depths of 15 m, 62 m, 185 m, and 212 m) to monitor displacement and stress changes, and pressure changes within discrete fractures, in the rock surrounding the shaft opening as the excavation proceeded [Thompson, Lang 1986]. Displacements were generally small, varying from 0.1 mm to 2 mm. Similar measurements were made during the excavation of the laboratory rooms. Also, about 800 overcoring tests have been done to determine stresses within the rock mass, using a variety of triaxial measurement cells [Lang et al. 1986]. Construction of the URL has also allowed us to test excavation techniques that could be used to construct a disposal vault, particularly drilling and blasting procedures that minimize damage to the rock near excavation surfaces.

Experiments are planned to test components of the disposal system under the complex conditions that are expected in a disposal vault and to develop and test the technology to emplace engineered barriers, such as buffer and backfilling materials, and shaft and borehole seals. The experiments being planned include the following:

1. An Excavation Response Experiment to determine the effect of excavation on the hydraulic conductivity of fractures in the rock surrounding the opening, the extent and conductivity of the damage zone near the surface of the opening, and the bulk mechanical properties of the rock mass surrounding the opening.

2. A Heated Block Experiment to assess the effect of thermal-mechanical conditions on the hydraulic properties of a single fracture contained within a discrete block of rock.

3. A Pressure Chamber Experiment to assess the response of a volume of rock (about 25,000 m^3) caused by thermal and pressure loading.

4. Migration Experiments to determine solute transport in rock masses with varying degrees of fracturing.

5. Buffer/Container Experiments to study the interaction between a sand/clay buffer, a simulated used-fuel container and the surrounding rock.

6. Borehole Sealing Experiments to demonstrate the technology for sealing boreholes and to determine its performance.

7. Shaft Sealing Experiments to demonstrate the technology for installing shaft sealing materials and bulkheads and to determine their performance.

CONCLUSIONS

Containers with titanium and copper outer shells can be expected to isolate used fuel from contact with groundwater for at least 500 years, the period during which the hazard is greatest. The used fuel has also been shown to be highly resistant to dissolution under the groundwater conditions expected in a disposal vault. Dissolution rates less than 10^{-8} per day have been determined for used fuel in the laboratory experiments and are consistent with observations of uranium ore deposits in the earth's crust. The movement of radionuclides dissolved in groundwater can be further retarded by placing a compacted clay layer between the container and the rock mass. Breakthrough times of thousands of years can be attained. Thus, the combination of the container, used fuel and clay layer can be expected to delay the release of radionuclides into the deep groundwater system for several thousand years and to maintain their concentrations at low levels.

A methodology for characterizing the hydrogeology of a plutonic rock mass has been successfully applied and validated in the field to a depth of 500 m. This methodology is now being applied at a regional scale comparable to that required to characterize a candidate disposal site. Based on our experience to date, we are confident that the process by which detailed in-situ measurements are used to develop a conceptual model of the hydrogeology of a site and then idealized into a three-dimensional description is generally valid.

Our field investigations in the Canadian Shield, supported by assessments of conceptual disposal vault designs, give us confidence that there are a large number of locations which, after detailed examination, will provide disposal sites that meet safety requirements.

The understanding of basic physical and chemical processes derived from the laboratory and field investigations highlighted above has been incorporated into a mathematical model that describes the complete disposal system for assessments of long-term safety. This model of the disposal system links together individual mathematical models for the vault, rock mass and surface environment to provide an estimate of the range of possible effects to individuals at some future time from an implementation of the disposal technology.

REFERENCES

AITKEN, J.M., HARRISON, J.M., and HARE, F.K., "The Management of Canada's Nuclear Wastes", Energy, Mines and Resources Canada Report, EP-77-6, 1977 August.

BAUMGARTNER, P., and SIMMONS, G.R., "Disposal Centre Engineering for the Canadian Nuclear Fuel Waste Management Program", Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 8, Numbers 2-3, pp. 219-239, 1987.

CHEUNG, C.H., "Evaluation of Methodologies for Determining Ionic Diffusion Coefficients in Clays", Proceedings of the Canadian Engineering Centennial Convention, Montreal, 1987 May.

CRAMER, J.J., "A Natural Analog for a Fuel Waste Disposal Vault", Proceedings of the 2nd International Conference on Radioactive Waste Management, Winnipeg, Canadian Nuclear Society, 1986 September.

DAVISON, C.C., "Hydrogeological Characterization of the URL Site", Atomic Energy of Canada Limited Technical Record, TR-299, pp. 231-52, 1985.

DAVISON, C.C., "URL Drawdown Experiment and Comparisons with Model Predictions", Atomic Energy Of Canada Limited Technical Record, TR-375, 1986.

DAVISON, C.C., CHAN, T., and SCHEIER, N.W., "Experimental Activities of the Canadian Nuclear Fuel Waste Management Program to Validate Geosphere Models", Proceedings of Geoval-87, Stockholm, 1987 April.

DORMUTH, K.W. (Editor), "Canadian Nuclear Fuel Waste Management Program", Special Issue, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 8, Numbers 2-3, 1987.

GUVANASEN, V., "Development of a Finite-Element Code and Its Application to Geoscience Research", Atomic Energy of Canada Limited Technical Record, TR-299, pp. 554-66, 1985.

IKEDA, B.M. and CLARKE, C.F., "Titanium Corrosion Under Canadian Nuclear Waste Disposal Conditions", Proceedings of the 2nd International Conference on Radioactive Waste Management, Winnipeg, Canadian Nuclear Society, 1986.

JOHNSON, L.H., SHOESMITH, D.W., and STROES-GASCOYNE S., "Spent Fuel: Characterization Studies and Dissolution Behaviour Under Disposal Conditions", Scientific Basis for Nuclear Waste Management XI, M. Ated and R. Westerman, editors, MRS Pittsburgh (in press).

KING, F. and LITKE, C.D., "The Corrosion Behaviour of Copper Under Simulated Nuclear Fuel Waste Disposal Conditions", Proceedings of the 2nd International Conference on Radioactive Waste Management, Winnipeg, Canadian Nuclear Society, 1986.

LANG, P.A., EVERITT, R.A., NG, L., and THOMPSON, P.M., "Horizontal In-Situ Stresses Versus Depth in the Canadian Shield at the Underground Research Laboratory", Proceedings of the International Symposium of Rock Stress and Rock Stress Measurement, Stockholm, 1986.

SUNDER, S., TAYLOR, P., and CRAMER, J.J., "XPS and XRD Studies of Uranium Rich Minerals from Cigar Lake, Saskatchewan", Scientific Basis for Nuclear Waste Management, vol. XI, 1988.

TEPER, B., "Feasibility Assessment of the Particulate-Packed, Thin-Walled Container", Atomic Energy of Canada Limited Technical Record, TR-350, Vol. 1, p.21, 1985.

THOMPSON, P.M., and LANG, P.A., "Rock Displacements Measured During URL Shaft Sinking", Proceedings of the 2nd International Conference on Radioactive Waste Management, Winnipeg, Canadian Nuclear Society, 1986.

WHITAKER, S.H., "Geoscience Research for the Canadian Nuclear Fuel Waste Management Program", Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 8, Numbers 2-3, pp. 145-195, 1987.

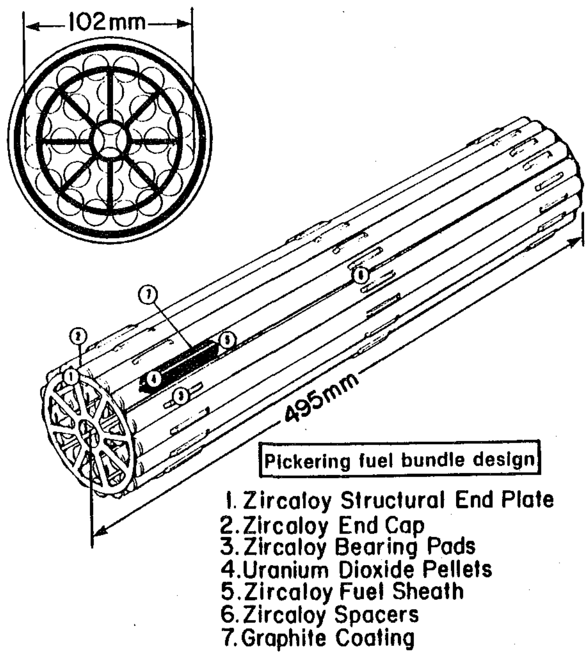


Figure 1: A Typical Fuel Bundle Assembly

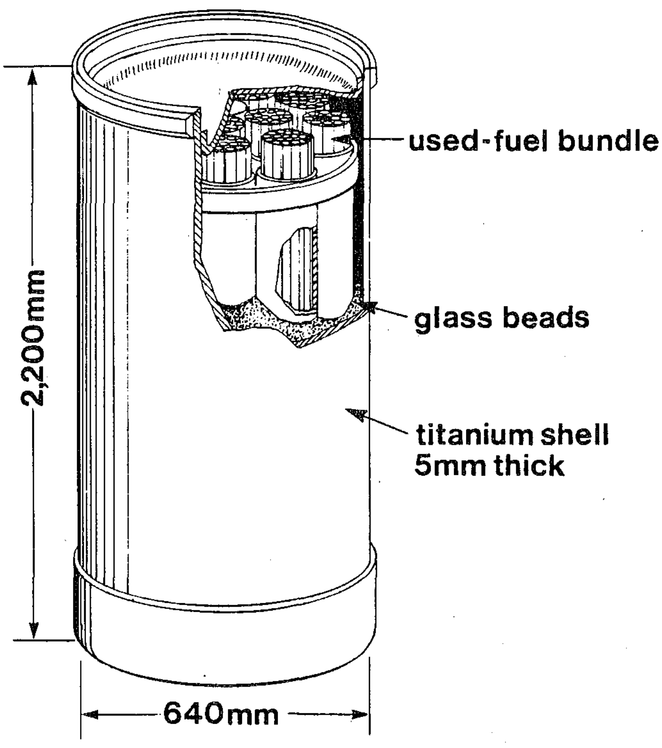


Figure 2: Conceptual Design for a Thin-Walled, Particulate-Filled Container for Used CANDU Fuel

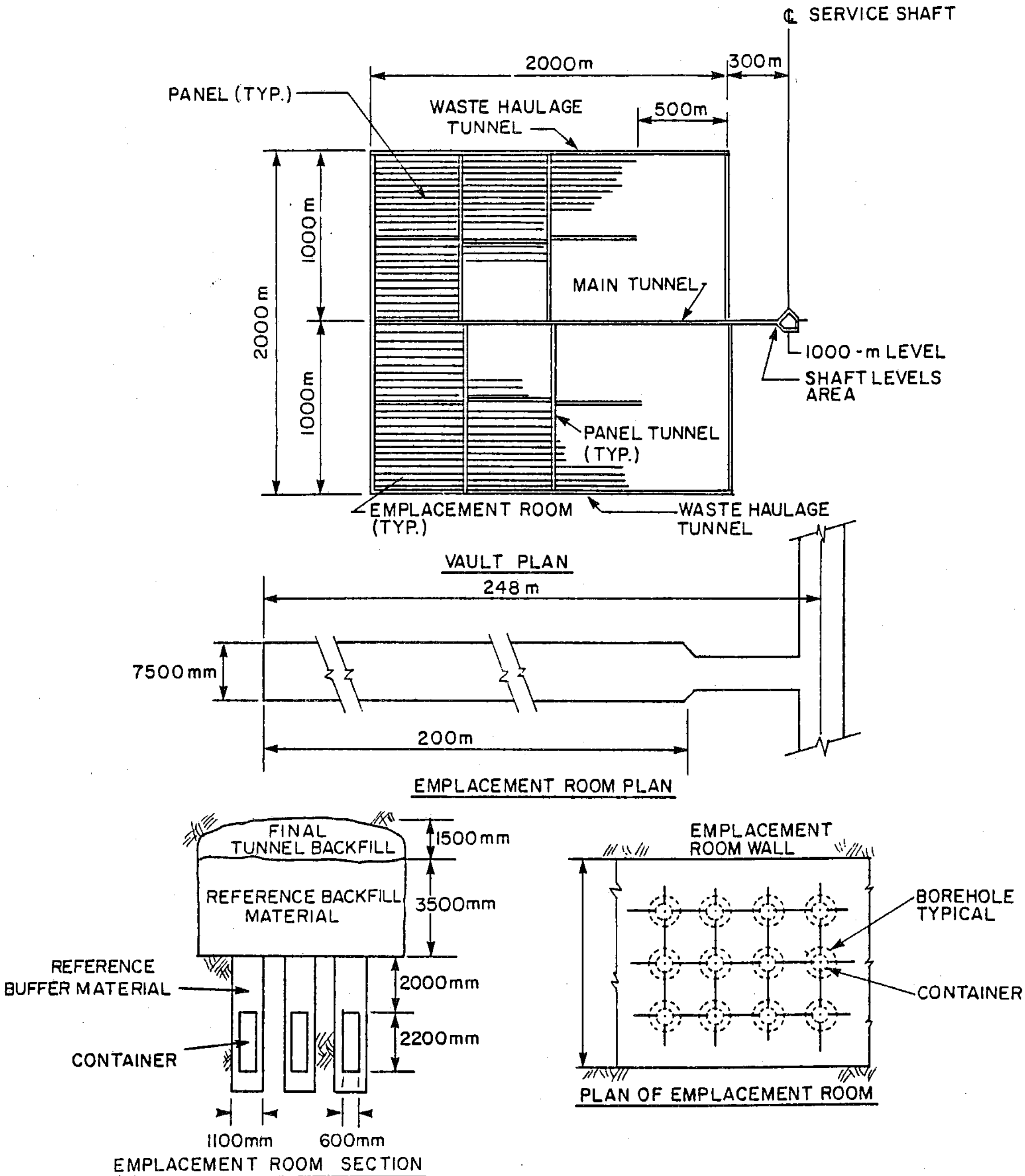


Figure 3: Reference Layout and Design for a Single-level Disposal Vault

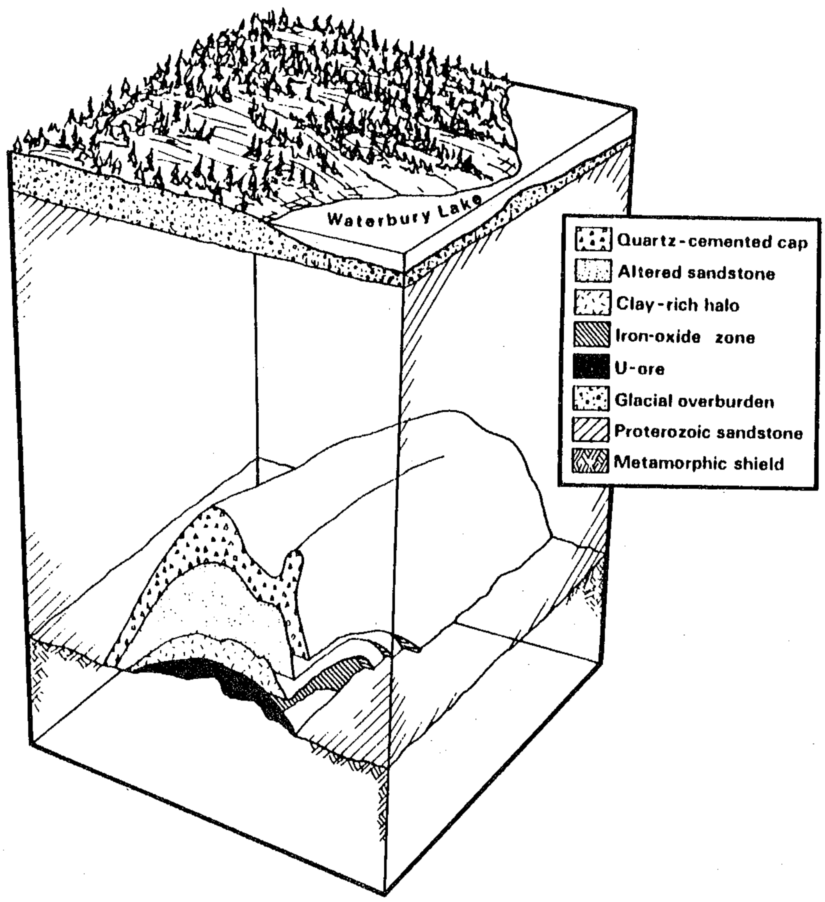


Figure 4: Cigar Lake Uranium Deposit

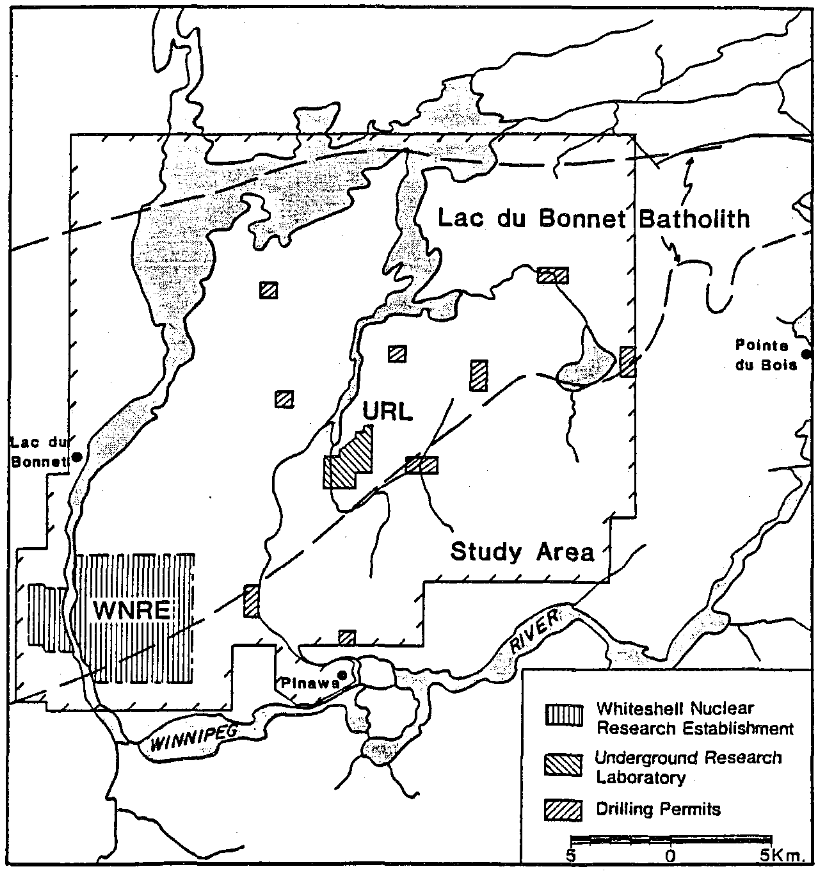


Figure 5: Location of the Whiteshell Research Area

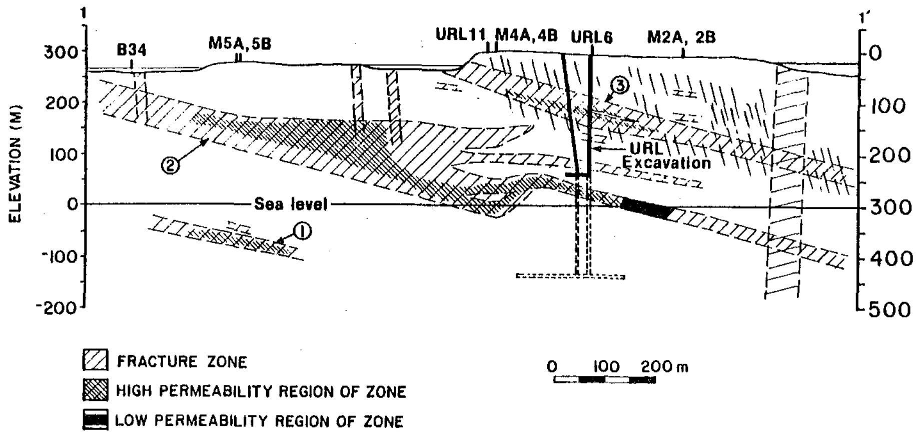


Figure 6: Cross Section Showing Fracture Zones in the Rock Mass Containing the URL

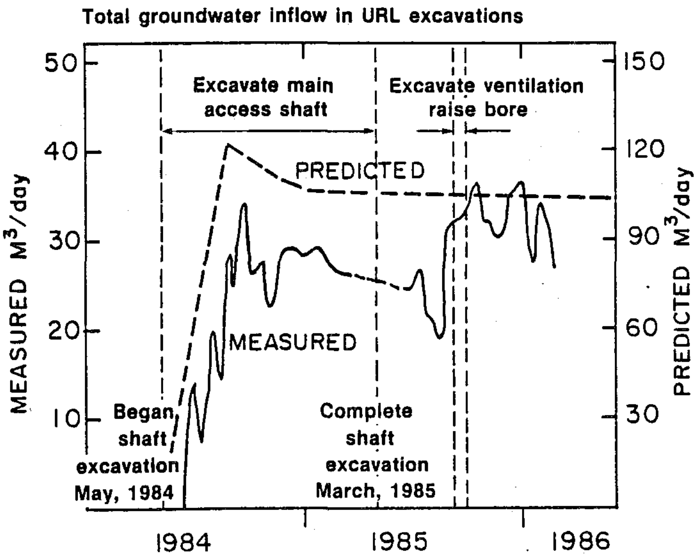


Figure 7: Comparison of Predicted and Measured Groundwater Inflow into the URL Shaft

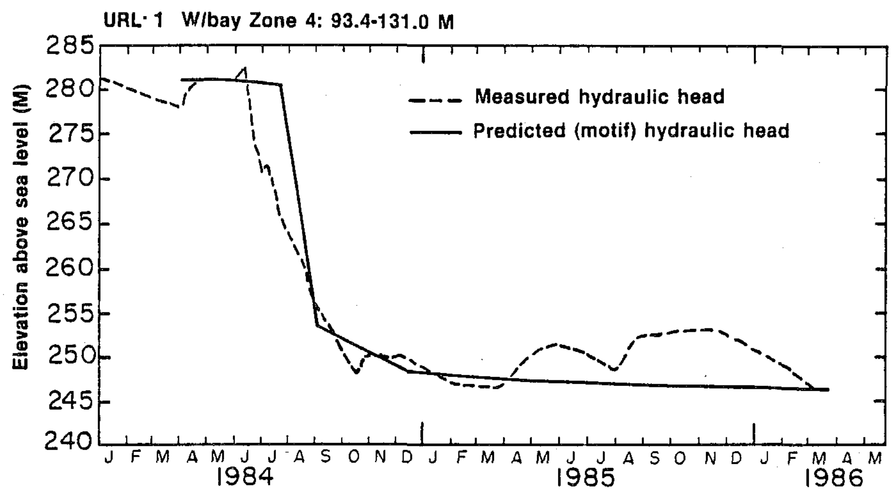


Figure 8: Comparison of Predicted and Measured Hydraulic Head at a Monitoring Location in the Upper Fracture Zone at the URL

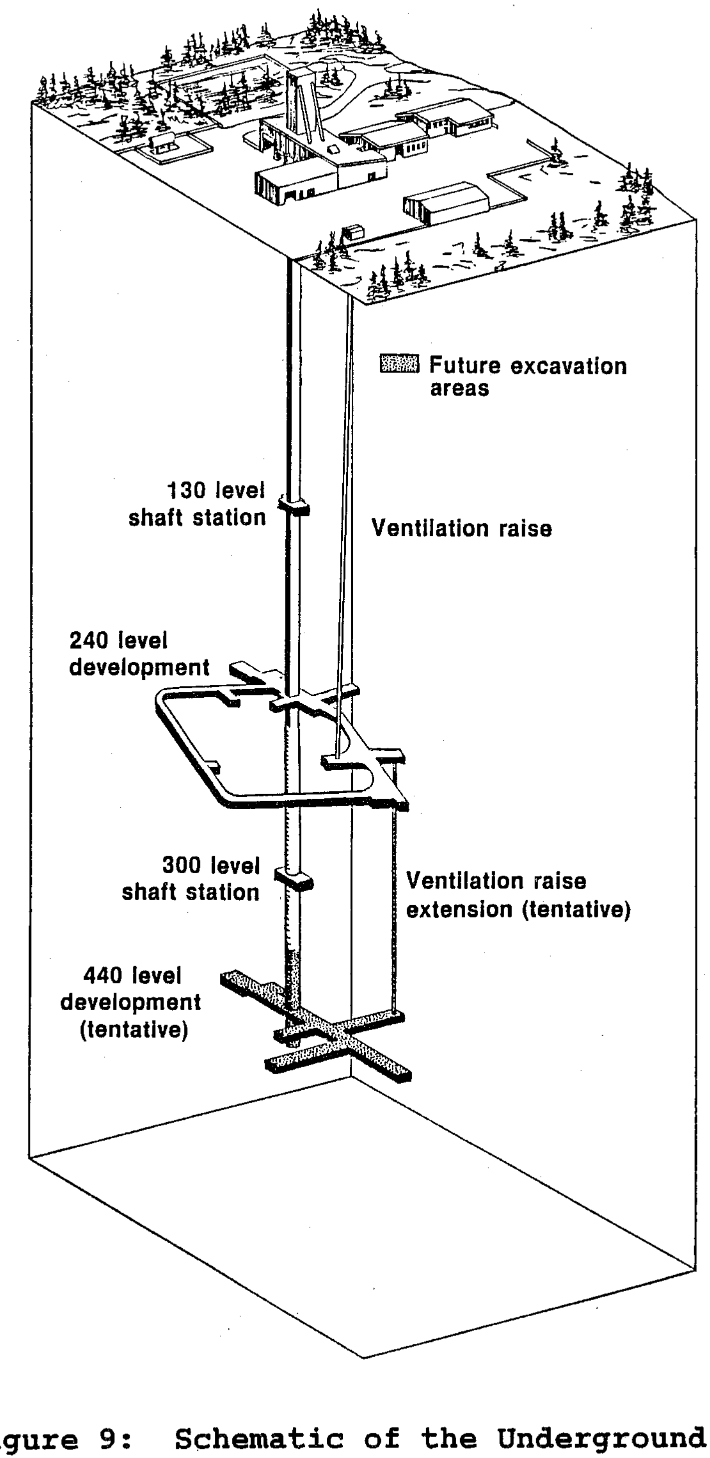


Figure 9: Schematic of the Underground Research Laboratory

Present Status of the Development of Uranium Enrichment Technology in France

(P. RIGNY. JH COATES and G. SAUZAY)

EURODIF has been under full operation since 1982 in accordance with the market demand. Costs have been optimized in particular by taking advantage of power consumption modulation. No future need of capacity is foreseen before the eve of the next century. During the past years, the CEA has evaluated a number of different processes which could have been in competition for the next isotope separation plant. Experimental studies have been carried on on the plasma separation process as well as on the molecular laser isotope separation and discontinued after a first step of evaluation. Likewise R and D on Chemex is to be closed by the end of 1988 after successful operation of a full length pilot plant.

Simultaneously, a large scale R and D effort has been started on SILVA, and has produced evidence of the technical ability of the process to enrich uranium. Separation results obtained on process pilots show that commercial assays can be attained in single step operations. Metal vapor production systems have been started up and tested. Laser systems under development achieve better results than planned. Plans for construction and operation of installations of increasing sizes leading to an industrial demonstration unit are under elaboration. Industrial cooperation is being assessed.

INTRODUCTION

The R and D program on Uranium Enrichment developped in France by the CEA during the years 1960-1980 has found its achievement in the EURODIF plant built in the frame of a multinational cooperation. The history of EURODIF has been presented in several conferences. I shall merely recall that the plant started operation in 1978 and attained full capacity in 1982.

Taking into account the fluctuations regarding market forecasts derived from nuclear energy development, CEA has investigated several Uranium isotope separation processes, trying to focus on those which show the best adequation to the most widely accepted scenarios of enrichment market. Back in the mid 70's, EURODIF was to be followed by COREDIF. But large increments in enrichment capacity soon appeared inedequate as shown recently, when part of the US gaseous diffusion complex was put in stand-by.Future plants have to be modular in capacity and yet, offer good economics even at low capacity.

Several processes have been evaluated by the CEA R & D teams : improved Gaseous Diffusion, gas centrifuge, CHEMEX, SILMO, PSP and SILVA). After comparative assessments, SILVA is recognized to have the best potential in terms of modularity and costs. CHEMEX would be a second choice since it allows stand alone capacities as low as some hundred thousands of SWU/y to remain competitive..

1/- *FUTURE MARKET SCENARIOS*

Nuclear power plant capacity of the Western world is fairly well known until the end of the century. Expected values are in the order of

270	GWe net in	1988	290 in 1990
310		1994	320 in 1995
330		1997	350 in 2000

the two last figures including 15 and 35 GWe not yet under construction. Those capacities can be subdivided among four world areas :

	1987	1994	1997	2000
Europe	104	128	132 (1)*	140 (10)*
Far East	37	50	61 (11)	68 (19)
USA	95	108	110 (0)	110 (0)
Others	16	24	28 (3)	33 (7)

** numbers in brackets give the capacity not yet under construction.*

The total enrichment capacity available today or planned to be on line by 1997 within the Western world compared to the demand (stock piles are not considered) would then be the following :

	1988	1997	
Enrichment Capacity	34,5	36	10^6SWU/y
Demand	26,5	31	

The comparison of the two sets of figures shows that taking into account that the US Oak Ridge GD plant is out of service, the demand will be roughly equal to the plant capacity around the end of the century with a slowly rising excess of demand after 2000.

Consequently there are no reasonable prospects for large size plants, the replacement of existing plants being put aside.

By the end of the century, EURODIF will be twenty years old while the US plants will be much older even if one takes into account the more recent CIP and CUP operations. A reshaping of the enrichment industry including the presence of new producers such as Japan can be expected around that deadline.

2/- *CHARACTERISTICS REQUIRED FROM NEW PROCESSES*

All GD plants will be fully amortized before the end of the century. The SWU costs will then be limited to maintenance, staff and energy costs. The last item will be of particular importance in the breakdown of the SWU cost. Contracts are already being negociated between power plants and GD plants to optimize the daily or seasonal power demand of enrichment plants. The SWU costs to be attained by new processes will have to match with resulting GD plant costs. In other words they will have to be compared to about 2400 to 2500 kwh/SWU with a kwh cost which can exhibit large variations reflecting the structural power demand by the nation and policies of the utilities.

Actual forecasts for nuclear power plants show a slowly increasing installed total capacity. Consequently new processes will be required either as add-on to the existing plants or as replacement of GD plants in case of obsolescence . These new processes should be able to reach commercial assays even with small installed capacities, say less than a few millions SWU's per year.

3/- *URANIUM ENRICHMENT TECHNOLOGIES'EVALUATION*

Gaseous Diffusion (GD)

Some twelve years ago, not long before the rapid decrease in forecasts of nuclear power plants construction, the CEA considered the construction of COREDIF . A new separation membrane was developed aiming at the decrease of energy dissipated by turbulent flow within the diffusion barrier. Small series of this new membrane were manufactured and experimental tests demonstrated that this new type of membrane allowed a 20% decrease of the specific energy consumption. The new technique involved deep changes in stage characteristics as well as in the technology of the main components. However these improvements were not sufficient to allow designing GD plants of small capacity at an acceptable cost. Therefore, this technique was abandonned a few years later.

Recently, the variability of power costs with daily or seasonal power demand was recognized and a major effort has been launched to study rapid transient behavior of GD plants. The US are studying freezer-desublimer systems which make the plant able to follow the power avaibility. Similar ideas are underway in France. However, it is difficult to compare objectives and performances to be attained in the two countries since both the power grid and the GD plant have significant differences. For instance, EURODIF already takes benefit of a very integrated power grid which helps transporting power from and to any part of the Country, whereas the US DOE may use the low UF_6 inventory of the GD cascade in order to favour rapid transients in plant operations and optimize a more local grid network.

Gaseous Centrifugation (UCG)

The CEA has recognized very early that UCG must face significant difficulties before reaching a state where attractive SW costs can be attained. In some cases, these difficulties seem to have been overcome ; in particular URENCO operates several centrifuge plants. Japan has announced and partly achieved a major program of pilot and production plants. Both seem to be working on non sophisticated reliable and cheap technologies, whereas the US DOE discarded in 1985 the construction of a production plant based on a more sophisticated technology which probably needed more maintenance. Even so, both costs and lack of market together with better costs expectation for AVLIS were probably the reasons which led the DOE to abandon its centrifuge technique.

Whatever the degree of sophistication of the technology, the unit separative capacity of a machine remains limited to some tens or hundreds of SWU per year, thus leading to large series of machines required for significant plant capacity. The improvement of costs requires increase of machine capacity at a constant or even decreased machine cost. High mechanical stress materials needed to increase rotational speed as well as the improvement of internal flow patterns are among the key research paths to be explored.

Some ten years ago, cost evaluations were made by french industrial companies. A few years later CEA, considering the success of the EURODIF enterprise and the results of those evaluations compared to other processes, decided to discontinue all R and D on this process. The actual previsions of SILVA costs lead to confirm that decision.

Chemex

Several chemical reactions between uranium compounds show isotopic effects which result from slight differences between the equilibrium constants of the reactions between the coumpounds of each isotope. At the time of the Manhattan project a large review of these techniques concluded that they could not be competitive. The very small separation coefficient of most of those processes leads to a very large number of theoretical stages and thus to a large volume for the plant and a very long equilibrium time or operation time before nominal production.

A japanese company, ASAHI, has made a vigorous effort to develop resins allowing for a very small height equivalent to a theoretical stage in a packed column of large flowrate. Simultanoeusly this company looked at catalysts to increase the kinetics of the exchange reactions.

Twenty years ago, CEA discovered an exchange reaction between U^3 and U^4 which showed a relatively large separation coefficient, twice higher than usual. Isotope separation cascade theory shows that this leads to a possible gain of a factor 4 in comparison with the previously known chemical exchange reactions. CEA made a review of possible technologies : mixer-settler, rotating contactors, resin packed columns and finally chose pulsed columns for a thorough investigation of that process named CHEMEX.

Low costs could be achieved provided limited energy is consumed in the chemical transformation of U compounds at both ends of the isotope cascade. Simultaneously the performances of the pulsed columns had to be improved to reduce the volume and the equilibrium time of the plant. These two objectives are almost fulfilled. Energy yield is as low as 1/6 that of GD , pulsed columns have comparable capacity and sizes as the GD stages.

The overall cost is then less than half the GD full cost for capacities of about 3 millions SWU's per year. In other words, CHEMEX would perfectly fit the requirements for new processes except one : the market is not there !

Before new needs appear, there is time to develop other processes the physical properties of which lead to a drastic improvement of performances.

4/- *CEA EFFORTS ON SILVA RESEARCH AND DEVELOPMENT*

Highly selective processes

Since the mid seventies, particular attention has been given to highly selective processes based on physical resonant excitations applied at relevant frequencies. The best known are photodissociation of UF^6 molecules by lasers (SILMO), cyclotronic resonance (PSP) and laser photoionisation (SILVA). Compared to other processes, the atomic vapour laser isotope separation, i.e. SILVA, was soon recognized as having a significant advantage in being able to reach commercial assays in only one stage with a high throughput capacity. This double advantage is probably unique even if the one stage characteristic can also be obtained by the plasma process. Let us spend a few minutes of each of these highly selective processes.

Ionic cyclotron resonance (PSP)

To our knowledge, only the US (TRW) and France (CEA) have developped substantial efforts in order to assess the performances of the PSP process. The separative unit is composed of four main parts : the superconducting magnet, the plasma source, the resonance zone and the collecting apparatus.

Using a plasma source avoids space charge effects and allows higher mass flow rates. The uranium plate, biased negatively, is sputtered and the resulting neutral atoms are ionized by electron cyclotron resonance. The plasma source must be stable, quiet, with a low electronic and ionic temperature ; its diameter must be high (2 to 4 meters) so that the fraction of processed material be high, more than 90%. No liquid uranium is present in such a source.

In the resonance zone, the magnetic field must be homogeneous to better than the relative mass difference, and high enough (about 3 Teslas), so that the resolution of the machine may yield a separation factor of about ten. The main problem which has to be overcome lies in the penetration of the electric field at the cyclotron frequency in the plasma. The radiofrequency is created by some antenna which has bo be matched to the plasma. Broadening of the resonance can stem from the collisional effects, especially the Coulomb ones ; this leads to keep the ion density to relatively small values.

The collecting system gives rise to difficulties very close to those which are encountered in SILVA : thermal stresses and loads, detrimental sputtering, collecting efficiencies. Here, liquid (continuous) or solid (batch) collection can be used.

Such a separative element is able to enrich uranium to 3.5% or more in one pass as the cyclotron resonance process is well adapted to minor resonnant ions. The stripping should be satisfactory compared to laser isotope separation processes, in particular to SILMO. On the contrary, the specific energy consumption is higher, about 250 Kwh/SWU. A typical unit could produce about 50000 SWU/yr with a load factor of 80%. The technology has been developped for other purposes (fusion, nuclear physics...), has reached some maturity and is reliable.

The main difficulty is to attain high load factors. Furthermore, one has to clean the screens due to imperfect material efficiency. Thermal loads may be important like in SILVA. Unknown still remain on the efficiency of the penetration of the cyclotron resonnant electric field for large separative units. The important operationnal costs, mainly due to the liquid helium consumption, could be relaxed with the use of the emerging new superconducting technology.

Laser molecular process

The molecular process based on laser photodissociation of molecular UF_6, is made of four main steps in the following order :

- Adiabatic cooling of the UF_6 molecule diluted in an inert gas, to achieve resolution of the isotopic absorption bands of 235 UF_6 and 238 UF_6. At a room temperature, the broadening of the bands by thermal excitation is such that no isotopic selectivity could be observed.

- Storage of internal vibrational energy by absorption of 16 micron infrared photons, delivered by a pulsed laser operated at a high repetition rate (10Hz).

- Photochemical dissociation in $UF_5 + F$, of the vibrationaly energetized 235 UF_6 molecules. This is achieved by using ultraviolet photons (308 nm) delivered by a pulsed excimer laser.

- Growing of the $(UF_5)_n$ crystals, allowing the collecting of the enriched fraction and the recycling of the depleted gaseous phase.

The American MLIS and French (SILMO) programmes were abandonned respectively in 1982 and 1986, in favour of the atomic vapour process.

From 1972 down to 1986, the French SILMO program has reached the stage of an integrated experiment. This set-up enabled to measure the global enrichment factors as a function of the operating conditions, and to seize the technical difficulties.

One major drawback is that the molecular process operated in realistic operating conditions revealed itself unable to achieve, in a single step, the standard enrichment operation from natural to 3.5% enriched uranium product. A reduced but significant number of stages (5 to 10) in an enrichment and depletion cascade is thus necessary with the hindrance of chemical change of state.

The build-up of internal vibrational excitation obtained by an increased fluence of the infrared laser is detrimental to the conservation of the isotopic selectivity. It is possible to combine a larger number of infrared lasers progressively tuned toward shorter wavelengths, in order to reach a higher internal vibrational excitation while preserving selectivity. But then, other drawbacks become prohibitive such as laser investment cost. Other ways of using infrared and/or ultraviolet fluences can be explored and remain interesting.

From the engineering stand-point the use of such extremely different wavelengths from the infrared (16 microns) to the ultraviolet (308 nm), is the source of severe problems for optical materials. The ultraviolet fluence is thousand times higher than the infrared fluence, due to the ratio of the absorption cross-sections, it renders the optimal gestion of the IR and UV laser beams somewhat difficult to achieve.

The technical solutions used for IR and UV lasers, although theoretically scalable, are far from industrial operating reliability.

These aspects among a few others have played against the selection of the molecular process.

The Silva process

The SILVA principle is well known. The selectively ionized U235 isotope atoms have to be collected independently of the U238 neutral atoms.

The CEA R and D programme which was initiated more than ten years ago has been organized around the following guidelines :

- Identify a high efficiency irradiation scheme in terms or cross sections and selectivity.
- Develop high reliability tunable laser instruments.
- Develop high reliability uranium vaporizers.
- Optimize the photo- ionization and extraction cells such as to maximize uranium flowrates while adjusting the assays at commercial levels.

The programme is made of consecutive and simultaneous sets of basic research, component development, test benches and assembled pilots the size of which increases with the development of individual parts.

Most of the basic studies, test benches and pilots required to reach industrial demonstration of SILVA have been undertaken by CEA :

- Spectroscopy has been studied for ten years.
- Studies of the physical processes within the photoionization cell started five years ago.
- A first uranium vaporizer was built in 1980.
- A first CVL lighted in 1981.
- A process pilot plant is presently under operation.
- Plans for a technology devoted pilot are under evalutation.

Performance indicators which help qualifying a process are the flowrate and the ratio PNp/FNf or product (P/F) x N_p.

Very soon after the first spectroscopy mesurements in laboratories (that was around 1980), it was recognized that assays N_p well above commercial values can be reached in single step operations. However these results were obtained with very low cuts (P/F) and flow rates (F), typically $<10^{-4}$ and around 1 mg/h provided by effusion furnaces. Improvement factors of some 10^{4} and 10^{8} had to be achieved for SILVA to become technically operational.

Consequently CEA efforts were oriented towards the develompent of metallic vapor sources able of large feed values.

Small sources flowing some kg/h of metallic vapor were available a few years ago and are used as routine instruments to help studying the detailed characteristics of uranium vapor required for a reliable optimization of the ionization cells as well as the study of the cell itself. Simultaneously the further increase of flowrate resulted from the association of individual units of improved yield. The balance between the number of units and individual performance is the result of a cost optimization taking into account :

- The space required to set the ionization cells.
- The distance between these cells and the uranium ingot.
- The power required to vaporize U.
- The cost of investment maintenance and operation of the components.

Early in the course of the programme it was recognized that among the difficulties to demonstrate the technical capacities of SILVA there was the rate of availability of tunable laser light with a fluence large enough to achieve a high ionization yield of U235 atoms which is a requisite for a large cut. Simultaneously a high recurrence of the pulsed laser is required to achieve that large cut (P/F). While the fluence is inversely proportional to the atomic light absorption cross section, the recurrence of the laser light system is related to the extraction geometry and vapor velocity.

Development of tunable lasers was initiated very early taking as reference solutions copper vapor lasers and dye lasers.

From the few watt power CVL available a few years ago to the hundreds of watt power laser required for an industrial plant several steps were planned. The optimization between high performance and good reliability is a permanent constraint kept in mind. High performance systems can be left aside because of poorer reliability. Several technical set ups had to be compared and evaluated. Recent versions of lasers of intermediate power achieve 50% better than expected performances, reliability is under evaluation.

Fluence and recurrence lead to a high product assay provided the flow of U^5 ions is not too degenerated by pollutions which are U^8 ions of various origins (photo-ions, ...) or neutral vapor of assay lower than required in quantities depending upon the selectivity the geometry and physical characteristics of the ionization and extraction cell.

A large cut $\frac{P}{F}$ and a product assay N_p result from an optimization balance between photo-ions and pollutions. Results achieved on pilot plants not equiped with fully recurrent laser systems produced evidence of technical ability of the process to enrich uranium. When taking into account scaling effects on recognized parameters, P/F and N_p are near the expected level.

Components are under test in order to allow to operate simultaneously at the expected level on all significant parameters. This is the next step under preparation on the process pilot plant.

The aim of the next equipment is to demonstrate simultaneously large feed and expected commercial P/F and N_p values. It is going to be a large size installation. Specifications are under discussion. Industrial cooperation may be required at that step since equipment costs become a major chapter of the process evaluation that need to establish the economical or cost competitiveness of the process.

5/- CONCLUSION

This brief review of enrichment processes studied by the CEA gives an idea of the attention given to enrichment techniques in France. Efforts in this field have been maintained for more than thirty years. Present challenges are comparable to them which were overcome in the past, and I have no doubt that they will meet with equal success.

Thank you for your attention.

日本のウラン濃縮技術

東京工業大学名誉教授
高 島 洋 一

日本は現在なおウラン濃縮に関して数々の技術を開発中である。 即ち、（１）ガス遠心分離法，ＧＣＰ （２）原子レーザー分離法，ＡＶＬＩＳ （３）分子レーザー分離法，ＭＬＩＳ （４）化学分離法，ＣＨＥＰ 等に関連した技術開発が精力的に行われており、いずれも少なからぬ研究費を投じ、多数の研究者を動員している。 今後、ウラン濃縮の国内事業が国際競争に耐え、生き残ってゆくためにはこれらの濃縮分離法を適切な時期に、適切に取捨選択して商業用プラントに取り入れる必要があり、国内での開発競争が一層激化することが予想される。

（１）ガス遠心分離法の技術開発と商業化

ガス遠心分離法の技術開発は既に２０年以上の歴史を有し、１９６９年、動力炉・核燃料開発事業団（ＰＮＣ）の東海事業所において、東京工業大学原子炉工学研究所と共同で開発された小型ガス遠心分離機により、初めてウラン－２３５を 1.025倍濃縮することに成功し、以後ＰＮＣは（株）東芝、（株）日立製作所、三菱重工業（株）等メーカーの協力により、商業用に適したガス遠心分離機の開発を積極的に行い、次のような進展を見た。

１９７８年、人形峠にパイロット・プラントの手初めとして、ＯＰ－１Ａの建設を開始し、１９７９年にその運転が始まった。 一年遅れであるが、技術の進んだより高性能のプラントＯＰ－１Ｂが追随し、更に一段と性能の向上した第三のプラントＯＰ－２の運転も１９８２年の初期に開始され、現在も順調に稼動している。 これらのプラントでは予め東海事業所において、長期運転に耐えることを十分実証したガス遠心分離機が使われており、実際パイロットプラントとして期待以上の成果を収めている。

更に同じ敷地にＰＮＣは性能ばかりでなく、経済性も顕著に向上した原型プラントを建設中で、そのＤＯＰ－１は１９８８年早早に完成したが、ＤＯＰ－２も８９年には完成し、フル運転に入るのも遠くはない。 その分離容量は夫々100,000 SWU/yrであるが、遠心分離機の製作は上記メーカー三社により８４年末に設立されたウラン濃縮機器（株）（ＵＥＭ）との契約によるものであり、同社は今後の商業用遠心分離機の製作を担当することになっている。

なお、周知のように、１９８５年４月青森県六ケ所村に原子燃料サイクル事業の立地が認められ、その１月前の３月、電力会社等の出資により設立された日本原燃産業（株）（ＪＮＦＩ）がウラン濃縮事業を行うことになった。 ＪＮＦＩの事業計画によると、遠心分離法による商業プラントの建設を８８年中に開始し、９１年より運転をすると共に、年150,000SWU/yr の増設で、600,000SWU/yr までは現在の技術を活用することになってお

り、その後はできればＰＮＣで以前より開発中の新素材を用いた超高性能遠心分離機を導入する意向である。

即ち、ＰＮＣ，電力会社、ＪＮＦＩ、ＵＥＭ及び８７年末発足した日本複合材料（株）（ＮＣＭ）らの共同開発体制を作り、この遠心分離機のブロック試験により、性能を実証するとともに、商業的生産ラインを確立して、少なくとも 1500,000SWU/yr の分離容量までは遠心分離法によるプラントの拡張を目指している。

（２）原子レーザー分離法の技術開発

１９８５年6月、米国ＤＯＥはＧＣＰプラントの建設を取り止め、次期にはＡＶＬＩＳを採用することを決定し、フランスＣＥＡも既にＡＶＬＩＳの技術開発に主力を注ぐことを決めていた。　日本でもこの方法は将来性のある新技術と見なされ、ＧＣＰが国際競争に耐えられなくなる場合に備え、この技術開発を行う必要性が認められた。　即ち、８５年１２月、原子力委員会にウラン濃縮懇談会が設置され、審議の結果、産、官、学の協力の下に加速的にＡＶＬＩＳの研究開発を推進する必要があるとの報告がなされた。

このウラン濃縮懇談会の方針を受けて、８７年４月、電力９社、日本原子力発電（株）、（財）電力中央研究所及びＪＮＦＩにより構成されたレーザー濃縮研究組合(LASER-J) が設立された。一応、４年間の研究計画をたて、前半２年は主としてレーザーシステム及び分離システムを構成する候補機器をメーカー数社により開発、試験を行う期間とし、後半２年は最も信頼性が高く、優秀な機器システムの製造メーカーを選定し、実験機の建設、運転を行う期間としている。

なお、日本におけるＡＶＬＩＳに関する基礎的研究は１９７６年に日本原子力研究所（ＪＡＥＲＩ）において開始されており、７８年にはその原理を実証し、８２年、約100 μg の低濃縮ウランを回収している。　更に組合の誕生までに原研では国内での銅蒸気レーザー、色素レーザーなどの機器開発を指導し、８５年１月には分離も含む工学試験に着手するなど、本格開発への魁となったが、現在ではＵ－２３５の超微細構造、電荷交換断面積、電離率の高い分離スキーム等、分離に使われるべきレーザーの最適照射条件を明確にするため、データーベースの整備に主力を注ぐことになった。

未だ技術開発を開始して間もないが、幾つかの成果を挙げ始めている。　例えば、銅蒸気レーザーに関して、単機でほぼ１００Ｗの出力を達成し、５ＫＨｚの繰返数が得られ、５０時間の持続性がある。　また増幅組み合わせ（ＭＯＰＡ）による目標出力２００Ｗに対し、１２０Ｗを得ている。　色素レーザーに関しても、ＭＯＰＡで４０Ｗの目標に対し、１１Ｗが得られ、光質も±１００ＭＨｚ以内で安定し、約１時間の持続時間の実績がある。

ウラン蒸気発生の為の電子銃に関しても、ほぼ目標に近い成果をあげており、総体的にはエネルギー効率に関して大幅な改善を必要とすることが明らかとなったが、初期としてはかなりの成果を収めたといえよう。　なお、予備試験ではあるが、2.4 ％の濃縮ウラン約１ｍｇを得て、ＡＶＬＩＳによる分離効果を十分確認しており、今後の開発で飛躍的成

果が期待される。

（３）分子レーザー分離法の技術開発

理化学研究所（ＩＰＣＲ）はレーザー利用に関して古くから広く開発研究を行ってきた実績があり、１９８２年ＤＯＥがウラン濃縮の三つの新技術（ＡＩＳ）即ちＡＶＬＩＳ，ＭＬＩＳ及びプラズマ分離法（ＰＩＳ）の内、ＡＶＬＩＳを主要開発の対象として採択したことに対しては極めて批判的で、ＭＬＩＳの技術開発をむしろ有望視している。　すなわち、ＭＬＩＳの場合、UF_6 を超音速ノズルを通じ、断熱膨脹により温度を約５０Ｋの過冷却状態にまで下げ、波長１６μｍ付近の赤外レーザーを当てれば、Ｕ－２３５を効率よく選択励起できることは既に認められており、問題は更に励起されたUF_6 分子を選択性を劣化させるＵＶレーザーで解離していたことにあり、もしそれに代えて赤外多光子解離法（ＩＲＭＰＤ）を用いれば、トリチウムの分離などの経験から、十分効果的に濃縮できると判断している。

なお、ＡＶＬＩＳにおいて、ウラン蒸気発生のためには局所的ながら２５００Ｋの温度をウラン金属に与える必要があるなど、分離装置に関して工学的に困難な問題が種々あるのに比べ、ＭＬＩＳでは従来の習熟した技術でUF_6 を取り扱うことができ、必要な解離エネルギーも、ウラン原子のイオン化エネルギーより低く、またより高密度状態でレーザー照射し易いなど、無視できない多くの利点がある。

理研では１９８４年既にウラン同位体分離用としての赤外可変ラマンレーザーの開発に成果を挙げており、上述のような見解から８５年度より３ケ年計画で、ＩＲＭＰＤを取り入れた、新らしいＭＬＩＳ法の原理実証試験を進めることになった。　１９８７年4月、理研において１００Ｋでの予備実験ではあるが、１６μｍ付近で僅かに波長が異なる２つの赤外レーザー光を照射し、分離係数が２を上回る値を得たことが報じられ、この方法が一段と注目されるに至った。　現在、理研では引き続き原理実証試験を進めるとともに、次期ステップに不可欠な高繰返しCO_2 ガスレーザーの開発に積極的に取り組んでおり、さらに分離プロセスにおける超音速ノズルの形状、過冷却現象、解離してできたUF_5 の粉末性状などについての基礎的研究も行われているが、新ＭＬＩＳの次の段階の研究開発は理研とＰＮＣが役割を分担して行うことになっている。

付記：　１９８８年4月６日、第２６回日本原子力学会年会における理研のＭＬＩＳに関する口頭発表によれば、彼等の考案したＲＩＭＬＩＳによるウラン濃縮実験の結果、分離係数４．７の値を得たという。

（４）化学分離法の技術開発

このプロセスの開発は旭化成工業（株）が単独で行ったものであり、１９７８年頃より始まっている。　分離は次の原理に基ずく。　陰イオン交換樹脂に吸着されたUO_2^{2+}と溶液中のU^{4+}が共存し、平衡状態にある時は存在比 ^{235}U／ ^{238}Uが樹脂中と溶液中では

等しくなく、存在比の比が 1.0012 とわずかではあるが、$UO_2{}^{2+}$側に ^{235}Uがより濃く存在することを利用したものである。 即ち、塔の中の下部より酸化剤帯、ウラン吸着帯、還元剤帯を形成し、上部より還元剤を供給すると、クロマトグラフィー展開により、ウラン吸着帯上端で還元されたU^{4+}が脱着され、溶液として流下する。 しかしその帯の先端に到達すると酸化され$UO_2{}^{2+}$となり、樹脂に吸着され、ウラン吸着帯は一定の長さを保ちながら下方に延びる。 その結果、相対的に$UO_2{}^{2+}$とU^{4+}が向流し、上下端で全還流する。 従って平衡関係から ^{235}Uは樹脂側に、^{238}Uは溶液側に僅かながら移動し、蒸溜の原理と同様に、ウランは上端で濃縮され、下端で減損される。

商業化のためには陰イオン交換樹脂の交換容量が十分大きく且同位体交換反応が速いこと、酸化、還元剤の再生に要する動力が少ないこと、樹脂の製作費、プラントの建設費等がスケールメリットにより、安く抑えられること等考慮すべき問題が多くあるが、既に実証の段階に入っており、遠からず、この方法の技術及び経済評価も可能となろう。 なお、これまでに多くの成果を挙げているが、歴史的には次のような進展を辿っている。

先ず、樹脂の改善、反応促進剤の開発等で１９８１年に、約３ケ月で３％まで濃縮できる実績を得ている。 その後、１０ｃｍ内径のベンチプラント、続いて１ｍの大型プラントを宮崎県日向市に建設し、長期運転の安定性とスケールアップの影響を調べている。安定運転のため必要なバルブの自動切換え、濃縮度の連続測定等の技術の開発を行い、一応、このプロセスのスケールアップに関する困難な問題は克服できる自信を得ている。

特筆すべき成果は１９８３年にスーパー法の開発を始め、実用化の目途がたったことである。 即ち、酸化還元剤が使われた後、相互の反応により、その大半が可逆的に復活され、再生のために必要な酸素、水素の量を著しく低減でき、これまで濃縮プロセス上、プラントとしては４塔を必要としていたのに対して、１つの長塔と、小容量の２つの再生塔で済むことになり、操作が単純化され、このプロセスの経済性は大きく向上した。

以上、日本におけるウラン濃縮技術について、その概略を述べたが、現在、商業化可能なものはＧＣＰだけであり、当分はなお進展が期待できるＧＣＰによって、国際競争に耐えて行かねばならない。

技術開発の進展度から言えば化学分離法が次いでいるが、熟成するまでには未だ数年を要すると見られる。 レーザー法は両方とも、技術開発が始まったばかりであり、将来性は非常に高いと見られているが、物になるためには１０年前後かかるものと考えられる。

現段階では、技術開発の観点から、いずれの方法も捨てがたく、相互に激しい開発競争が当分続けられるであろうが、国内の濃縮需要にも限りがあり、事業を行う上では、恐らく１つの選択に絞らざるを得ないであろう。

従って約３年後には、技術の成熟度や経済性についての評価が上述の４つの方法について比較検討される事になっており、どの様に推移するかは予測しがたいが、技術開発の存続のためには少なくとも国際的に競争できる目途がたっていることが肝要であろう。

TECHNOLOGIES FOR URANIUM ENRICHMENT IN JAPAN

Professor Emeritus of Tokyo Institute of Technology
Yoichi Takashima

Japan has been actively doing R & D of four processes for uranium enrichment and has spent a considerable amount of money and held a high level of man power for each R & D. Those processes are (1) Gas Centrifuge Process,GCP (2) Atomic Vapor Laser Isotope Separation, AVLIS (3) Molecular Laser Isotope Separation, MLIS and (4) Chemical Enrichment Process, CHEP.

As a matter of fact, the Japanese domestic uranium enrichment business is in a severe situation against its international competition. Therefore, it needs for its survival to add on a more advanced enrichment plant than the previous one each time, specially in the case of GCP and on the other hand it also needs to decide at a proper time to introduce a new process into the next commercial plant, if it has been technically well developed and regarded as obviously a better and more prospective process than the existing one.

(1) R & D of GCP and its Commercialization

The R & D of GCP have been made for more than 20 years and the first trial of enriching uranium was successfully made with the separation factor of 1.025 in 1969 at PNC's Tokai works by a small type of gas centrifuge designed and used by Tokyo institute of Tecnology.

Since then, PNC has developed more advanced centrifuges successively, aiming at the commercial use, in co-operation with Toshiba Co., Hitachi Co.and Mitsubishi H.I.Co. The first plant, OP-1A as one of the GCP pilot plants was built at the PNC's Ningyo-Touge Works in 1978 and was operated from 1979, following by the second and more advanced plant, OP-1B one year later. The third and the most advanced plant, OP-2 was brought into operation in early 1982. These pilot plants have been satisfactorily operated up to now.

Then, PNC built up the first half of the demonstration plant, DOP-1 early in 1988 at the same site, which was largely improved in construction economy as well as in separation performance and the last half, DOP-2 is just under construction. Each capacity is 100,000 swu/y and the new company, UEM co. established in 1984 has supplied these centrifuges as the first job and soon will manufacture commercial gas centrifuges steadily.

Rokkasho-mura in Aomori Prefecture was officially admitted as the site of nuclear fuel cycle center in April,1985, soon after the JNFI co. was born in March,1985 to undertake the uranium enrichment business and the low-level waste management. According to JNFI's business plan, the construction of its commmercial uranium enrichment plant will start in 1988 and its operation in 1991, with the successive add-on of 150,000swu/y every year up to the total capacity of 600,000 swu/y by adopting the current gas centrifuge technology.

JNFI is then intending to introduce a considerably more advanced type of gas centrifuge which has been developed at Tokai, into the next plant up to 1500,000swu/y. In fact, PNC,, most of electric power cos., JNFI, UEM and NCM started recently their joint venture of R & D on the new production system of this centrifuge and in parallel, PNC will soon begin the block test to assure its stable separation perfomance.

(2) R & D of AVLIS

Japan AEC set up an ad hoc committee for making future enrichment scenario in December,1985 and it was reported that it should be neccessary to promote AVLIS R & D activity by a joint collaboration of industry, government and university, because of its high potential for the commercial application.

Based upon this report's suggestion, Japanese electric utilities and their daughter companies created LASER-J in April,1987. LASER-J, then, has drawn up a master plan for 4 years period that it will mainly develop components of laser and separater systems in first 2 years with a few manufacturers and then select suppliers of best components for the AVLIS facility which will be built and operated in latter 2 years.

JAERI, independently, started AVLIS R & D in 1976 and was already successful in demonstrating its feasibility in 1978 and collected 0.1mg of enriched uranium in 1982. Furthermore, JAERI led and contributed to developing such components as copper vapor laser and dye laser and undertook an engineering test for the uranium isotope separation in January, 1985, to develop its overall technology till the appearance of LASER-J. JAERI is now focusing its main targets to such foundamental but very vital tests as to search for data of ^{235}U super fine structure, charge exchange crosssection schemes and the optimized laser irradiation condition.

LASER-J has been acquiring such valuable results for only one year that the copper vapor laser has been developed its output up to 100 watts/unit with the repetition rate of 5KHz for 50 hrs and 120 watts by its MOPA chain against the target of 200 watts and the dye laser also developed its MOPA output up to 11 watts within the frequency deviation of less than 100 MHz for one hrs against the target of 40 watts/MOPA. As for the separation system, several electron beam guns for local vaporization of uraium metal have been tested and its availability was confirmed. Then, about 1 mg of 2.4 % enriched uranium was obtained at a preliminary separation test. However, it was recognized that the power consumption in both laser and separation systems should be remarkably reduced for the future.

(3) R & D of MLIS

The Institute of Physical and Chemical Research, IPCR has been studying laser development and application for many years and is quite critical about the USDOE's decision in 1982 that it selected AVLIS as a main R & D theme for the future among three processes of advanced isotope separation (AIS), AVLIS, MLIS and PIS. IPCR, however, does deem MLIS the most prospective new technology instead.

In the case of MLIS, ^{235}U can be selectively excited by irradiating the infrared laser about 16 micron in wave length to UF_6 gas, under a supercooled state of UF_6 down to the temperature about 50 K which could be realized by passing UF_6 through a super sonic nozzle. This process is well acceptable as a first step, but IPCR pointed out that the problem should exist in the use of ultraviolet laser as a second step for dissociating the exited UF_6 moleculs, because it would reduce the selectivity of ^{235}U. Then, IPCR offered, based upon the experience of tritium separation by the Infrared Multi-Photon Dissociation, IRMPD, that IRMPD would be sufficiently effective for dissociating UF_6 to UF_5, holding the much higher selectivity of ^{235}U. Thus, IPCR has choiced MLIS R & D, indicating some other reasons as follows:

The temparature of uranium metal must be locally kept more than 2500K to generate the atomic vapor in AVLIS, while in MLIS, UF_6 can be handled at a moderate condition. The ionization energy of uranium atom is higher than the dissociation energy of UF_6 molecule. The density of UF_6 vapor can be higher at the laser irradiation than that of uranium atomic vapor.

Then, IPCR developed and made up the infared Raman laser for uranium isotope separation in 1984 and started a 3 years'project for developing its new MLIS feasibility test by adopting IRMPD. In April,1987 it was reported and called our attention that the separation factor of more than 2.0 was obtained at its preliminary test, in which UF_6 was irradiatted at about 100K by two infrared lasers slightly different each other in wave length of 16 micron. IRCP is now actively continuing its feasibility study and challenging the development of a CO_2 gas laser with a high repetition rate that should be indispensable for the next step of R & D and also conducting some fundamental studies on the supercooling phenomena of UF_6 vapor through the supersonic flow, the powder characteristics of generated UF_5 and so on.

The engineering R & D on the total system of this new MLIS will be pursued by IRCP and PNC, dividing their own roles.

(4) R & D of CHEP

ASAHI Chemical Industry co., ACHI started solely the R & D of an original chemical enrichment process by using a special type of anion exchange regin in 1978. The isotope separation is based upon a chromatograghic process by a cumulative effect of equilibrium separation factor which is quite similar to the distllation process by the effect of relative volatility.

When UO_2^{2+} is adsorbed into the anion exchange resin and contacts with U^{4+} in the solution in chemical equilibrium, the abundance ratio of $^{235}U/^{238}U$, R_U is a bit higher in UO_2^{2+} than that in U^{4+} and the equiliblium separation factor, that is, the ratio of these R_U was found by ACHI to be about 1.0012.

The essential points on this chemical process are as follows:
The anion exchange regin must have a very high capacity for adsorbing UO_2^{2+} and the rate of exchange reaction of ^{235}U and ^{238}U through the boundary of regin and solution must be quite high. The production cost of regin, the construction cost of equipments and the operation cost must be relatively low in the commercial scale. The main equipments must bear well against a severe corrosive attack and be soundly available for a long period.

ACHI has been making tremendous efforts for overcoming all these problems and achieved such fruitful results that the uranium enrichment to 3 % from 0.71 % was attained at a feasibility test by using 4 anion exchange regin columns 2 cm in diameter and 1 m in height within 3 months operation in 1981, due to the improvement of regin and the finding of catalytic reaction agents.

Then, a bench plant 10 cm in dia. and a little later, a pilot plant 1 m in dia. were built at Hyuga, Miyazaki Pref.and ACHI is checking the operational stability, the effects of scale-up and so on by these plants.

The most notable finding by ACHI would be that both oxidizing and reducing agents can be reversibly revived in more than 60 %, by the reaction of both spent agents. Thus, ACHI is testing so called "ASAHI Super Process" in which the operation can be acomplished with only a single ion exchange tower and two relatively small regenerators, due to this revival reaction.

Various technologies which have been developed for uranium enrichment in Japan were just overviewed relating 4 processes of GCP, AVLIS, MLIS and CHEP.

Only GCP is commercially available for the time being and even for GCP, it will need a continual progress for the newer plant to be added so that the domestic enrichment business can survive in the international market.

As for the technical maturity, CHEP developed by ACHI is next to GCP, but it may still need a few years for the confirmation of its reliability.

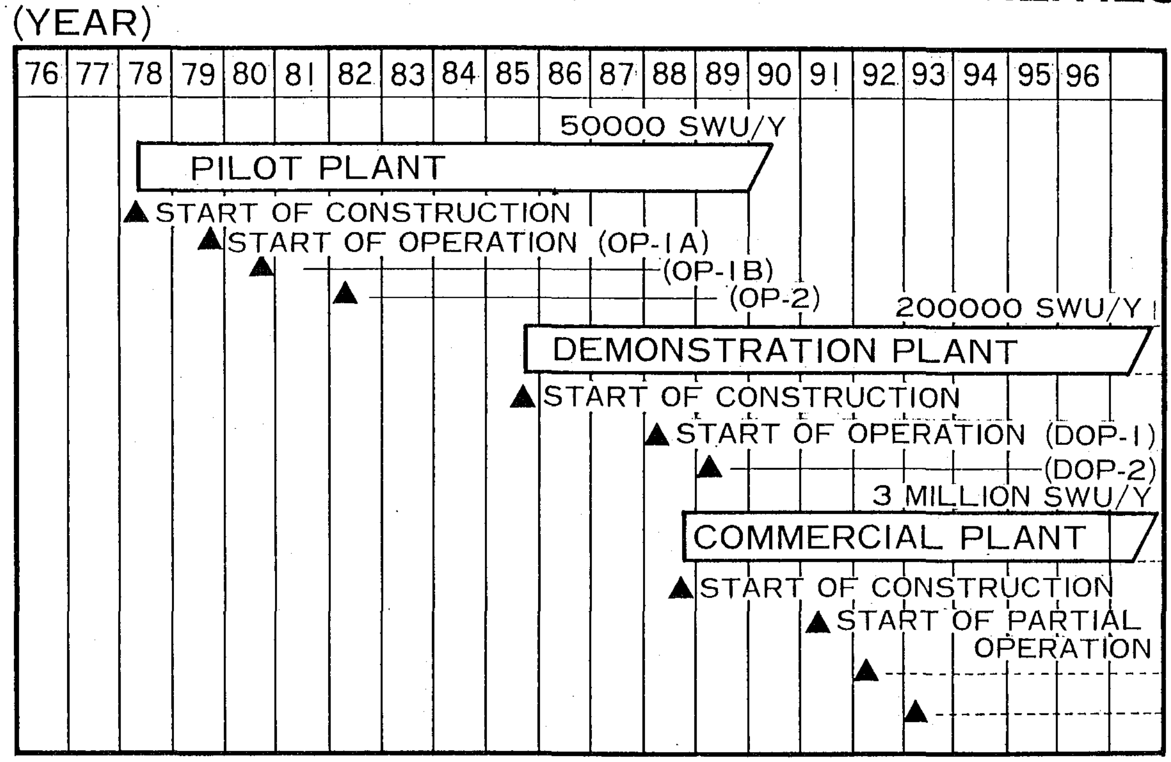
The real R & D projects on AVLIS and MLIS started about a year ago, since it had been admitted on both laser processes at the ad hoc committee set up by Japan AEC that both would have a great potential for uranium enrichment and may become its leading process for the future, although it may take 10 years or more until their technologies have been fully matured.

It, however, needs to make clear or demonstrate their superiority in some future. Because, the domestic demand of toll enrichment is rather limited and maybe only one process can be applied as a new type of commercial plant.

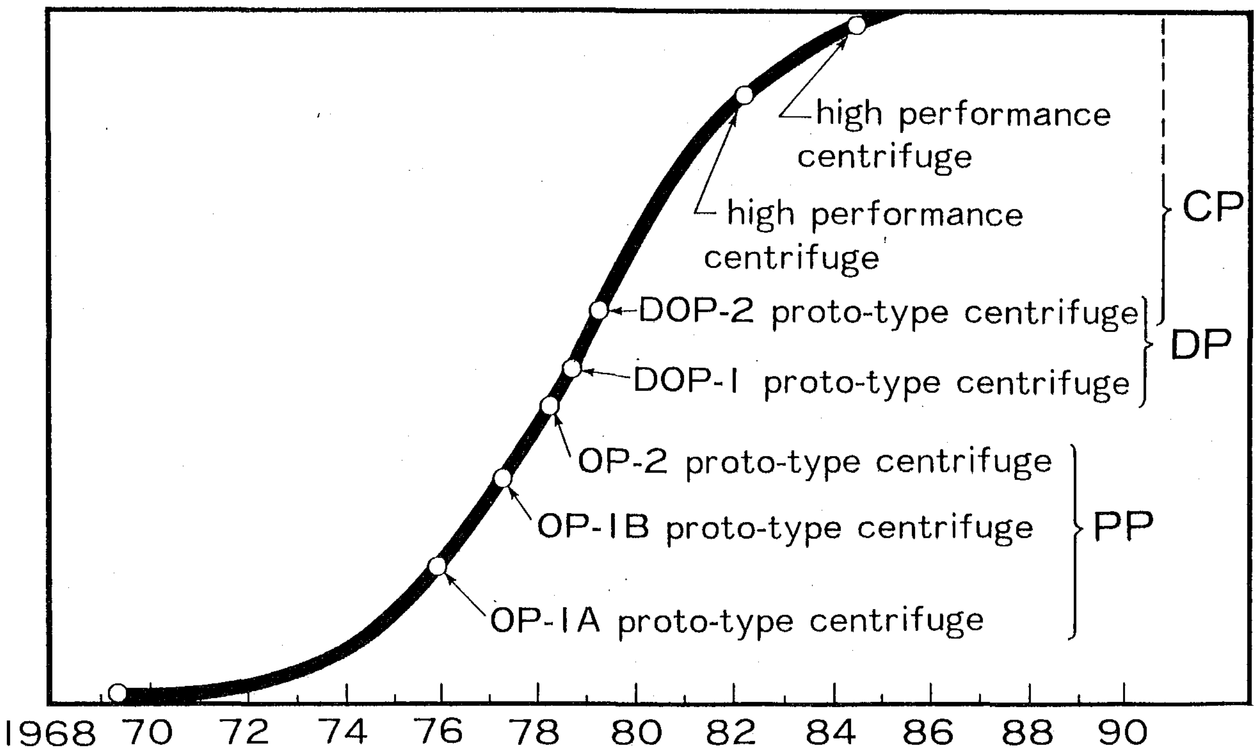
Then, it is so decided in Japan that four processes mentioned above will be comparatively checked and reviewed from the technical and economical points of view in about 3 years from now. It, therefore, will be necessary for continuing their R & D work thereafter that some definitely valuable results can be provided at its C & R committee.

P.S. According to the oral presentation on R & D of MLIS by a IPCR's group at the 26 th. Annual Meeting of AES of Japan on the 6th of April, 1988, they succeeded in attaining the separation factor of 4.7 at a test of uranium enrichment by their MLIS, RIMLIS in which AII Solid-State Exciter,ASSE was applied for the switching.

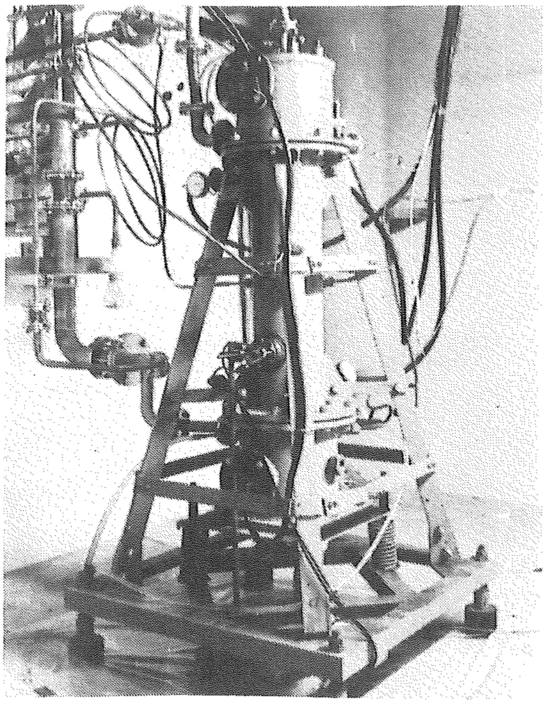
CURRENT STATUS AND DEVELOPMENT PLANS FOR JAPAN'S URANIUM ENRICHMENT FACILITIES



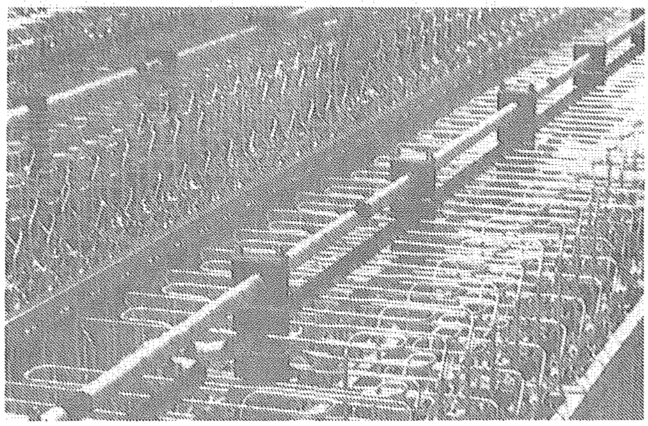
THE IMPROVEMENT OF GAS CENTRIFUGE SEPARATIVE PERFORMANCE



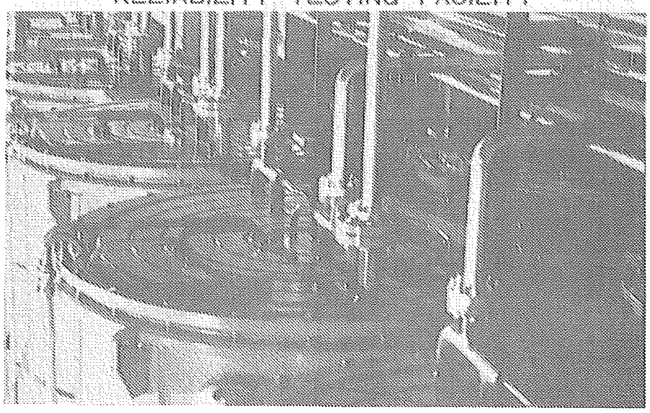
ORIGINAL SMALL CENTRIFUGE



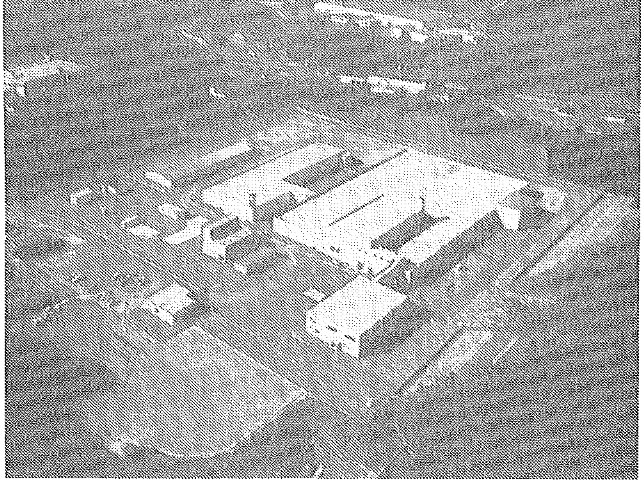
CENTRIFUGE CASCADE IN PILOT PLANT

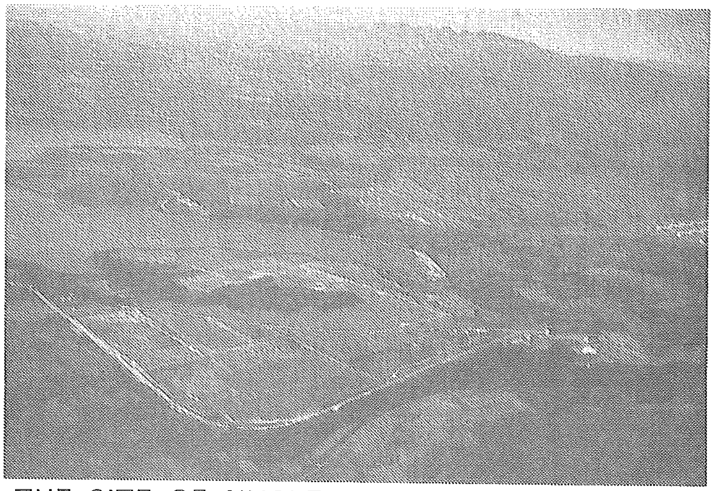


GROUP-MOUNTED CENTRIFUGE
RELIABILITY TESTING FACILITY

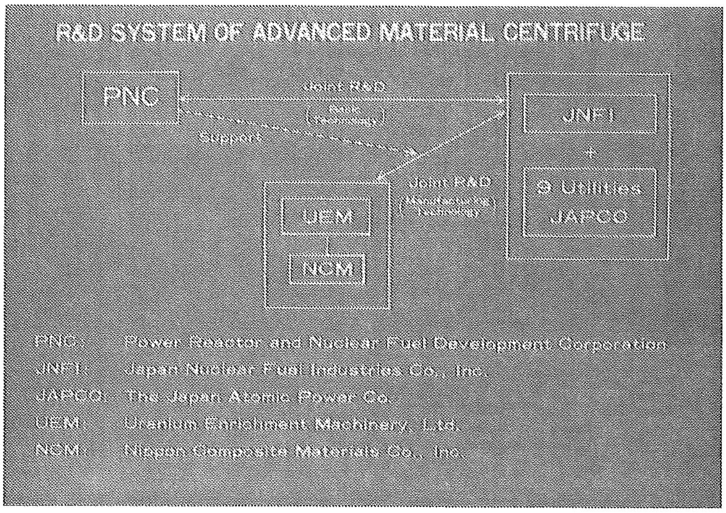


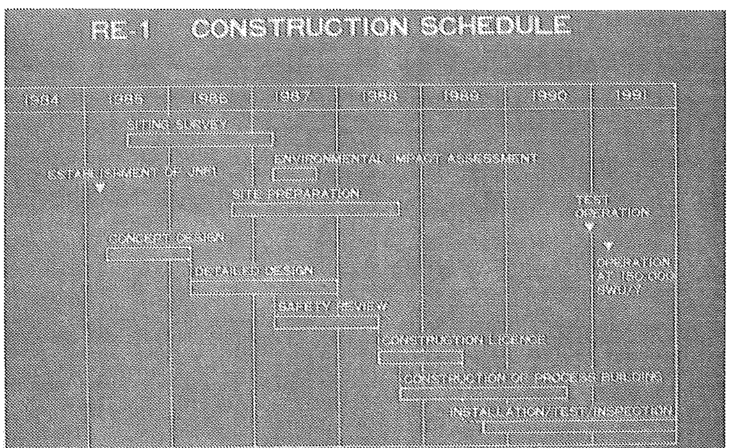
DEMONSTRATION PLANT

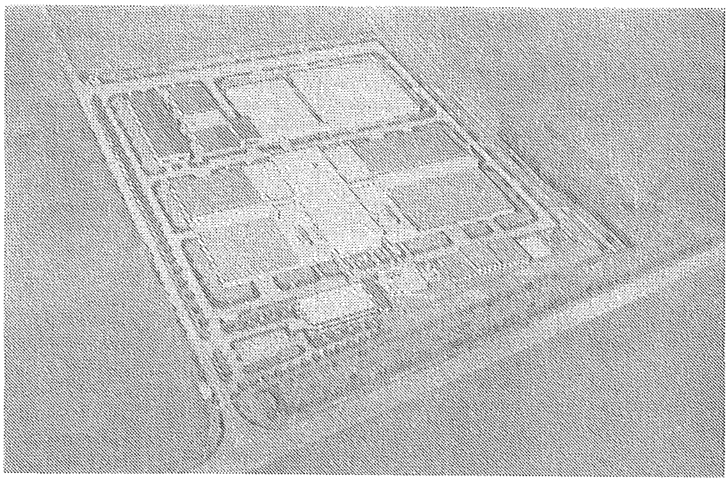




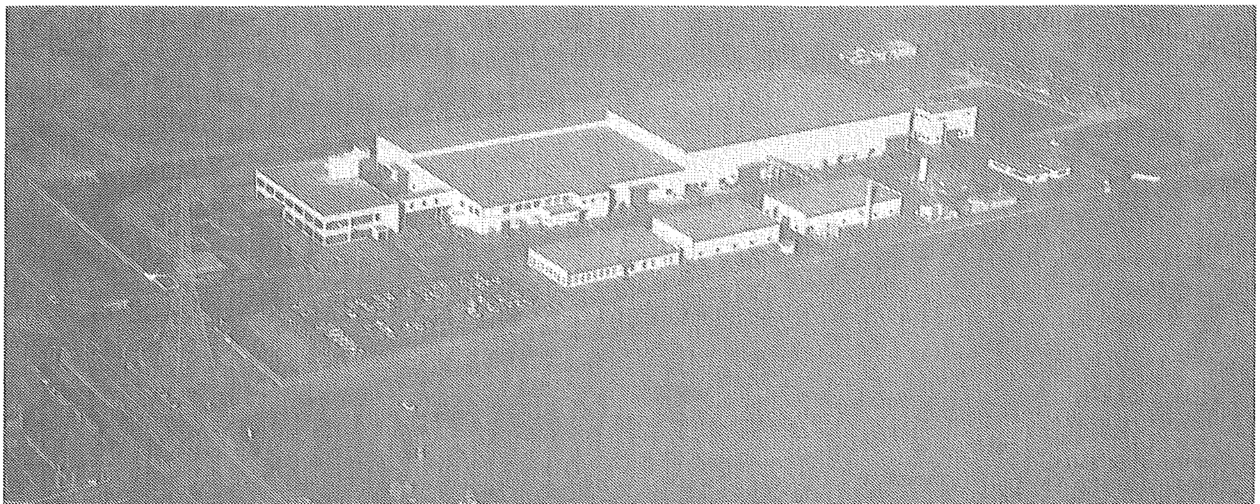
THE SITE OF NUCLEAR FUEL CYCLE CENTER
AT ROKKASHO-MURA



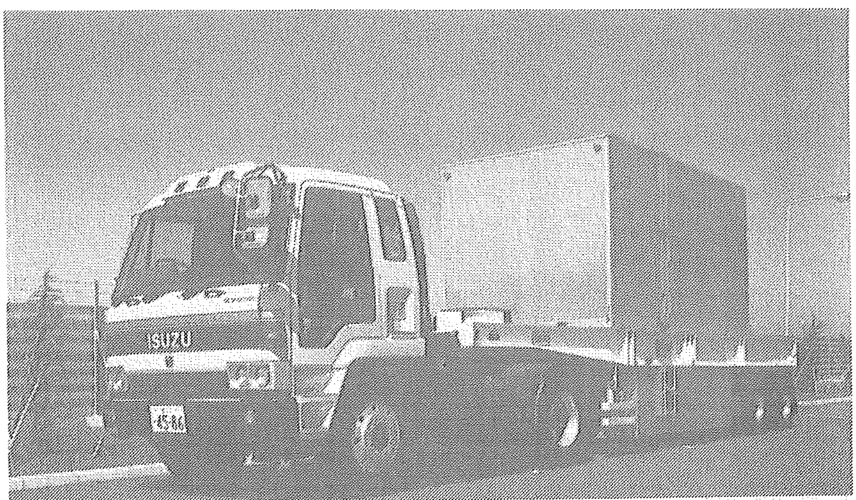




ENVISIONED JNFI'S COMMERCIAL ENRICHMENT PLANT OF GCP



Uranium Enrichment Machinery, Ltd.
Sendai Works



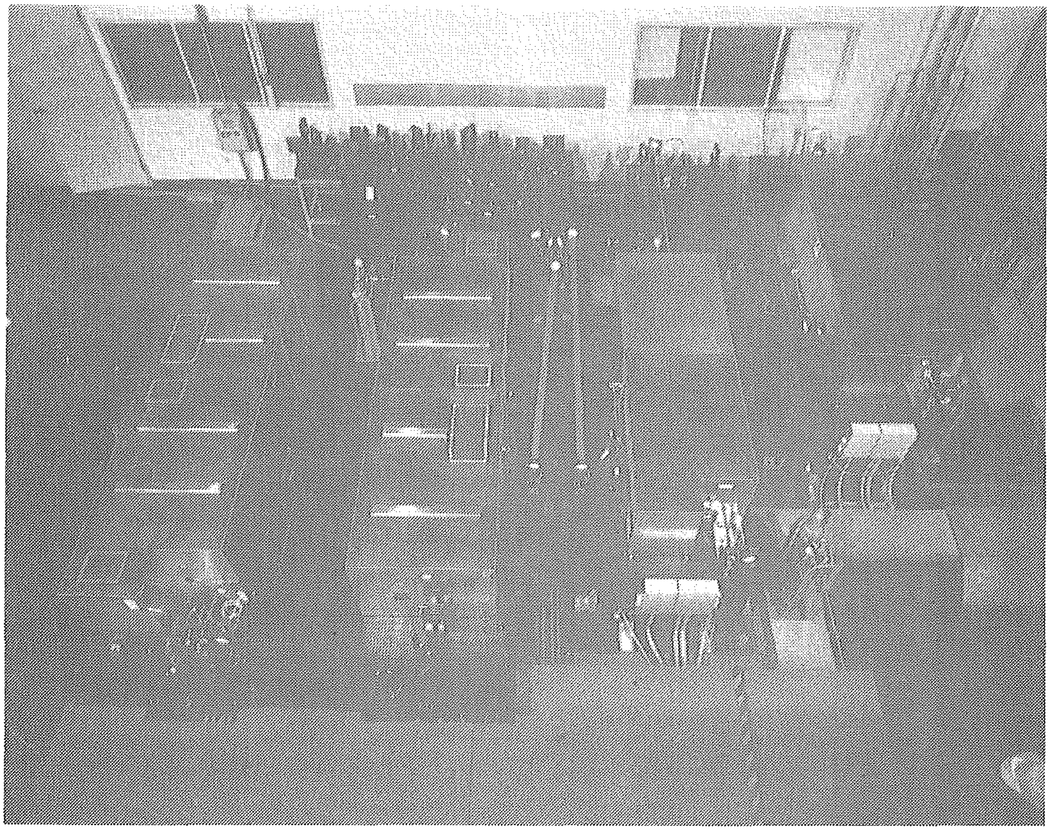
Special Transport Trailer
for Uranium Enrichment Centrifuges

Project schedule

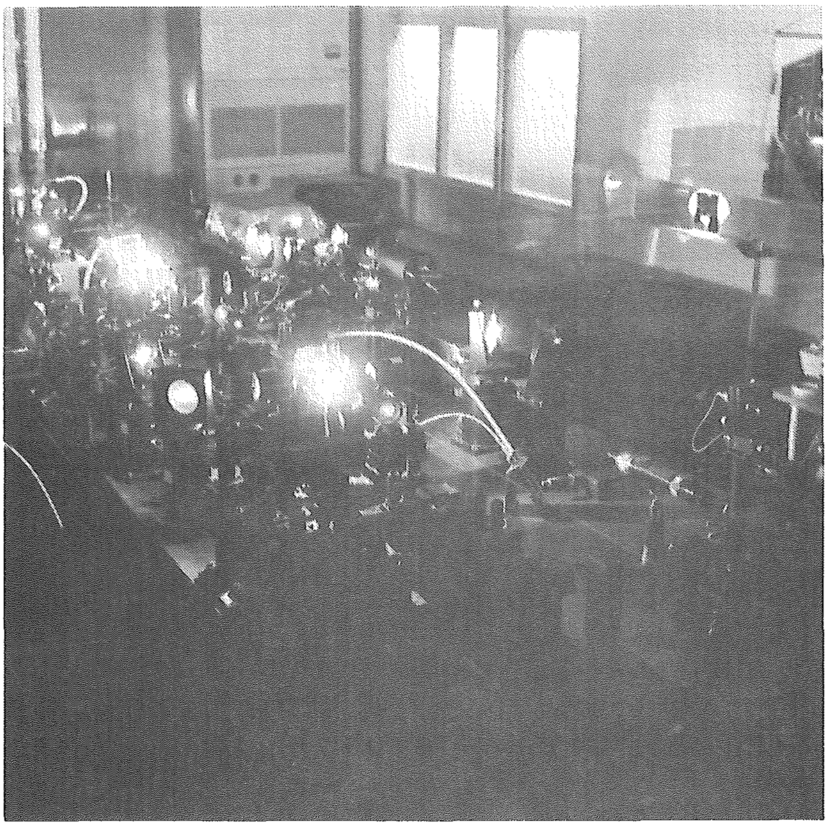
Fiscal Year	1987	1988	1989	1990
1. Preliminary separation test	—			
2. R&D on system components				
(1) Laser equipment development	—	—		
(2) Separation cell development	—	—		
3. Design, construction and operation of experimental facility				
(1) Experimental facility design and construction	—	—	—	
(2) Experimental facility testing				—

Targets and Present Status of Experimental facility

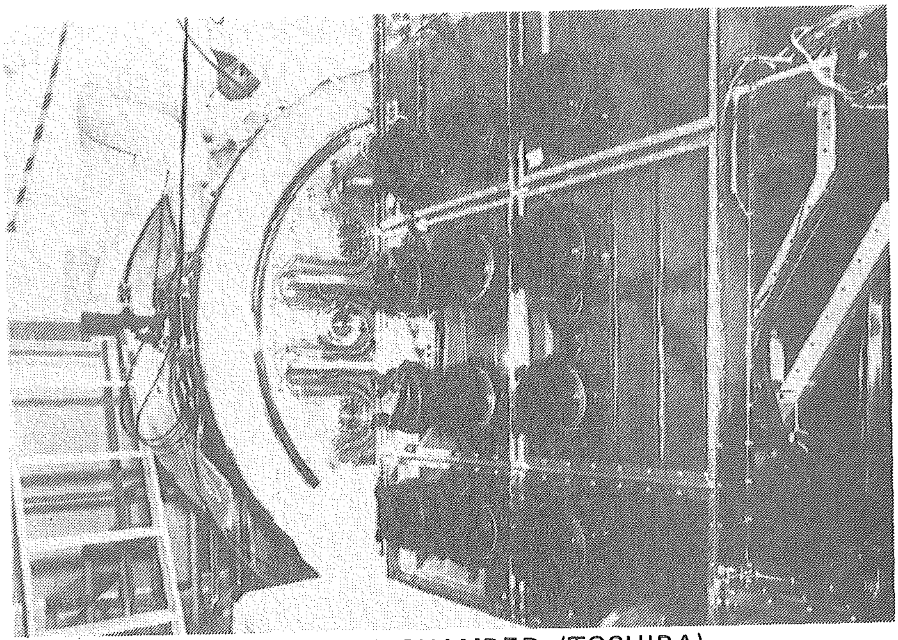
Item	Target	Present Status
(1) Copper vapor laser		
·output (single)	100 W	90~100 W
·output (MOPA)	200 W	120 W
·operational duration	200 hrs.	50 hrs.
·repetition	5 kHz	5 kHz
(2) Dye laser		
·output (MOPA)	40 W	11 W
·stability of wavelength	±100 MHz	±100 MHz
(3) Electron beam gun (linear cathode)		
·output	100~300 kW	130 kW (pulse)
·operational duration	200 hrs.	10 hrs. (30kW)
·cathode length	30~45 cm	10~20 cm
·concentration of beam	uniformity & high concentration	6 mm
(4) separation cell material (crucible etc.)		
·duration time in uranium environment	200 hrs.	studying for final selection
(5) experimental facility	1~5 tSWU/y.	0.4 mg/2.4 wt% (sample plate)
	4.5 wt%	2.5 mg/1.3 wt% (collector av.) (Preliminary separation test)



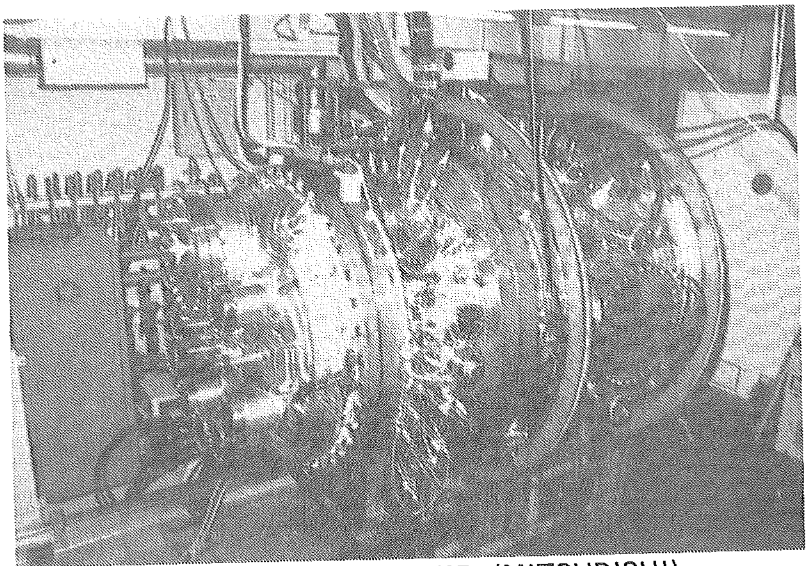
COPPER VAPOR LASER



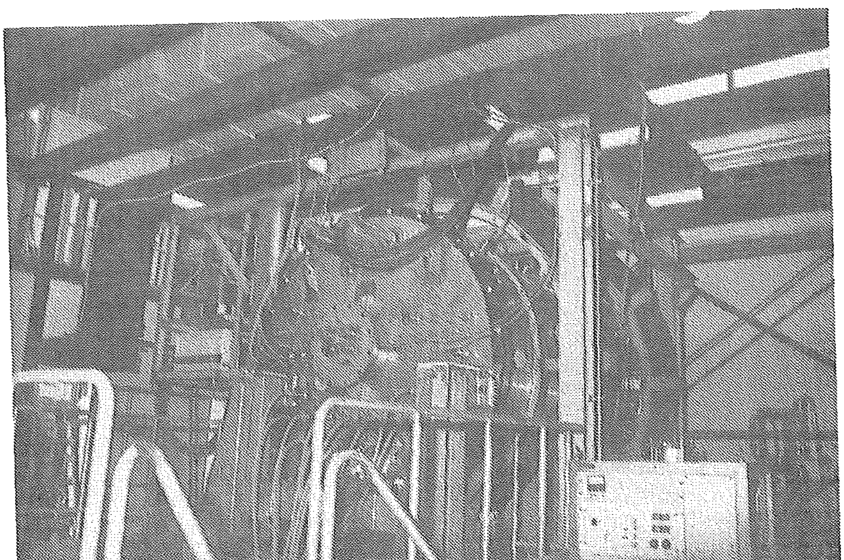
DYE LASER



SEPARATION CHAMBER (TOSHIBA)



SEPARATION CHAMBER (MITSUBISHI)



SEPARATION CHAMBER (HITACHI)

Table 1. Combinations of Excitation Processes and UF_6 Temperatures in MLIS

EXCITATION PROCESS / UF_6 TEMPERATURE	IR LASER + UV LASER	IRMPD (ONLY IR LASERS)
ROOM TEMPERATURE	S ~ 1	S = 1.2 (EXXON, USA 1982)
~ 100K (SUPER-SONIC NOZZLE)	S is estimated to be less than 2 even at extremely low temperature. (Saclay, CEN, France) (LANL, USA)	RIKEN'S MLIS (RIMLIS)

IR : Infrared

UV : Ultraviolet

MPD : Multiphoton Dissociation

S : Separation Factor

Figure 1. Comparison of Riken's MLIS with Conventional MLIS

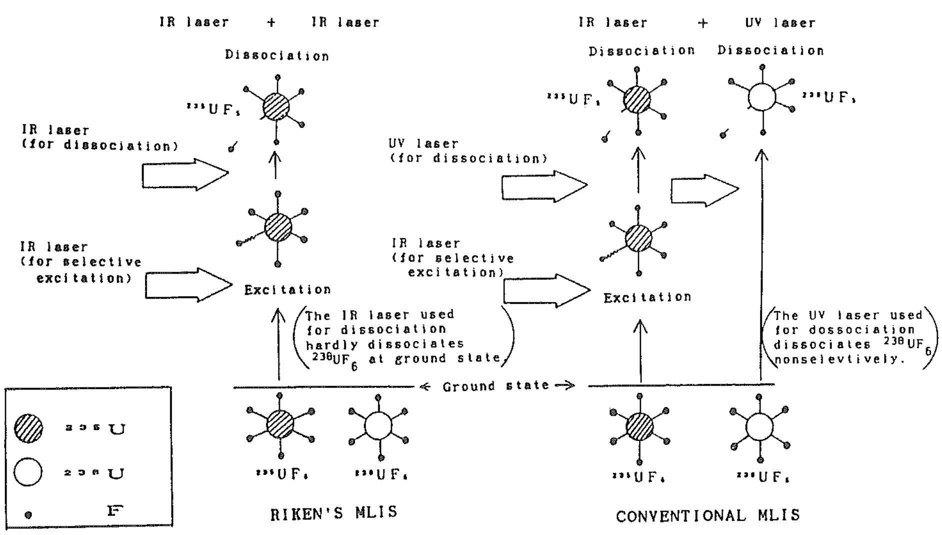


Figure 2. Schematic Diagram of the Experimental Apparatus

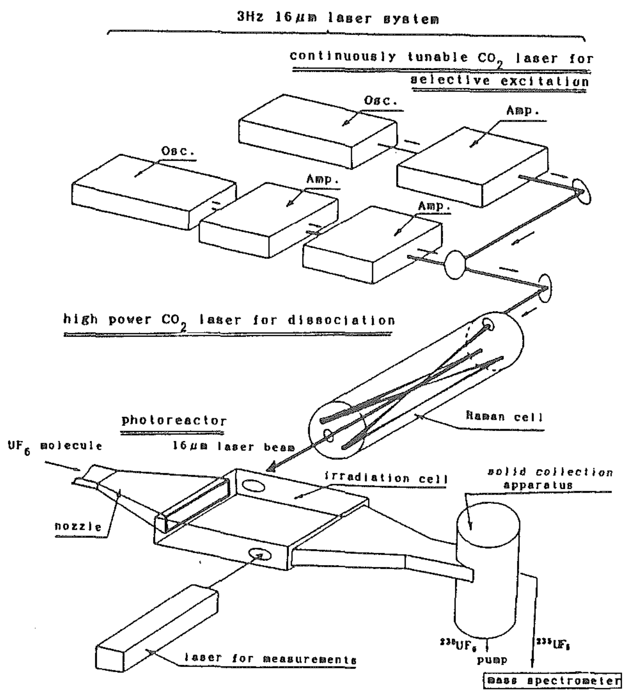
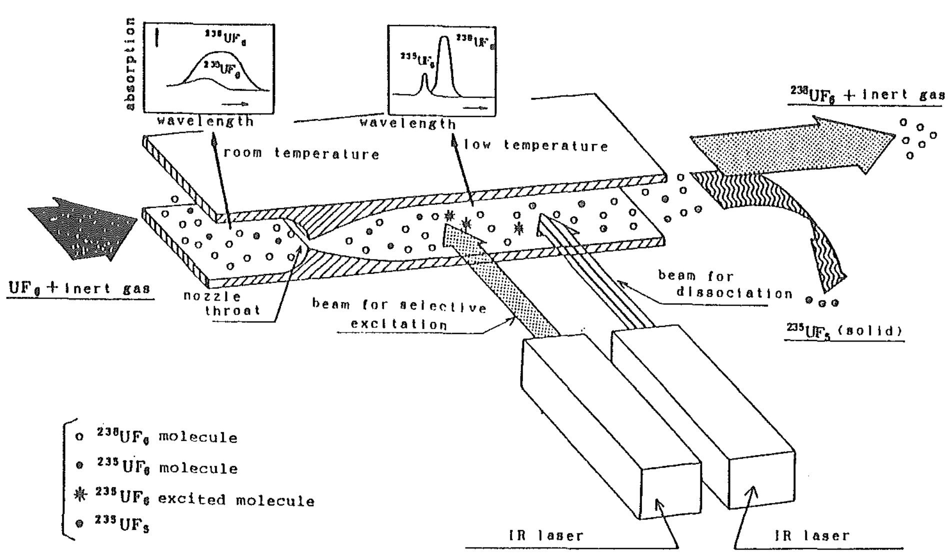
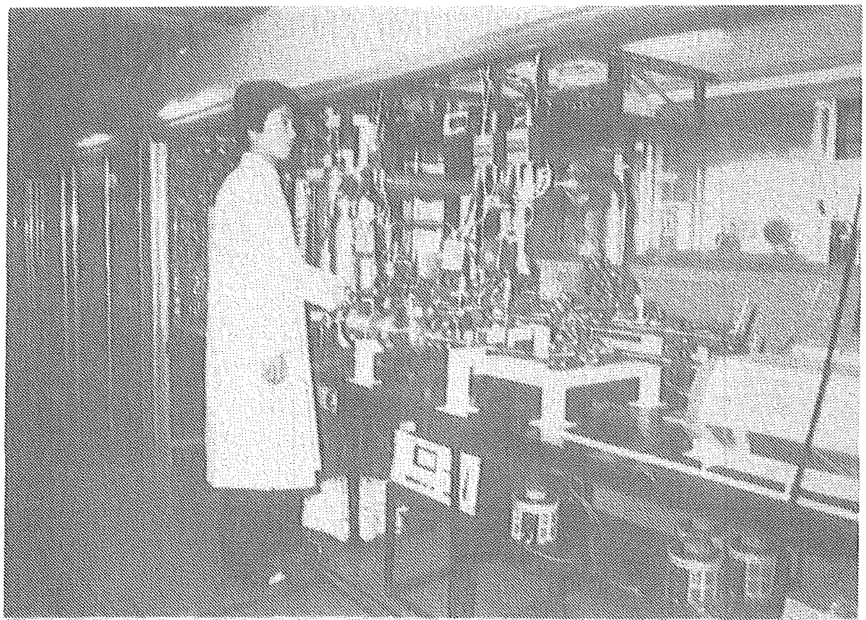
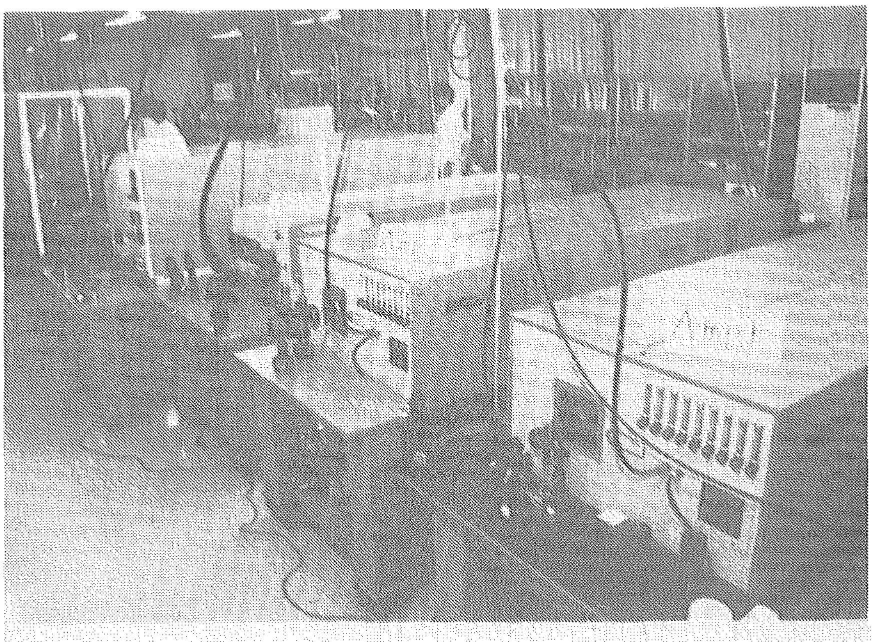


Figure 3. Reactor for Molecular Laser Isotope Separation





Super-sonic Nozzle Reactor
(Riken's Molecular Laser Isotope Separation)

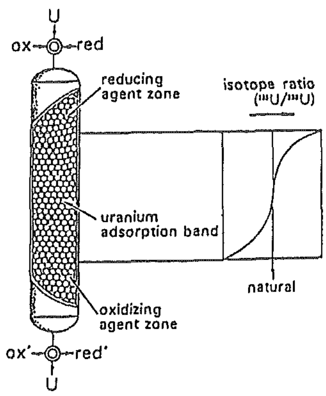


16μm Raman Laser System
(Riken's Molecular Laser Isotope Separation)

CHEMICAL ENRICHMENT PROCESS

by ASAHI CHEMICAL INDUSTRY

SCHEMA



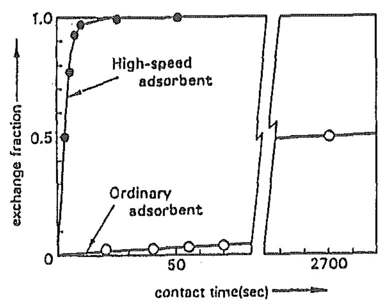
HISTORY

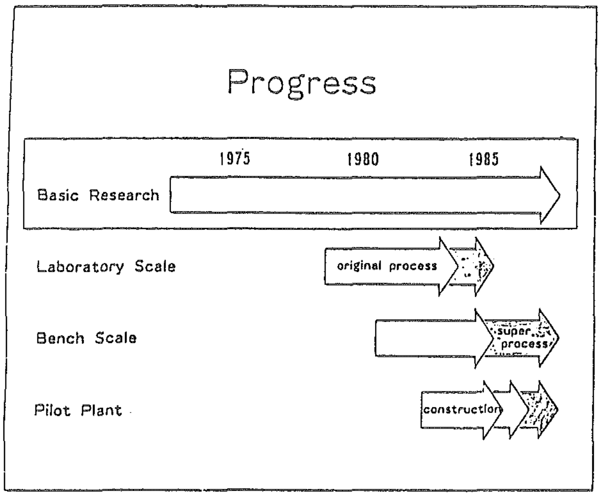
	U.S.AEC	FR.CEA	JAPAN
Year	1972	1978	1981
Separation System	Cascade	Cascade	Single Column
Equilibrium Time	Several Centuries	1.5 Year	3 Months
Report	ORO-694	Salzburg	Private Communication

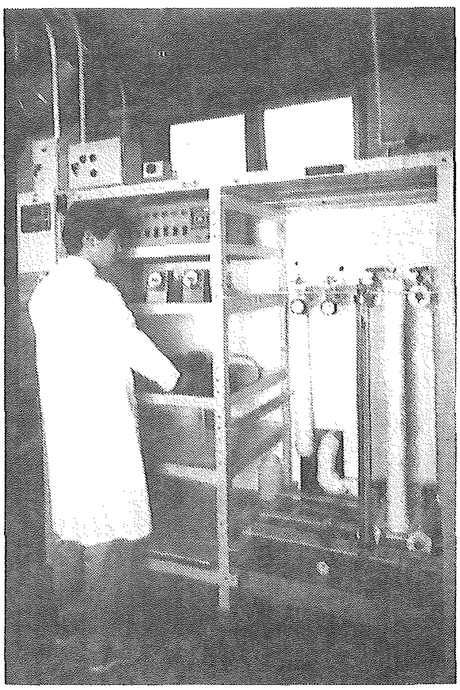
IMPROVEMENT

Reaction

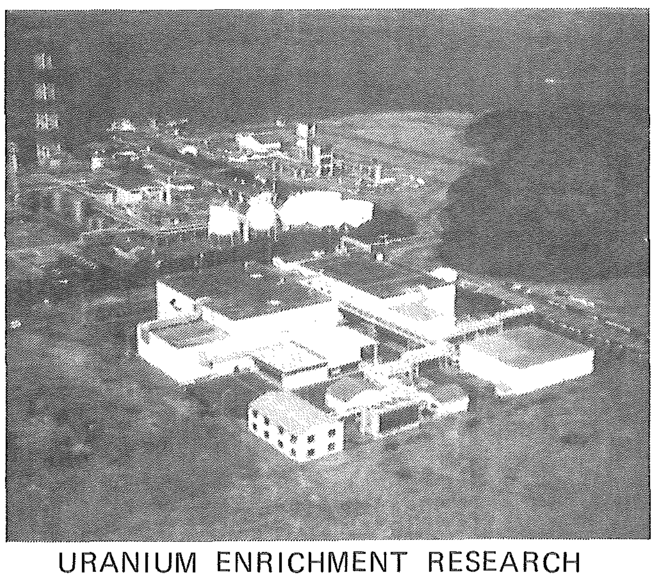
$$\overline{{}^{*}UO_2^{2+}} + U^{4+} \overset{k}{\rightleftharpoons} \overline{UO_2^{2+}} + {}^{*}U^{4+}$$



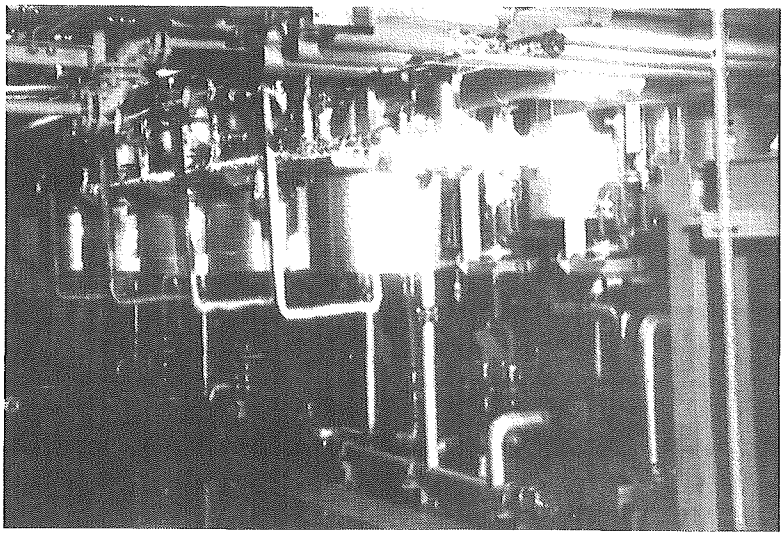




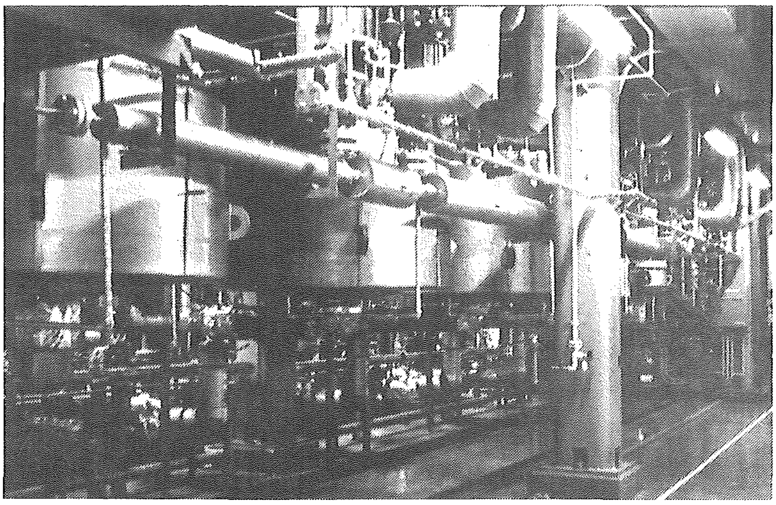
LABORATORY SCALE FACILITY



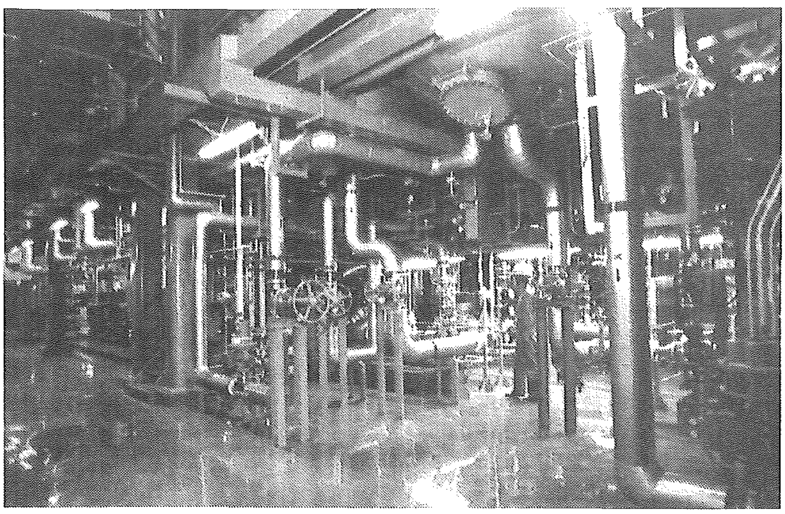
URANIUM ENRICHMENT RESEARCH
ESTABLISHMENT OF ACHI



BENCH PLANT

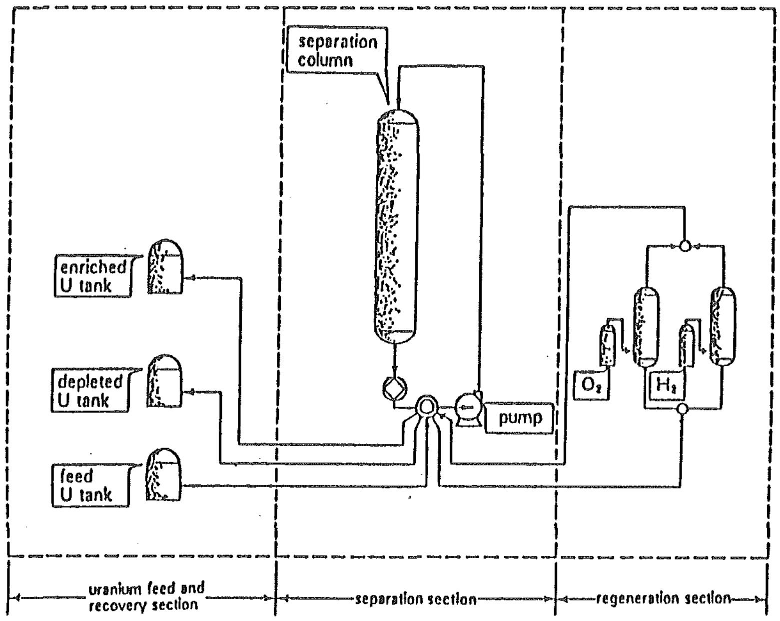


PILOT PLANT

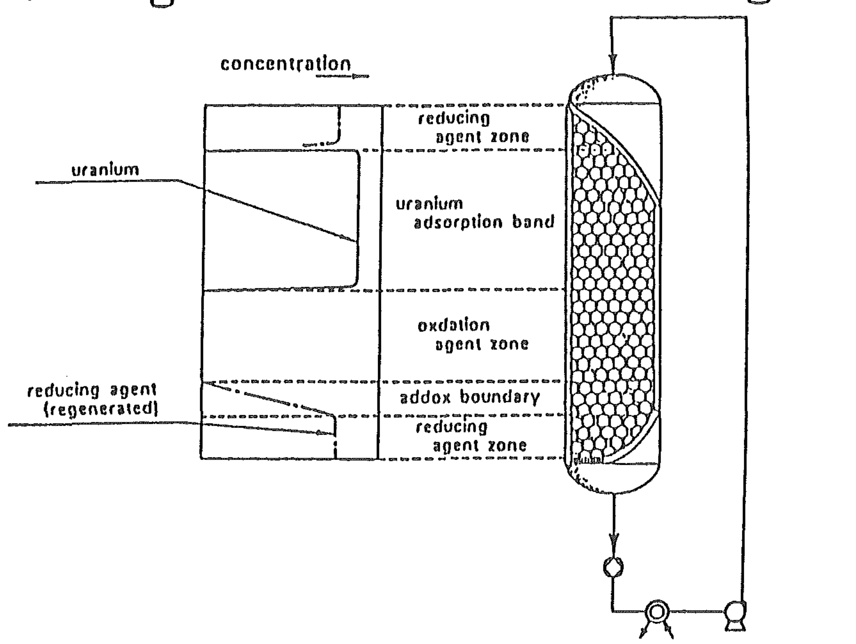


PILOT PLANT

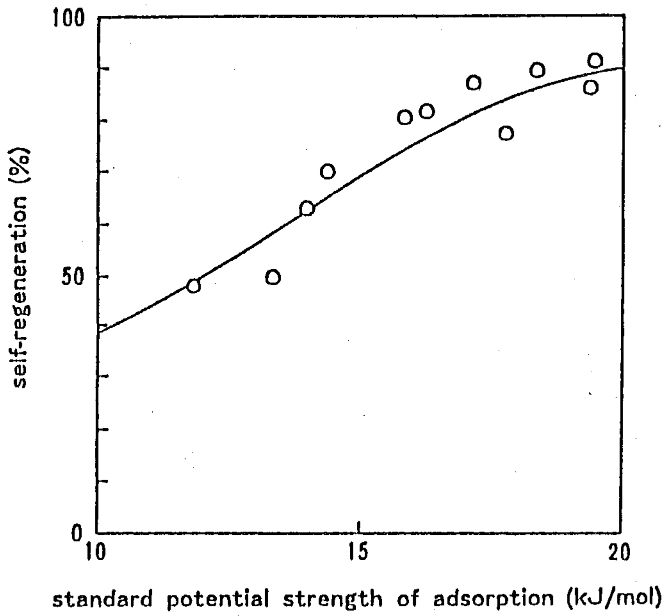
Flow Diagram



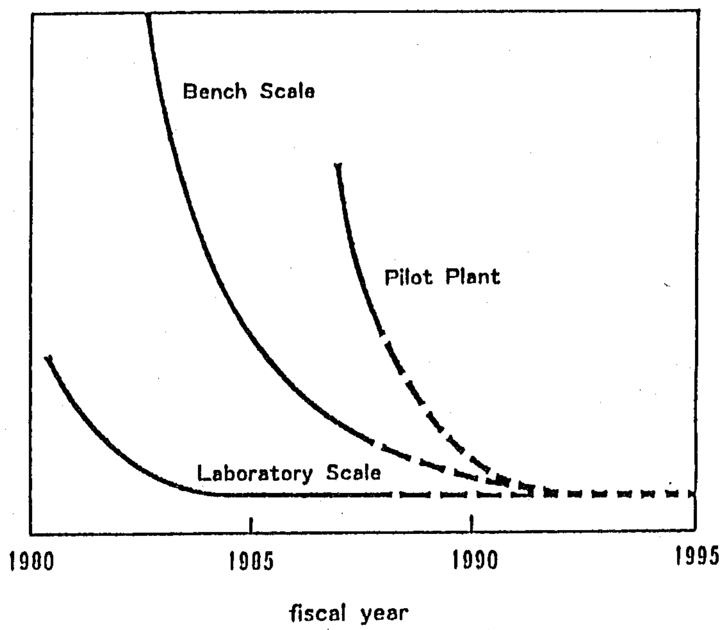
Self-regeneration of Redox Agent



Self-regeneration Ratio



Cost Estimation



高速増殖炉の革新技術

動力炉・核燃料開発事業団
理事　澤井　定

1．はじめに

高速増殖炉（ＦＢＲ）の開発の歴史は長く，米国の高速実験炉ＥＢＲ－Ｉが初めて原子力による発電に成功してから，すでに37年が経っている。現在，世界でＦＢＲを所有している国は７ヶ国，プラント規模も電気出力 120万Kwの仏国のスーパーフェニックス－１が稼働する段階まで開発が進展している。

しかしながら，最近ウラン供給の長期安定化，エネルギー需要の低迷に加え，軽水炉技術の著しい進展等により，ＦＢＲに要求される技術，経済性および信頼性のレベルが非常に高くなってきている。

このような情勢下でＦＢＲ実用化の課題である，安全性を確保しつつ，経済性の大幅向上を達成させるために，我国においては，以下の基本的な考え方によりＦＢＲの研究開発を進めている。まず第一に，原型炉「もんじゅ」までの開発で培ってきた技術基盤を有効に活用し，これをさらに高度化すること，第二に技術的ブレークスルーを達成するために，新しい技術の開発に積極的に取組んでいくこと，第三にＦＢＲ燃料再処理などの燃料サイクルの開発との整合性を取りつつ進めていくことである（表－１）。

ＦＢＲの実用化時期は，現在2020年から2030年頃と見込まれている。そこに至る開発過程を考慮すると，実用炉に用いる主要技術の基本的部分は2000年から2010年頃までに確立すべきものと考えられる。従って，この時期までに，実用化に必要な安全性，経済性を確立するための基本的技術の開発を達成できるように，システムの簡素化，プラントのコンパクト化，機器の高性能化，炉心・燃料の高性能・長寿命化，プラントのインテリジェント化，安全性確保などについて研究開発を積極的に進める必要がある（表－２）。以下に世界におけるその主要な研究開発について紹介する。

2．技術革新

2.1 システムの簡素化・高信頼性化

(1) 自然循環による崩壊熱除去等によるプラント安全性の確保と高信頼性化

崩壊熱除去系は，原子炉停止後，炉心を安全に冷却するシステムで，その機能と役割から高い信頼性が要求される。この高信頼性の要求に応えつつ，経済性を確保する方策として，外部電源に頼らず自然循環により，炉心崩壊熱を大気に放散するシステムの導入が世界的に考えられている。

大型炉では，図－１に示すように，ＤＲＡＣＳ（Direct Reactor Auxiliary Cooling System ）あるいは，ＰＲＡＣＳ（Primary Reactor Auxiliary Cooling System）が考えられている。

中小型炉では，米国のＰＲＩＳＭ等の設計にみるように，原子炉容器外面を空気の自然循環で冷却するシステム（Reactor Vessel Auxiliary Cooling System ）も考えられている（図－２）。

原子炉の安全確保の信頼性を高めるため，通常の原子炉停止系に加え，安全保護系に依存せずに作動する自己作動型炉停止機構（Self-Actuated Shutdown System ）の開発が進められている。

現在，最も有望と考えられているのは，制御棒を保持する電磁石の磁気回路の一部に所定の温度がキューリー点である材料を設置した装置である（図－３）。原子炉内炉心上部のナトリウム温度が異常上昇し，キューリー点に達すると磁気回路が自動的に遮断され，制御棒が落下する。

(2) 合理的原子炉格納施設の採用

図－４は，仏国スーパーフェニックス－Ⅱ（ＳＰＸ－Ⅱ）の設計で考えられた角型原子炉格納施設である。通常の円型原子炉格納施設と比較して，建設工期の短縮，空間の有効利用等が図られる。

(3) 耐高温ナトリウム用セラミックスの採用

ナトリウム機器室は，ナトリウム漏洩対策として鉄板ライニングが施されている。

耐高温ナトリウム用セラミックスを開発し，鉄板ライニングを削除し，建設工期の短縮と建設費の低減を図ることが考えられている。また，ＳＰＸ－Ⅱの設計では，原

子炉ピット表面ライナーに耐高温ナトリウムコンクリートが考えられている。

(4) 二重管蒸気発生器による二次系削除

ＦＢＲプラントの二次系を削除できれば，その建設費は大幅に低減できる。これを実現可能とする方策として，二重管蒸気発生器の導入が考えられている（図－５）。

二次系削除プラントは，従来プラントの二次系が果たしている安全性と信頼性に関する役割を，二重管蒸気発生器とシステム構成で受持たせるシステムである。

従って，二重管蒸気発生器は全てのナトリウム－水の境界を二重にし，これら一方の破損を早期に検出できるとともに，高い信頼性と健全性が要求される。

二重管蒸気発生器は，米国のＥＢＲ－Ⅱで10年以上使用されており，日米共同開発も進められている。

(5) 機器・プラントの標準化

機器・プラントが標準化・モジュラー化が進むと，建設費の低減，建設工期の短縮が期待される。このようなプラント構想の顕著な例として，米国のＰＲＩＳＭ（図－６）およびＳＡＦＲの設計がある。前者の基準プラントは，原子炉（ 155MWe ×３基）とタービン１基の構成で，後者は原子炉（ 350MWe ×１基）とタービン１基の構成である。

2.2 プラントのコンパクト化

(1) 配管短縮によるプラントのコンパクト化

ＦＢＲの熱輸送系の配管は，オーステナイトステンレス鋼であり，ナトリウムが高温であることから，熱膨張による応力を許容値以下にするため，長い配管になっている。

配管の熱膨張を吸収する技術には，配管ベローズ継手，逆Ｕ字型配管，機器浮動支持等があり，これらの方式により，配管は半減すると期待されている。

一例として，配管ベローズ継手（図－７）を採用した場合，期待されるプラントのコンパクト化を図－８に示す。

(2) 建家免震によるプラントの合理化

ＦＢＲの機器・構造は，ナトリウムの温度変化に伴う熱応力と地震に耐えることが

要求される。前者に対しては，薄肉構造が，後者に対しては，剛性をもたせる必要がある。

建家免震は，機器・構造に加わる地震力を軽減するので，特にＦＢＲの機器・構造の設計を合理化すると期待されている。建家免震の方策は，建家固有周期の伸長と地震エネルギーの吸収で，積層ゴム等が使用される。

その効果を図－９に示す。

建家免震を，原子力施設に使用すべく世界的に開発が進められており，フランスのCrous 発電所（ＰＷＲ， 880MWe ）等に用いられている。

2.3 機器の高性能化

(1) 一体型機器の導入

一体型機器は，機器の高性能化のみならず，プラントのコンパクト化にも効果がある。現在，蒸気発生器と過熱器を一体化した一体貫流型蒸気発生器，中間熱交換器とナトリウム循環ポンプの一体化の開発が進められている。

(2) インデューサポンプ，超電導電磁ポンプの導入

ナトリウム循環ポンプの小型化にインデューサポンプが考えられている。また，超電導材の開発が進めば，電磁流体のナトリウムを冷却材に用いるＦＢＲは，安全性・信頼性および経済性に大きな効果を受ける。

2.4 炉心・燃料の高性能化・長寿命化

燃料サイクル費の低減と設備利用率の向上の観点から，炉心・燃料の高性能・長寿命化の開発が世界的に進められている。

そのポイントは，

(a) 燃料の高燃焼度化

(b) 燃料交換間隔の長期化

であり，さらに，炉心のコンパクト化・性能向上等のために

(c) 線出力密度の向上

(d) 出力ピーキング係数の低減

(e) 遮蔽体の軽量化

(f) 酸化物燃料以外の燃料の開発

が考えられている。

燃料に関しては，20万MWd/t 以上の燃焼度達成を目標に，特にその中性子照射に耐える改良オーステナイトステンレス鋼，および酸化物分散強化型フェライト鋼の開発に重点をおいて進められている。また，酸化物以外の燃料，金属燃料，炭化物燃料，窒化物燃料等の開発も進められている。

炉心に関しては，長期的視野において非均質炉心，太径燃料の採用，中空燃料ペレットについて検討が進められている。

ＦＢＲの遮蔽のポイントは中性子遮蔽であり，それに効果あるB_4C，ＺｒＨ等の遮蔽体の開発が進められている（図−10，11）。ＳＰＸ−Ⅱ，ＰＲＩＳＭ等の設計にはそれらを採用し，原子炉容器の小型化が考えられている。

2.5　プラントのインテリジェント化

ＦＢＲプラントの安全を確保しつつ，高信頼性で効率よく稼働させるため，人工知能を最大限活用したシステムの開発が進められている。その目標とする所は，全自動運転・安全管理に加えて運転経験・実績を評価・判断して活用できる機能も持たせることである。

ＦＢＲの安全確保に当たっては，ＦＢＲの安全上の特質，以上の技術の高度化等を基に，深層防護の考え方に基づく安全設計を行って，事故防止及び緩和を図っている。

３．おわりに

ＦＢＲの開発は，各国で積み上げれている技術を国際的に有効に活用することが重要である。我国も二国間協力，多国間協力，国際機関を通しての協力を今後さらに発展，強化し，これによって我国の開発を補完するとともに，世界のＦＢＲの開発に貢献していく所存である。

表－1

日本におけるＦＢＲ開発の基本的考え方
(1) “もんじゅ”までの開発で培ったきた技術を高度化する。
(2) 革新技術を開発する。
(3) 炉と燃料サイクルの開発を密接に関連して進める。

表－２

FBR実用化へ向けての革新技術

(1) システムの簡素化・高信頼性化

- 自然循環による崩壊熱除去等によるプラント安全性確保と高信頼性化
- 合理的格納施設の採用
- 耐高温Na用セラミックスの採用によるNa機器室鉄板ライナーの削減
- ２重管型蒸気発生器による２次系の削除
- 機器・プラントの標準化

(2) プラントのコンパクト化

- 免震技術開発によるプラントの合理化
- ベローズ継手方式，機器浮動支持方式などによる配管の短縮

(3) 機器の高性能化

- 一体型機器の導入
- インデューサポンプ，超電導電磁ポンプの導入

(4) 炉心・燃料の高性能・長寿命化

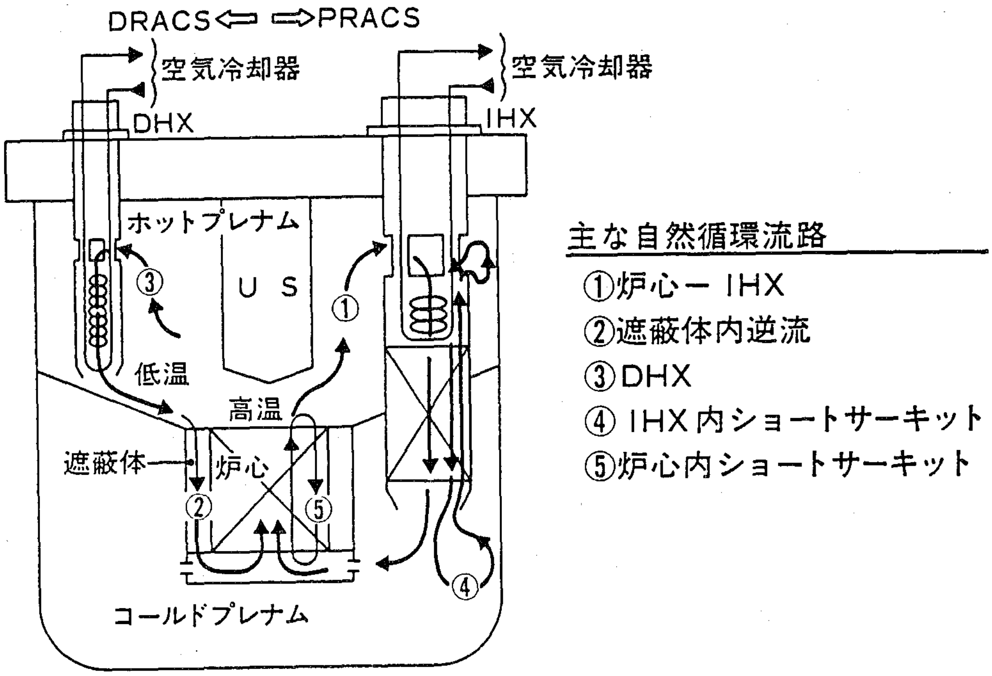
- 長寿命燃料（燃焼度20万ＭＷｄ／ｔ目標）の開発
- 高燃焼度，大型炉心のための最適炉心構成
- 炉心の軽量，コンパクト化のための新遮蔽体の開発

(5) プラントのインテリジェント化

- 運転の自動化，高信頼性化，効率化およびプラント実績反映の自動化

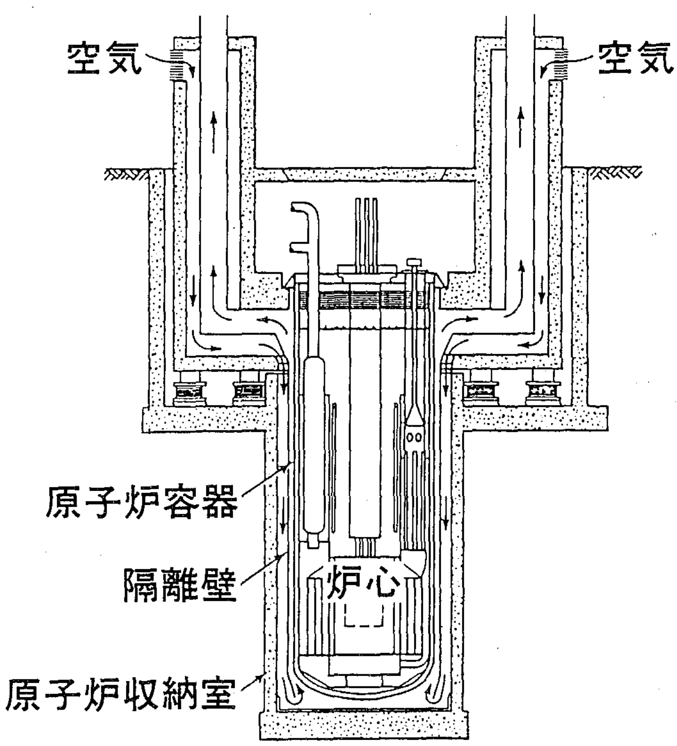
図－1

崩壊熱除去時の原子炉内自然循環流路



図－2

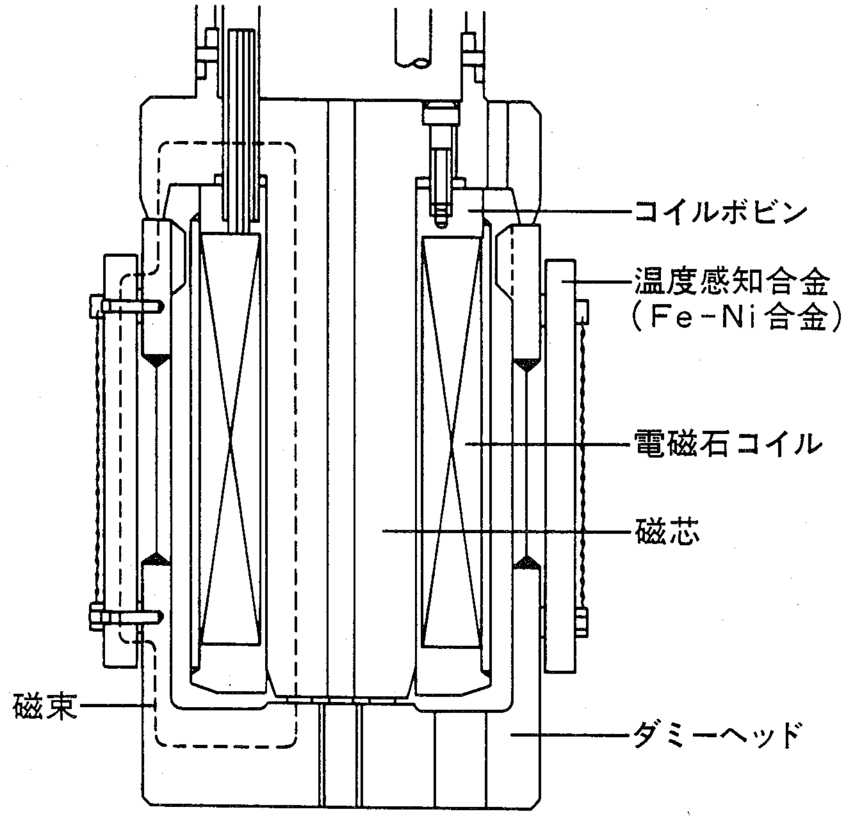
原子炉容器補助冷却系



縦断面図

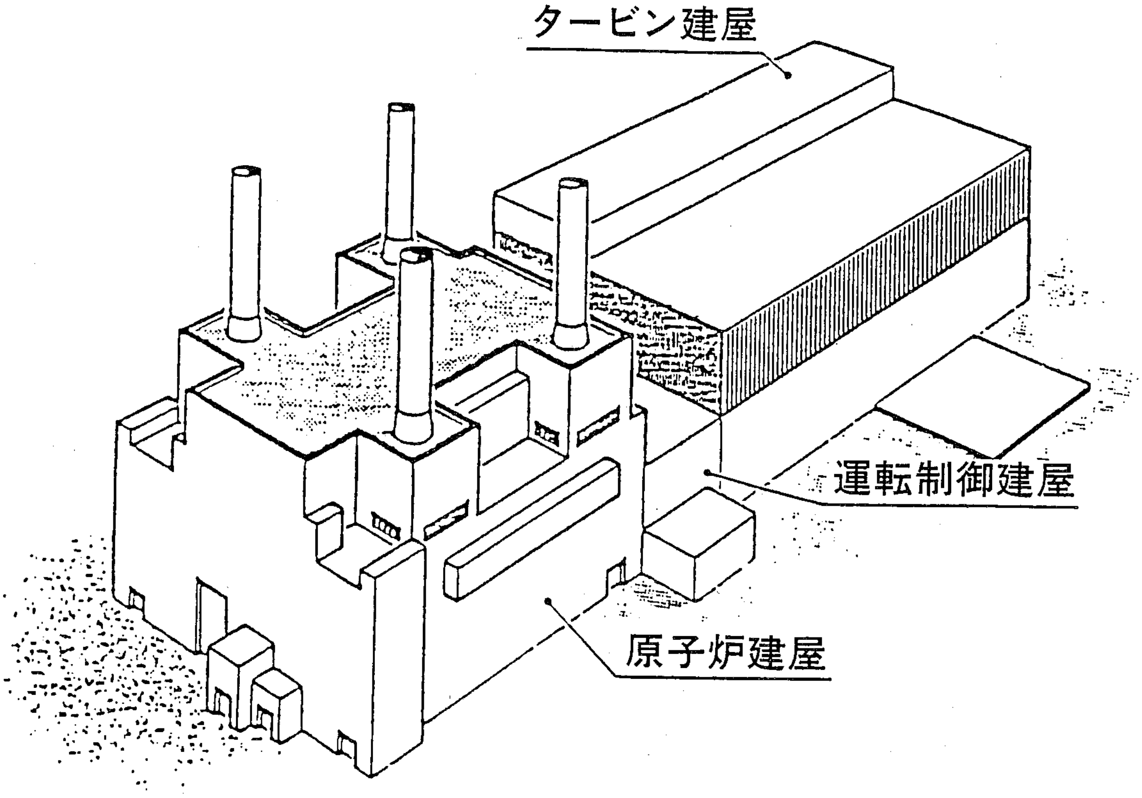
図－3

自己作動型制御棒原理図

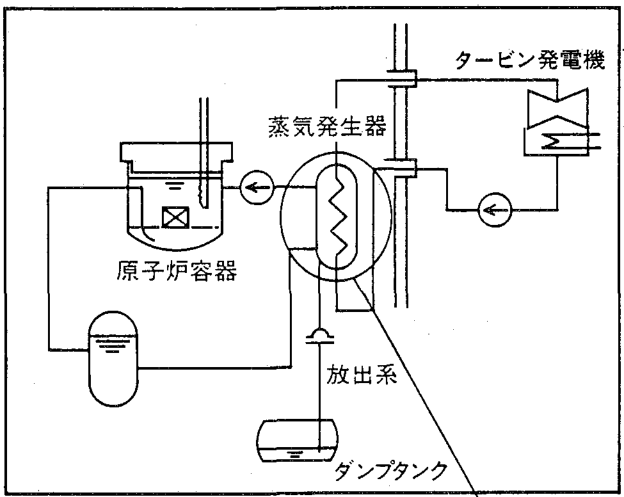


図－4

SPX-2建屋外観



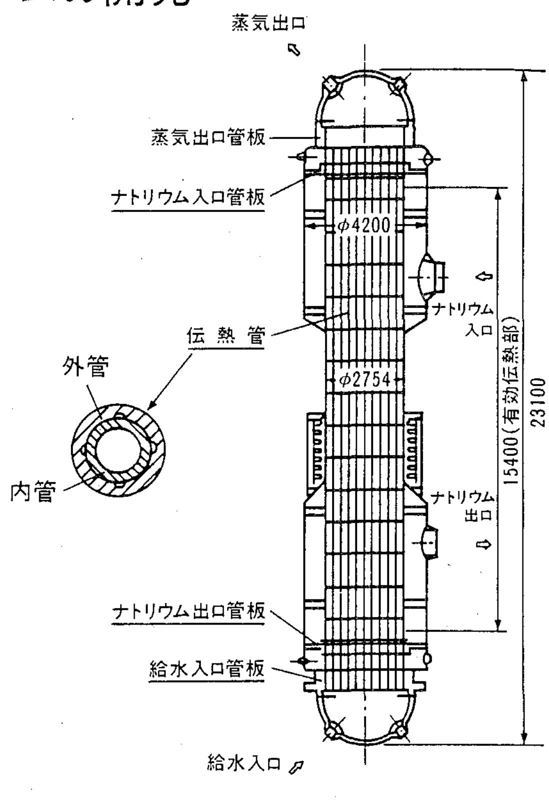
図－5　　2次系削除システムの開発



ナトリウム・水境界の多重性	早期伝熱管破損検出

2重管蒸気発生器の開発
- 2重伝熱管の開発
- 管－管板等SG基本構造要素の開発
- 保守・補修技術の開発

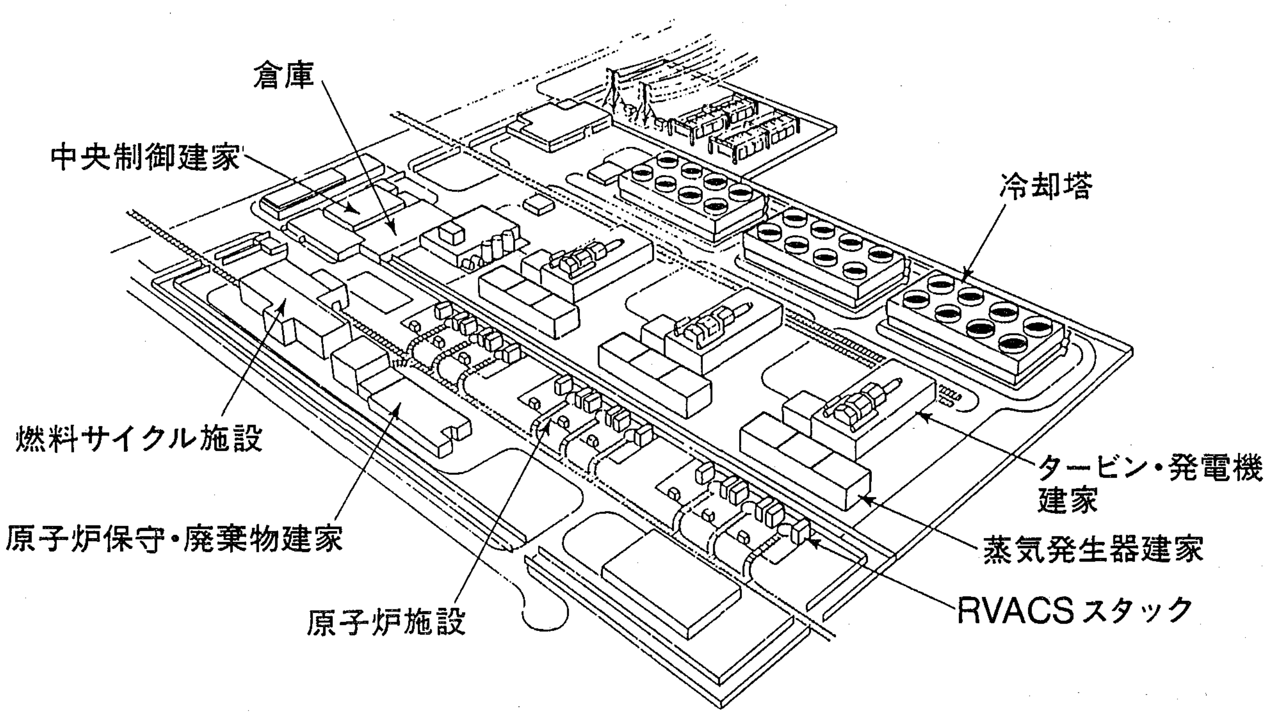
2次系削除システムの例



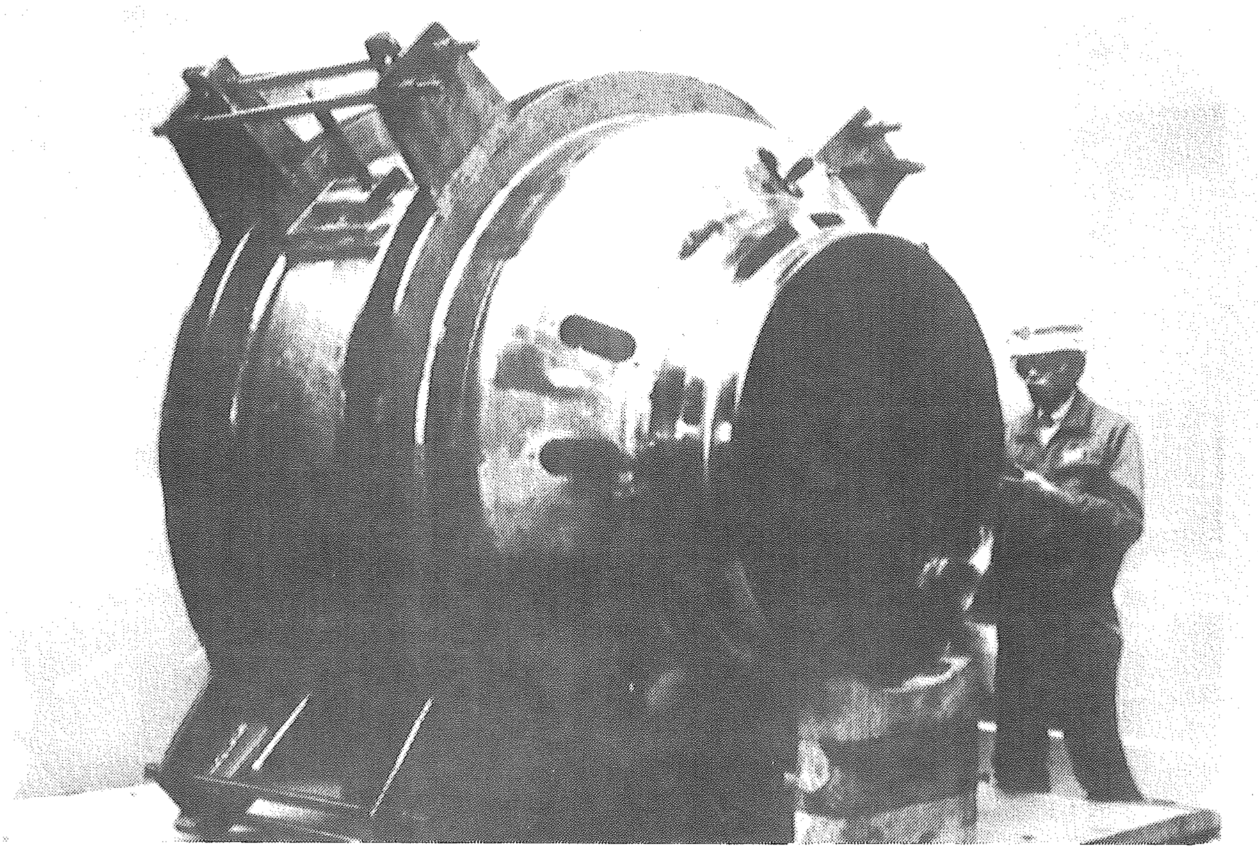
2重管型蒸気発生器の例

図－6

発電プラント全体配置図

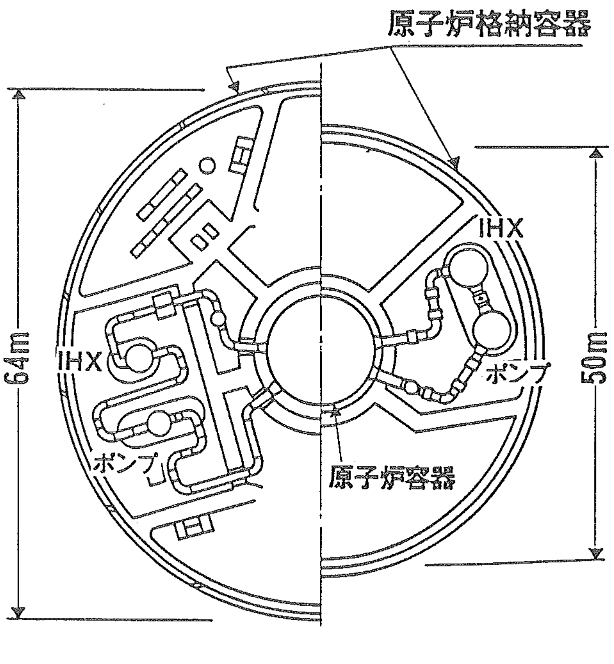


図－7



図－8

配管ベローズ使用による合理化例
(100万kwe)



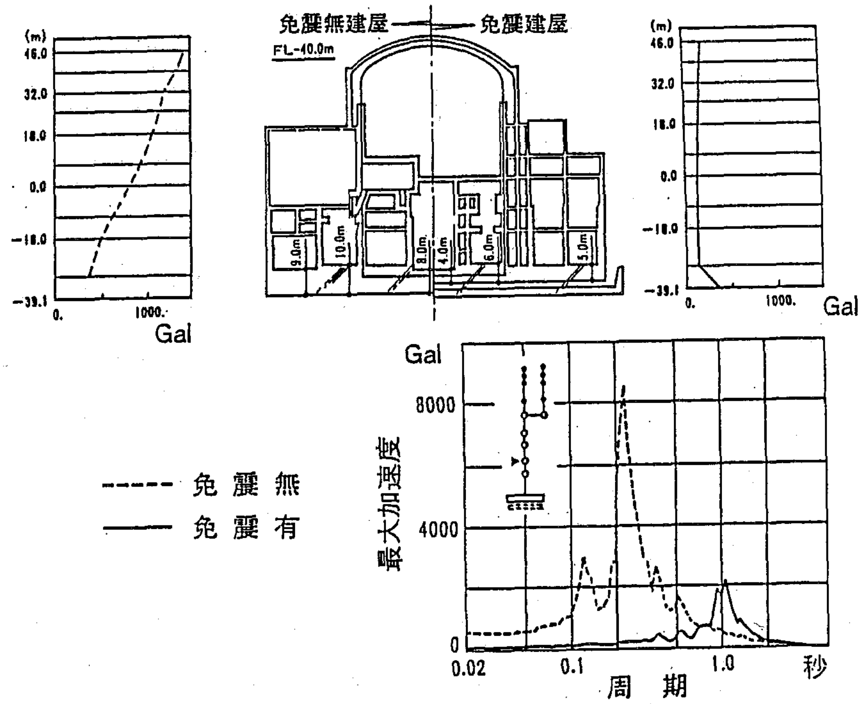
従来方式
(高所配管引廻し方式)

配管ベローズ
継手採用方式

(動燃大型炉設計研究)

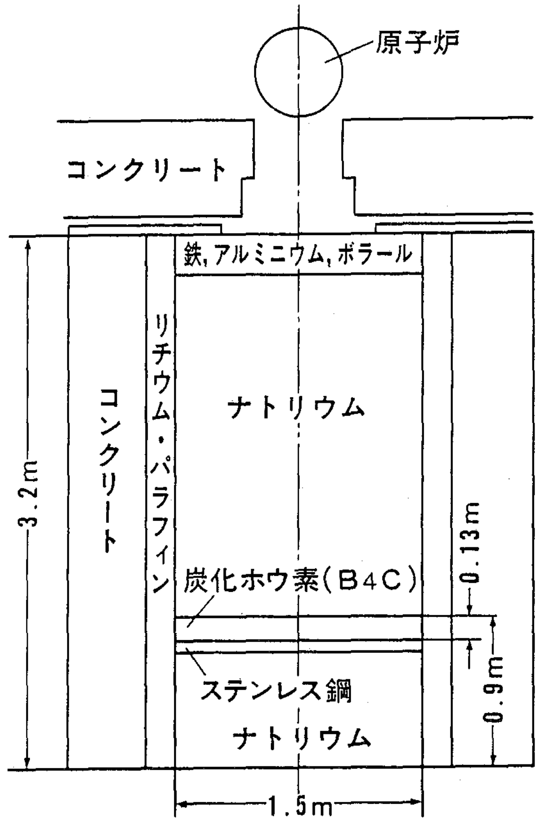
図－9

FBRへの免震構造適用の効果

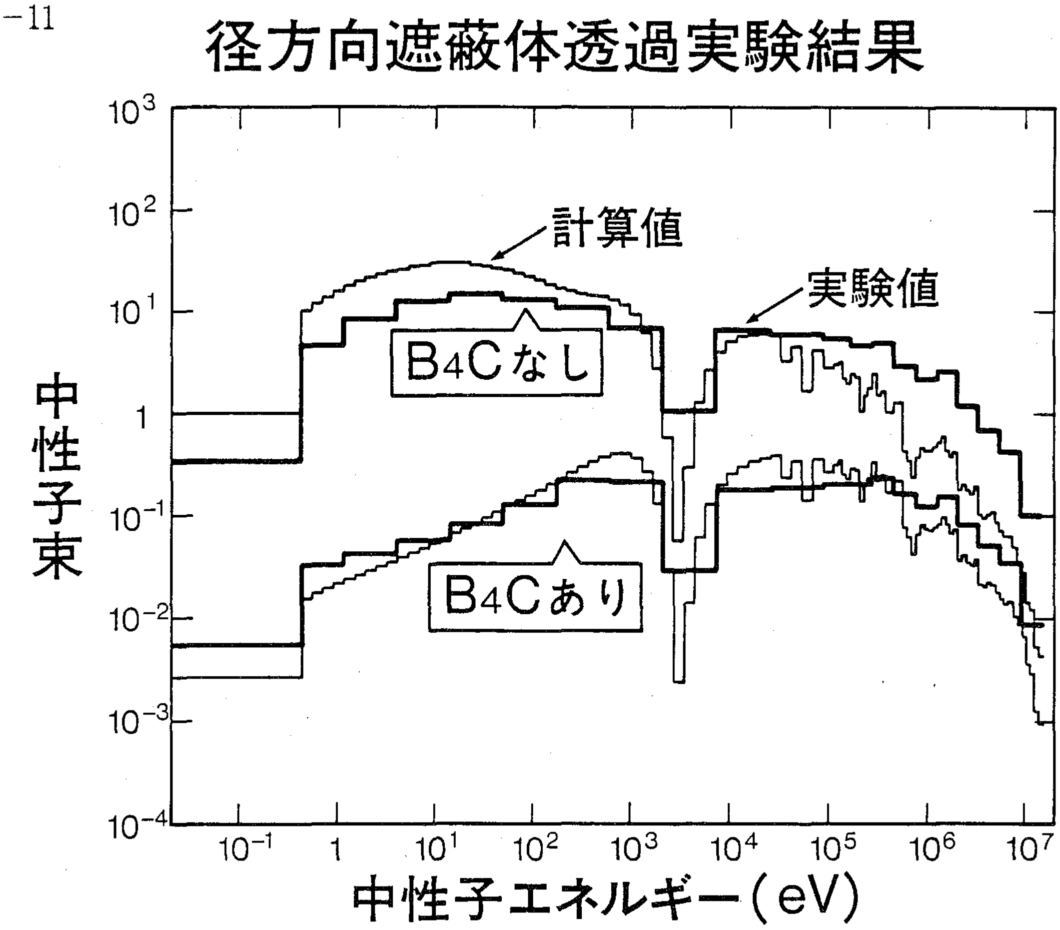


図－10

径方向遮蔽体透過実験（JASPER計画）



図－11


径方向遮蔽体透過実験結果
計算値
実験値
B4Cなし
B4Cあり
中性子束
10³
10²
10¹
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻¹
1
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
中性子エネルギー（eV）

昭和 63 年 4 月 14 日

「核融合実験炉への道」

日本原子力研究所

特別研究員　苫米地　顕

(1)　核融合プラズマ

水素等の軽い原子核の融合によって生ずるエネルギーを利用する為の核融合の研究は、近年著しく進展して、核融合プラズマの科学的研究から実際に核融合によってエネルギーを発生させる核融合実験炉の実現に向けての研究へ進むべき段階に達した。以下に核融合研究の現状と、今後の核融合実験炉へ向けての開発の動向に就いて述べる事とする。

水素の同位体の重水素と三重水素を融合させると、1グラム当たり石油 8kl の燃焼に相当するエネルギーを発生する。これは、ウラン1グラムから 2kl 相当のエネルギーを発生する核分裂同様、膨大なエネルギーの発生を意味している。

然し乍ら、このように水素の原子核同士を融合させる為には、それらの原子核同士の電気的な斥力に打ち勝つだけの高速、つまり高温の状態を作り出す必要がある。現在の核融合研究は、差し当り、最も反応を起こし易い重水素と三重水素の反応を目標にして研究を進めている。

実際に重水素と三重水素の反応を起こさせる為には、数千万度の温度が必要で、そのような高温状態では、水素は、原子核と電子がばらばらになって独立に飛び回る状態、所謂プラズマ状態になる。このような高温のプラズマを発生させ、閉じ込める方法として、強力な磁場のある場所にプラズマを発生させる磁場閉じ込め方式が考案された。今日までの実験によれば、その中でも、トカマクと呼ばれる装置が最も優れた性能のプラズマを発生している。

(2)　JT-60 による最近の成果

現在、アメリカ、欧州、日本に、温度数千万度のプラズマを発生させる事を目標とした大型トカマク装置が作られ、実験が行われている。アメリカのプリンストンの TFTR, 欧州のカラムの JET、日本の那珂町の JT-60 がそれで、これらの装置は三大トカマクと呼ばれている。

実は、核融合反応を起こさせるプラズマの性能としては、温度のほかに、プラズマの粒

子密度、及びプラズマのエネルギー閉じ込め時間が大切な指標である。

三大トカマク装置で作られたプラズマの性能は、既に、温度が数千万度、密度と閉じ込め時間の積が $10^{19}m^{-3}$秒 台となっている。これは、実際に重水素と三重水素の反応を起こさせたとした場合の、プラズマの加熱の為の入力と、核融合による出力エネルギーが等しくなる、所謂臨界プラズマ条件に相当する性能のものである。JT-60 では、昨年秋に、そのような性能のプラズマを作る事に成功している。

従って、JT-60 の次ぎの目標は、これまでの研究の結果に基づき、実際に核融合反応によってエネルギーを取り出す核融合実験炉を目指した、より一層高性能のプラズマを生成する研究を進める事である。JT-60 では、今春から、水素の氷のペレットをプラズマに打ち込んでプラズマ密度を高める実験を開始した。また、64 年度から 65 年度に掛けてプラズマ容器等を新型のものに交換して、より大型で、大電流が流せるプラズマを作れるように、装置を改造する計画を進めている。

このように、大型トカマク装置で良好な成果が得られたのを機に、核融合研究は、愈々核融合実験炉へと進む事になりつつある。そして、プラズマ物理のみならず、核融合実験炉の建設に必要な工学技術の開発も平行して進められつつある。

(3) 核融合実験炉へ向けての工学技術開発

我国における工学技術開発の現状に就いて、超電導コイル開発、トリチウムガス精製技術開発に例を採り、述べる。

超電導コイル開発に関しては、IEA の許で進められていた Large Coil Task と呼ばれる国際協力が、昨年成功裡に終了し、日本が持ち込んだ N_bT_i のコイルは予想通りの良好な成績を上げた。このコイルは、約 10,000 A 用の超電導線を内径約 2.5 m X 3.5 m の楕円形に巻いた、重量約 40 トンのコイルであり、核融合実験炉用に使われるであろうコイルの約半分の寸法のものである。実験では、このコイルによって、最大 8 テスラの磁界を発生させる事に成功している。

この開発に引き続いて、現在、パルス磁界発生用のコイルの開発を進めており、又実寸大のコイルの試験を日米の協力研究として実施する事が検討されている。

核融合実験炉で燃料として用いるトリチウムガスの精製等に用いられるガス処理装置の開発も進んでいる。原研の東海研究所に作られた Tritium Process Laboratory, TPL, で

は、今年度からトリチウムを用いて実験を始めた。この施設では、10 グラムのトリチウムを保有して、各種のトリチウム処理用機器の開発試験を実施する。

又、日米協力により、アメリカのトリチウム施設 TSTA で、日本で開発され、制作されたトリチウム精製装置の試験が、約百グラム／日のトリチウム循環量で進行中であり、将来は、核融合実験炉の循環量に近い約1キログラム／日の試験が予定されている。

最後に、新しい技術開発の一例として、トリチウムガス用の全セラミックス製ターボ分子ポンプの開発に就いて述べる。このポンプは、圧搾空気で駆動され、強磁場中での運転も可能であり、又油は一切使用しない。従って、トカマク装置の電磁石コイルの近くに設置する事が可能であり、此れ迄に、約 100 l/s の排気速度のポンプの試作に成功している。そして、今年度は 1000 l/s 級のポンプの試作試験を実施する予定である。

以上述べたように、工学技術の開発も、核融合実験炉の 1990 年代前半の着工を目指して着々と進められている。

(4) 各国の核融合実験炉計画

以上述べたように、核融合開発研究は、実験炉を目指して計画を進めるべき段階に到達し、夫々の国状に応じて、核融合実験炉の構想が具体的に描かれつつある。

即ち、欧州では、大型トカマク装置 JET で 1992 年頃に重水素と三重水素の実験を実施し、その成果に基づいて、 NET と呼ばれる核融合実験炉を 1993 年頃に着工する計画を進めている。その為、約三十名からなる NET 設計チームが編成され、西独のガルヒン研究所に常駐して設計作業に当たっている。

ソ連は、大型トカマク装置として、超電導線を用いた意欲的な T-15 を現在建設中であり、この装置の次ぎには、 OTR と呼ばれる核融合実験炉を建設すべく、開発を進めていると伝えられている。

アメリカは、大型トカマク装置 TFTR の施設を有効利用して、取り敢へず 1992-3 年頃に数秒間の核融合反応を行う事が出来る小型の装置、CIT を建設する計画を進めている。

我国は、昨年策定された原子力開発利用長期計画において、2000 年頃の実験開始を目標に核融合実験炉の開発を進める事としており、欧州の計画と良く似た計画となっている。

このように、若干の差はあるものの、今世期末頃の実験開始を目標に、各国とも核融合実験炉へ向けての開発を進めつつあるのが、核融合開発の現状である。

(5) 新しい国際協力の動き

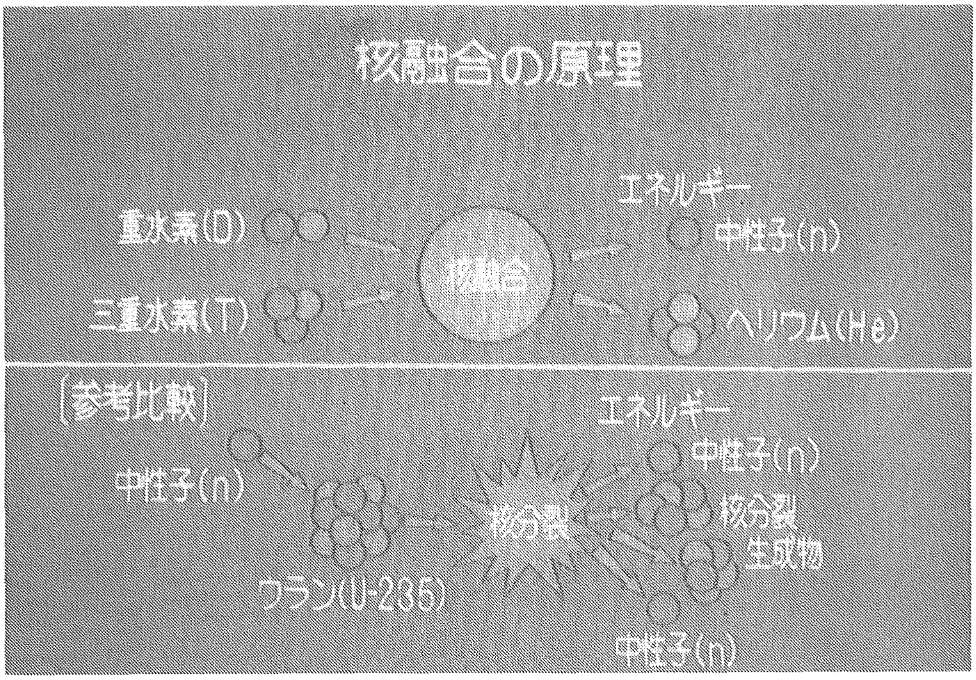
偖、このような各国の核融合実験炉へ向けての開発の推進と呼応して、核融合実験炉の共同設計を実施する新しい国際協力活動が、近く開始される事となった。それは、国際熱核融合実験炉 (International Thermonuclear Experimental Reactor), ITER, と呼ばれる装置の概念設計を、欧州、日本、アメリカ、ソ連の四者で、1990 年末までに完成させようと言うものである。

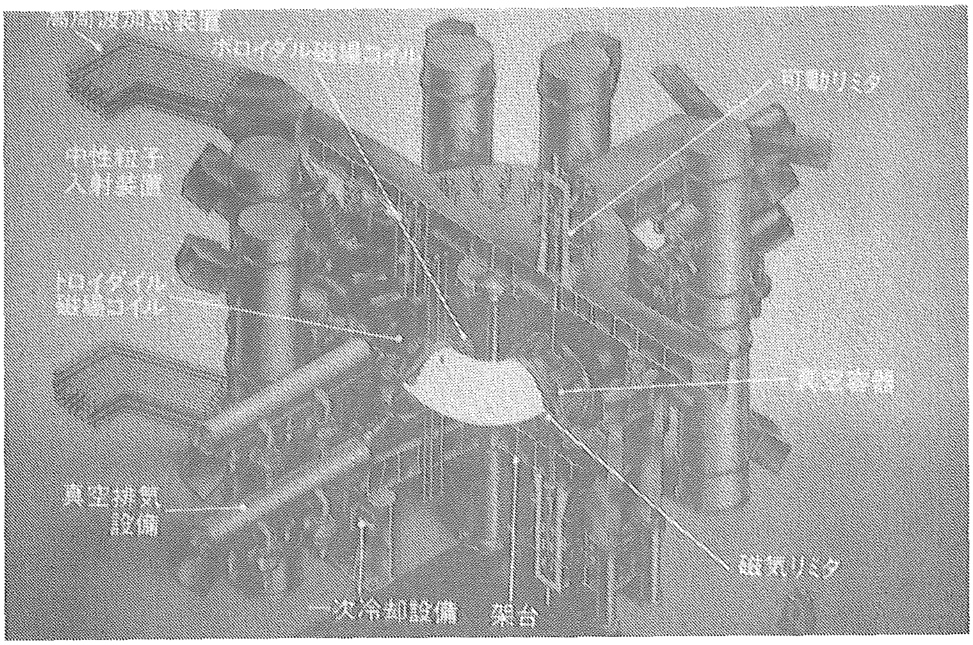
この国際協力の発端は、実は、1985 年 11 月の Geneva における米ソ首脳会談にまで遡る。即ち、Geneva での米ソ首脳の共同声明には、「両首脳は、全人類の為に役立つ実質的に無限な核融合エネルギーを手にする為、実際的な、最大限の国際協力を進める事を支持した」と述べられている。その後、Reykjavik でも、この事は話題になったと言われており、関係国間の協議の結果、欧州、日本、アメリカ、ソ連の四者による概念設計の実施が合意され、近く開始される事となったものである。

この協力は、ITER と呼ばれ、自国の計画の為、或いはより大きな国際協力に役立てる為、各国が対等の立場で協力し、1990 年迄に概念設計を纏め上げようと言うものである。具体的には、各国夫々年間約三十人年の設計作業と 10 M$ 相当の研究開発を負担して、実施するものである。従って、全作業では、四者合計約 400 人年の設計作業と、120 M$ の研究開発と言う事になる。又、各国より約十名の設計者が毎年数カ月間一カ所に集まって、共同作業を実施して、設計を纏め上げようと言う事になっている。

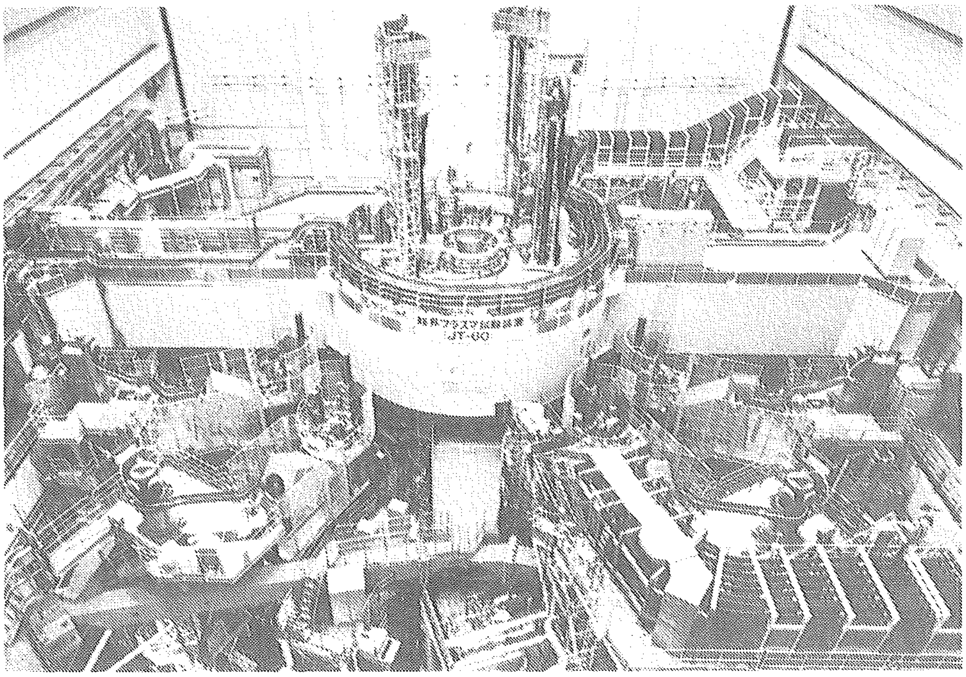
この協力活動は、国際原子力機関 (IAEA) の許で実施され、活動の実行の為に ITER 評議会と ITER 運営委員会を設け、評議会の諮問に応える為に ITER 科学技術諮問委員会を設ける事になっている。

この様に、ITER の計画は、核融合実験炉へ向けての画期的な国際協力である。現在の国際情勢を眺めれば、この概念設計の完成後に、直ちに四者による共同建設へと更に協力が進展するには種々の困難が予想されるけれども、世界の核融合研究者の知識を結集した優れた設計が得られ、それを糧として、少なくとも何れかの国により、核融合実験炉の建設が開始されると言う新たな段階へと、研究開発が進められる事が期待されている。

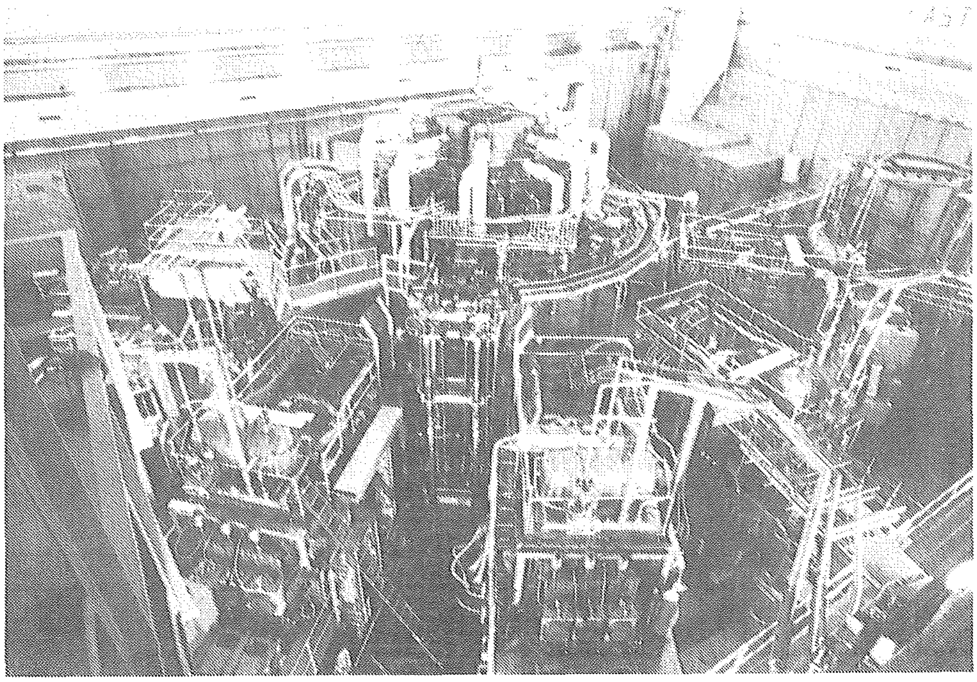




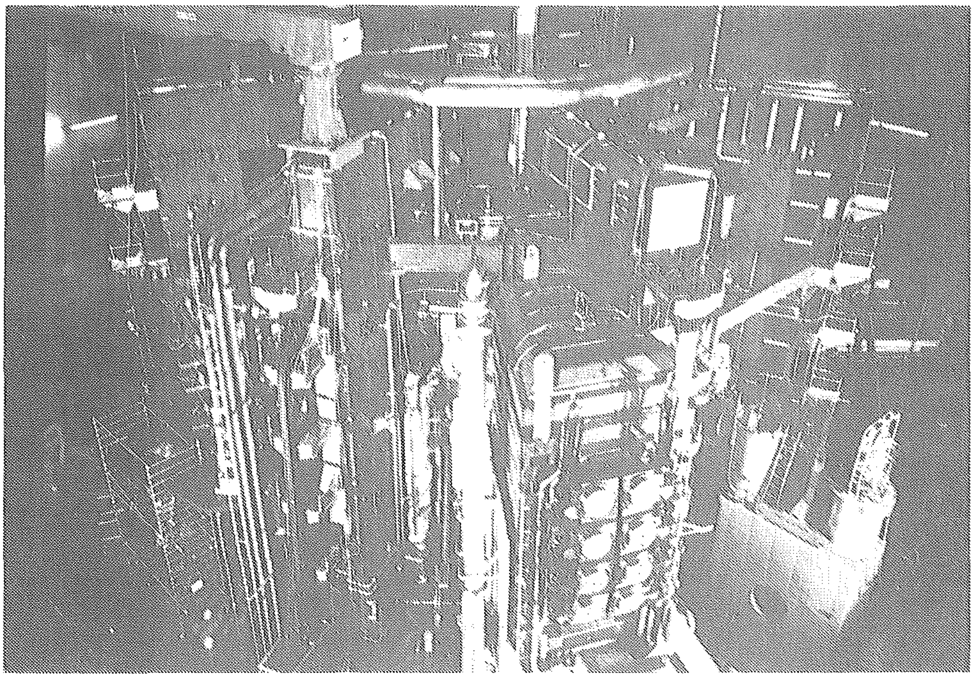
臨界プラズマ試験装置(JT−60)



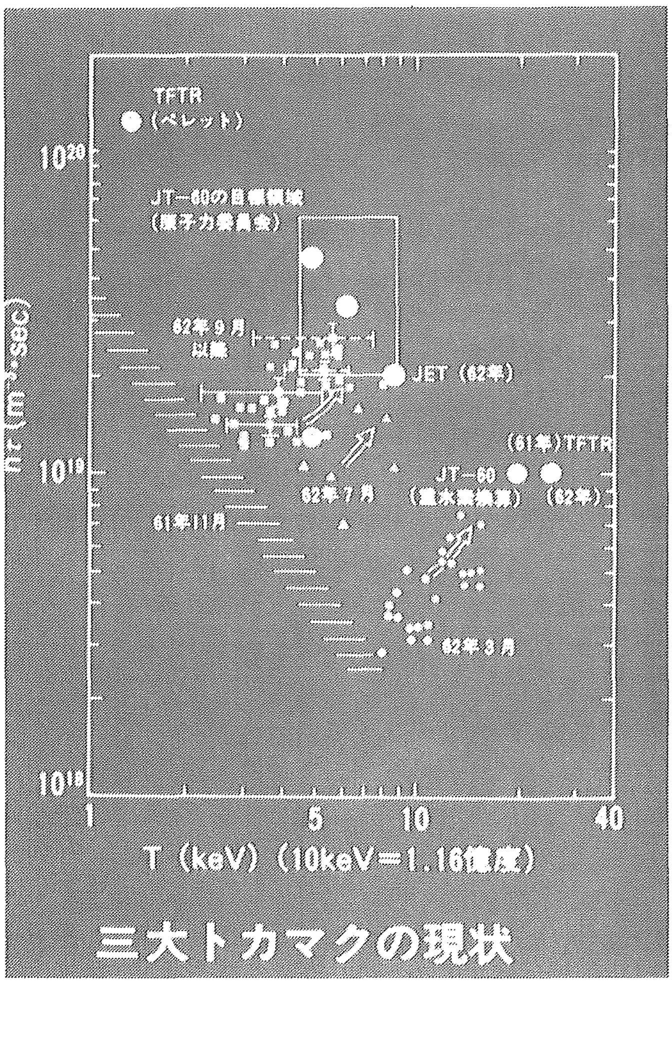
わが国のＪＴ－６０

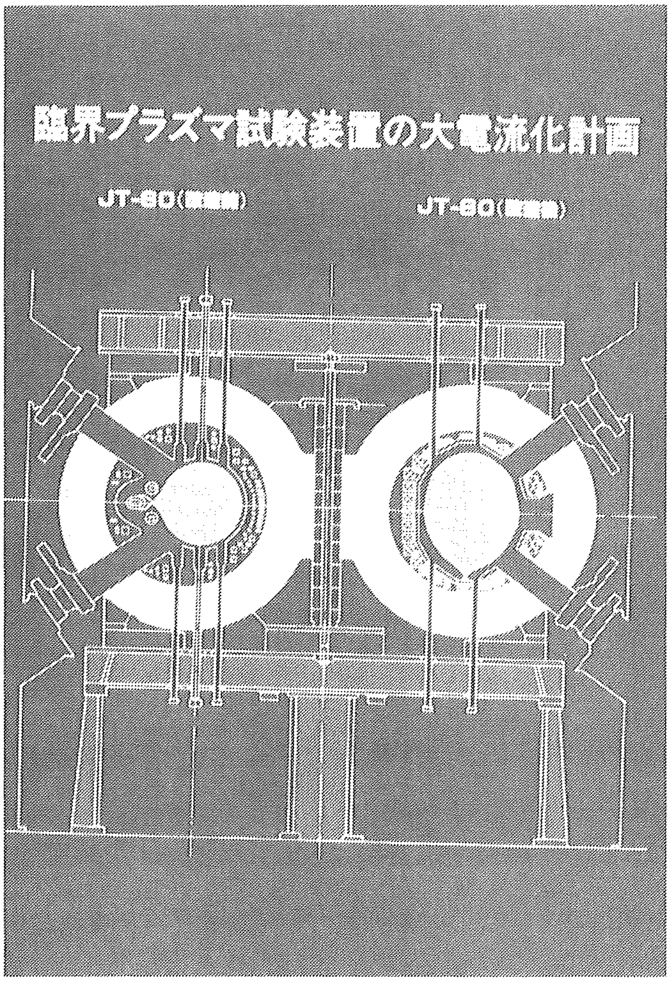


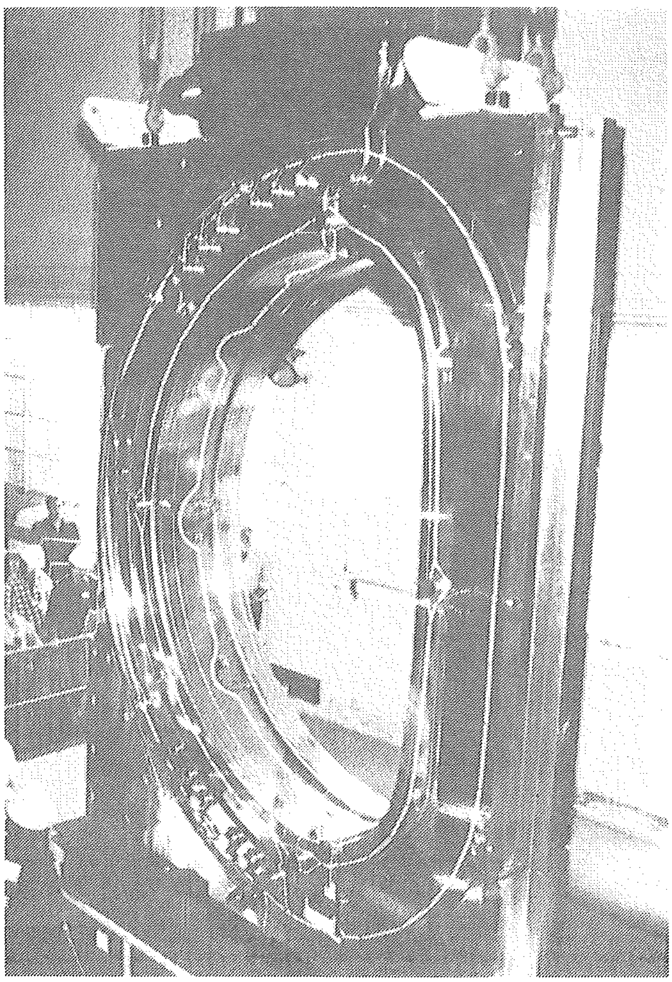
米国のＴＦＴＲ



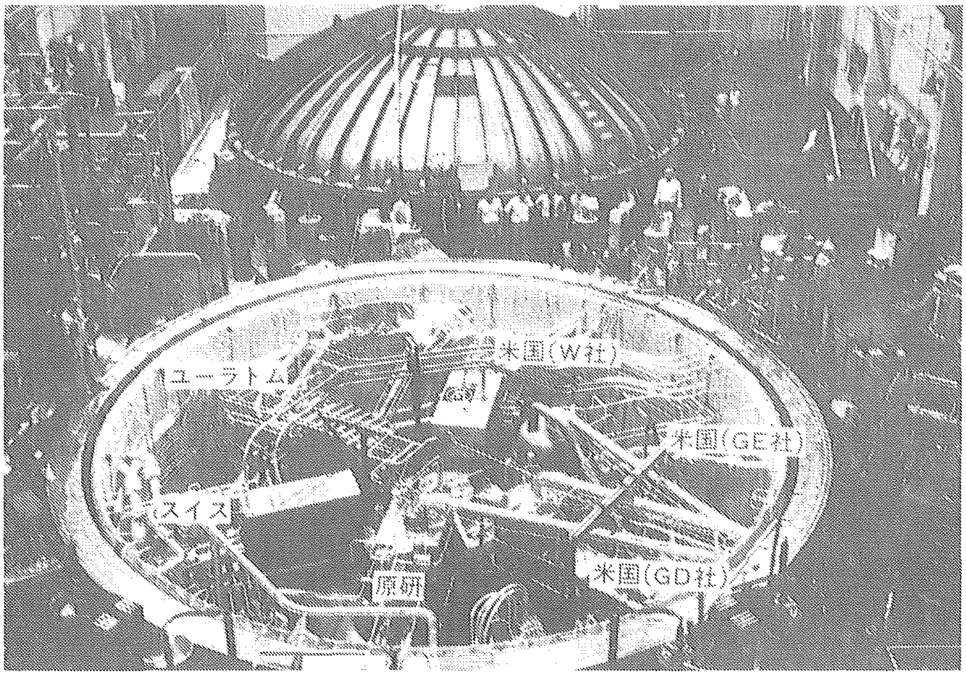
ECのJET


TFTR
(ペレット)
10^{20}
JT−60の目標領域
(原子力委員会)
62年9月
以降
JET (62年)
(61年)TFTR
10^{19}
JT−60
(重水素換算)
(62年)
62年7月
61年11月
62年3月
10^{18}
1
5
10
40
T (keV) (10keV=1.16億度)
三大トカマクの現状

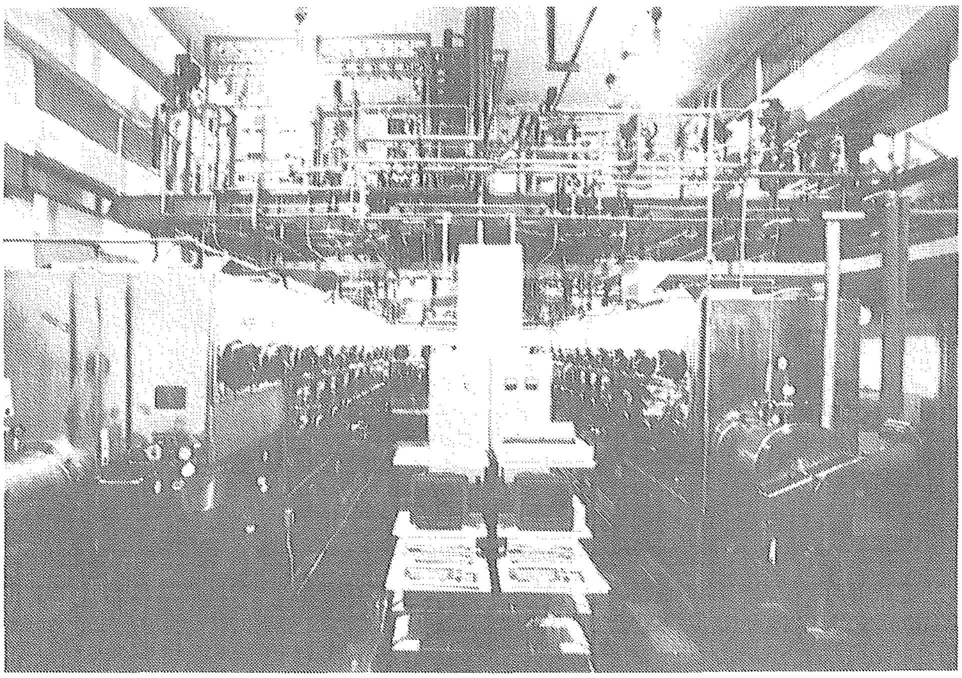




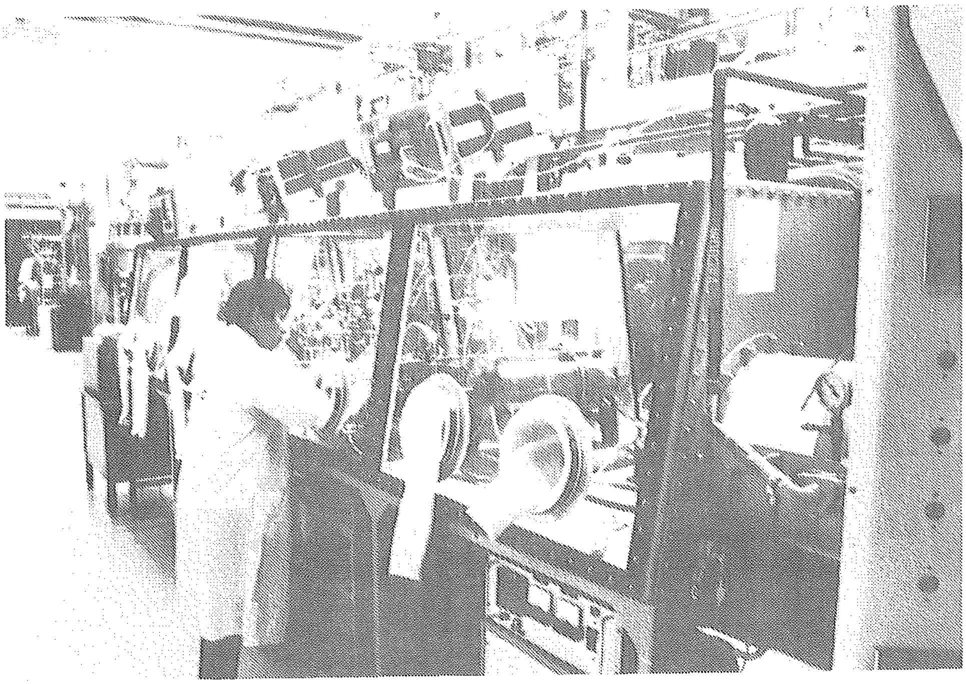
わが国のLCT用超電導コイル



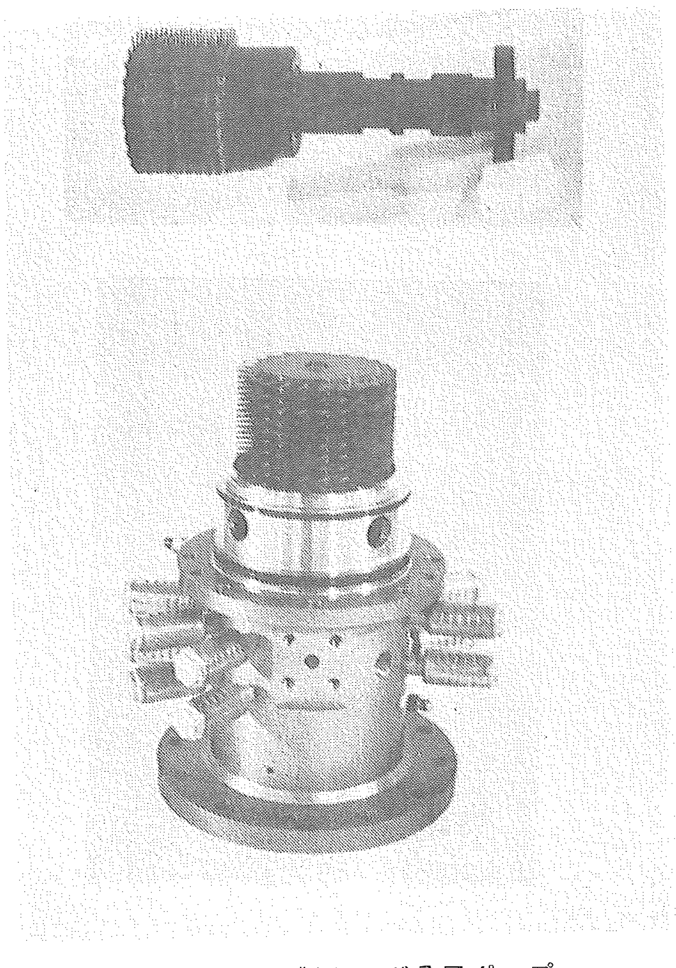
LCT 実験装置



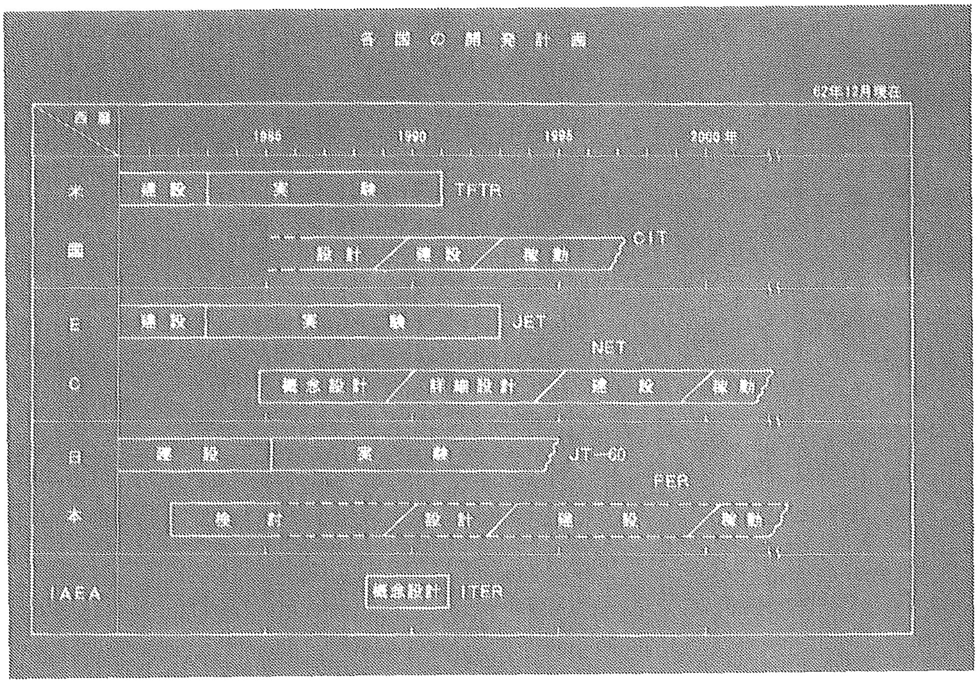
東海に完成したトリチウム施設(TPL)



米国のトリチウム施設（TSTA）



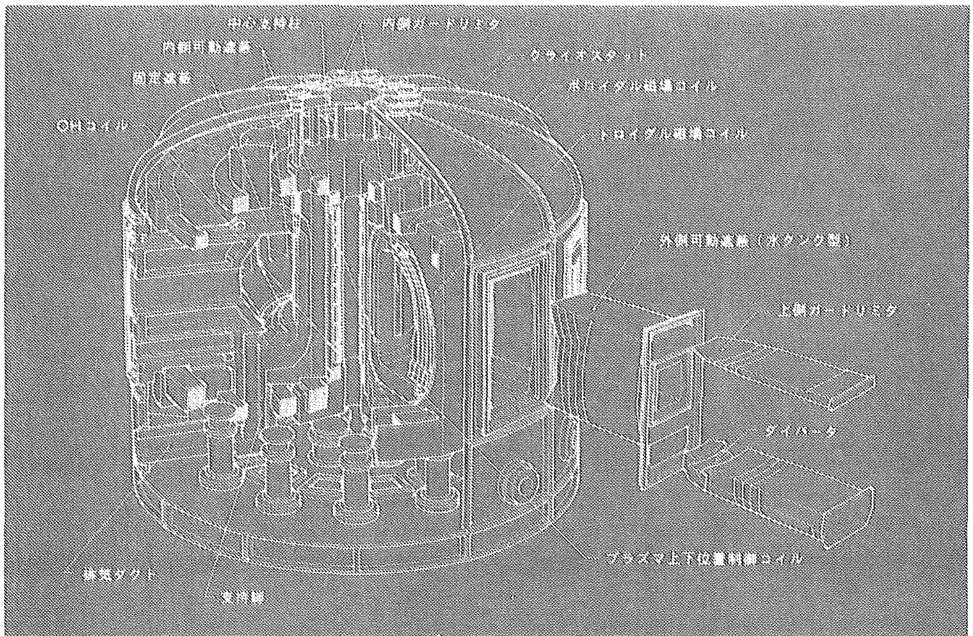
セラミック製ターボ分子ポンプ



トカマク形次期装置設計の比較

項目 / 装置	ITER (IAEA)	INTOR (IAEA)	FER (日本)	NET (EC)	CIT (USA)	OTR* (USSR)
プラズマ条件	自己点火	同　左	同　左	同　左	同　左	同　左
燃焼時間	長時間燃焼 (数百秒ー定常)	同　左 (100/150秒)	同　左 (800秒)	同　左 (>200秒)	短時間燃焼 (5秒)	長時間燃焼 (600秒)
ブランケット (トリチウム増殖比)	全装備 (~1.0)	装備 (≳0.6)	テストモジュール (~0)	装備 (>0.3)	なし	全装備 (>1.05)
中性子フルエンス	1.0~3.0 MWY/m²	~3MWY/m²	~0.3MWY/m²	~0.8MWY/m²	なし	5MWY/m²
熱出力	未定	585MW	460MW	585MW	300MW	500MW

*ハイブリッド炉



FER鳥瞰図

国際熱核融合実験炉

International Thermonuclear Experimental Reactor (ITER)

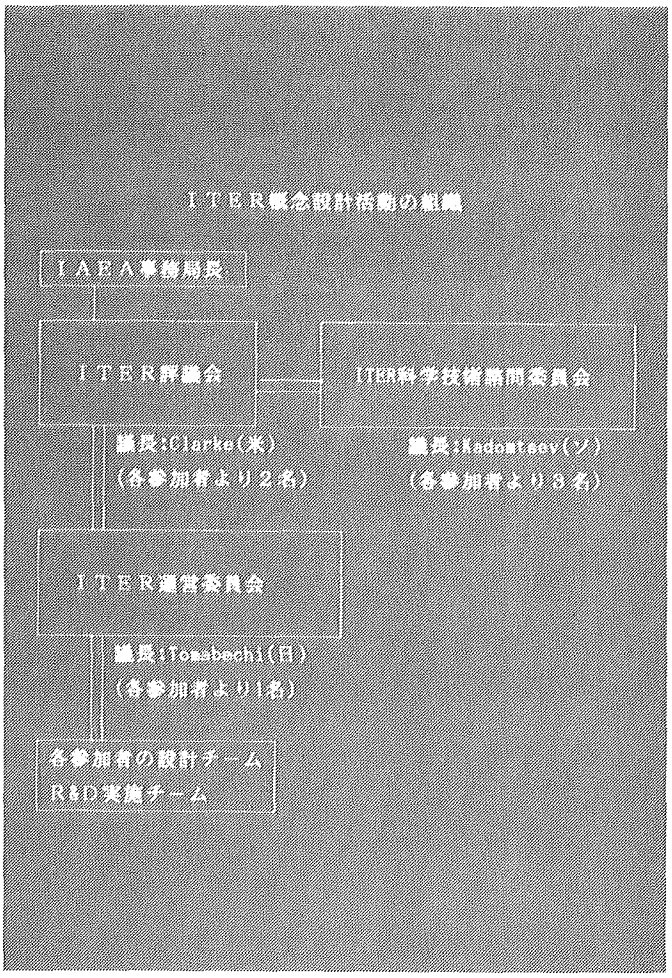
参加国 ： ユーラトム，日本，アメリカ，ソビエト

（国際原子力機関，IAEA，のもとで）

活　動 ： 設　計 ： 各参加者　80 － 100 人年

R&D ： 各参加者　年間約10M＄

目　的 ： 自国の計画，或は国際協力に用い得る設計の提供


ＩＴＥＲ概念設計活動の組織
ＩＡＥＡ事務局長
ＩＴＥＲ評議会
ITER科学技術諮問委員会
議長:Clarke(米)
(各参加者より２名)
議長:Kadomtsev(ソ)
(各参加者より３名)
ＩＴＥＲ運営委員会
議長:Tomabechi(日)
(各参加者より1名)
各参加者の設計チーム
R&D実施チーム

放射線利用と先端技術

東京大学　田畑米穂

§１．放射線利用の現状

現在、放射線、アイソトープは、医学、薬学、理学、工学、農学の非常に巾広い分野において、生活に密着したところで、我々の生活に不可欠の存在として利用されている。　その利用は、更に普及し、拡大しつつある。　図１にその様を示す。

図１

放射線発生装置の事業所数の推移

§２．進みつつある放射線利用

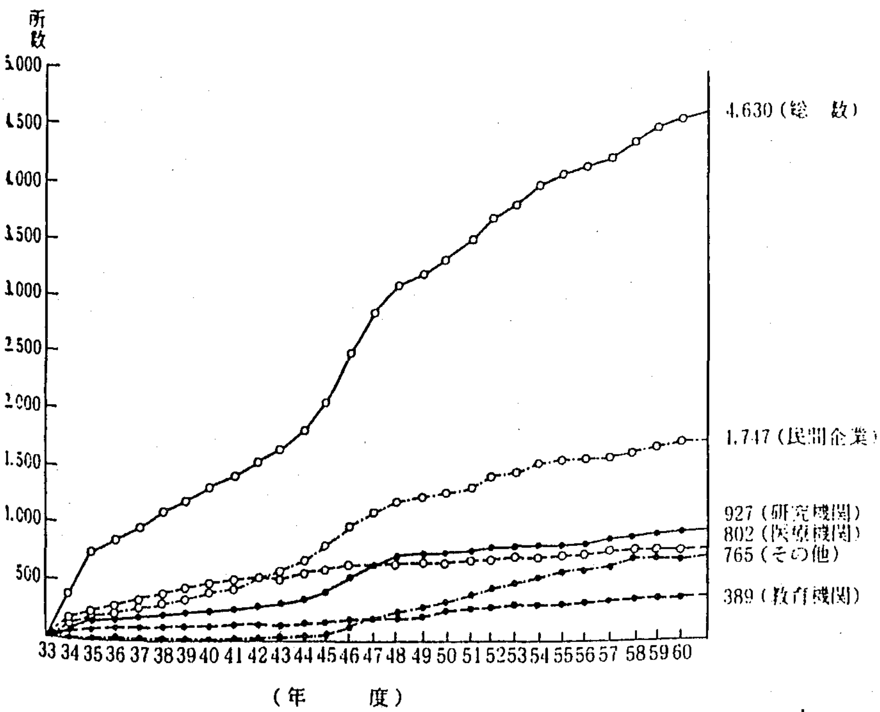
（１）．滅菌（Sterilization）　主として、医用、医療の材料や容器および関連した人体に接触して使用する多くのものは滅菌処理を行う。　この分野で、従来の蒸気加熱やエチレン・オキサイド燻薫法にかわって、放射線照射による滅菌法が急速に普及しつつある。　γ線照射プラントは、１００をはるかに越え、最近では、加速器よりの電子線による処理、滅菌が次第に行われるようになり、近い将来は、急速に普及するものと考えられる。　我が国には最近世界最大規模のプラントが２ケ所に設置され、１ケ所に現在建設中である。

（２）．食品保存（Food Preservation）　世界的な人口の増加と資源の枯渇に対応して、食糧の確保と無駄の無い利用は、極めて重要である。　従来法にかわる極めて有効な食品保存の手段として、放射線照射による方法が提案され、国際機関（IAEA,FAO,WHO）を中心に研究･開発が進められてきた。

食品保存で国際機関によって、認可されている品目は、３０以上の多くにおよび、実施している国は、２０ケ国の多きに達しており、今後更に拡大する傾向にある。　我が国では、世界最初の商業プロセスとして、じゃがいもの発芽防止法が開発され、現在に至るも稼働を続けている。

最近では、日本を除く諸外国にて、急速に実用化が進んでいる。　特に、照射

図1. RIまたは放射線発生装置の使用事業所数の推移（各年度末現在）



厚生年報 昭和62年度より

食品の貿易の問題が、クローズアップしており、今秋　ＧＡＴＴを加えた国際機関による放射線保存の国際会議が開かれるのを機会に、この分野が一段と進展するものと予想される。

（３）．廃水、上水の放射線処理　　水に関わる環境保全と安全な飲料水確保は重要であることはいうまでもない。　都市廃水、工業、産業廃水の浄化処理、上水の殺菌に当たって、化学処理法や物理的吸着処理法にかわって、放射線処理法が注目されている。　生物的、化学的汚染に対して極めて有効な手段であることが明らかにされており、^{60}Ｃｏや^{137}Ｃｓ よりのγ線照射と加速器による電子線照射が行われている。

現在、いくつかのパイロット・プラントが我が国と欧米で稼働しており、近い将来、従来法と組み合わせて、実用化する可能性が出て来ている。

（４）排煙処理　　　ＮＯ$_x$ やＳＯ$_2$ による大気の汚染は、地球的規模で問題になっており、酸性雨による自然破壊は深刻になりつつある。

火力発電所、製鉄工場およびその他の大規模工場よりの排煙を浄化することが必要であり、その新しい有効な手段として、加速器よりの電子線処理法が提案それ、パイロット・プラントが、我が国と米国および西独において、実施されてきた。　これは、我が国の独自の技術として生まれ、発展してきたものであり、近い将来、実用化の可能性が出て来ている。

§３．ビーム利用の展望

新しい放射線利用の中心的役割を担うのが、各種の加速器より得られるビームである。　高エネルギーの大型加速器が素粒子物理や核物理の研究に使われているのは周知のことであるが、現在、各種のビームを、医療や工学、産業の分野で巾広く利用する技術の開発が急速に進みつつある。現在使用され、近いうちに広拡大または新たに利用が可能になる主要なビーム源には次の三つが挙げられよう。

放射光施設 (Photon Factory)

中間子施設 (Meson Factory)

ポジトロン・ビーム施設 (Positron Factory)

(1) 放射光は、高強度の単色化された光が、広いエネルギー範囲で利用できる。

広く、理、工、医、生物、農学の分野での利用が行われ、各分野での格段の研究の推進や、新しい技術の創出に役立っている。　新しい技術の創出、極限へのアプローチに大いに貢献しており、産業界への直接的なインパクトも大きく、現在広く産業の共同利用が実施されつつある。 放射光源は利用という立場かりは、分極化が進んでいる。 大型化と小型化、コンパクト化であり、前者は、より多くの可能性の探求と広い範囲の共同利用に供せられるためであり、後者は、特定目的のための専用化であり、簡易化である。

(2) 中間子は、$\pi^+ \to \mu^+$があり、現在その Factory は、世界に4ケ所、米国、カナダ、スイスおよび我が国のＫＥＫとである。

μ^+ は、材料、物質中に打ち込まれ、周辺との磁気的相互作用をとおして、新しい状態分析の開発やテスト法に重要な役割を果たしている。 一方、μ^- は、核との直接的な相互作用をとおして、元素分析の新しい手段を提供している。
さらに、中間子触媒核融合の誘起が明らかにされており、全く新しいタイプの核融合の可能性について、本格的な関連基礎研究がスタートしている。

(3) ポジトロン・ファクトリー　ポジトロンの強力なビームは、物質の電子状態を中心に、固体の表面状態分析などに極めて強力な手段を提供する。 ポジトロンやポジトロニウムの回折や散乱、ポジトロンのエネルギー損失などにより、電子をプローブとして用いる場合と比較して、補足的な重要な情報を得ることができる。　半導体、触媒、電子素子、新素材の開発などに極めて重要な役割を果たすことは、間違いないと思われる。　我が国で初めての本格的ポジトロン

ファクトリーの計画が進行中で、この分野で世界の先導的役割を果たすことが期待される。

§４．先端技術分野におけるビーム利用

(1) ビームによる加工

放射線硬化

イオン照射による半導体の加工

ＬＳＩ，ＶＬＳＩ，ＳＬＳＩ　分野での利用

その他

(2) 高温超電導体の研究開発におけるビームの利用

(3) 加工手段としてのイオン・ビーム

究極の加工手段として、一つ一つのイオンが使用される。

§５．結論

(1) 原子力開発

エネルギー ｛ 電力 → 成熟期 ／ 非電力 ｝

非エネルギー　→　主として放射線利用

↕

他分野との広い接点

(2) 原子力技術　→ ｛ 多様化 ／ 実用化　→ 他分野での利用 ｝

技術移転の促進

(3) 先端技術分野における放射線利用

先端技術　⇔　放射線利用

極めて大きな相互依存関係にある。

(4) 放射線利用

原子力分野で重要な役割を担いつつある。

セッション4

原子燃料利用体系の展望と課題

原子燃料利用体系の展望 ― 21世紀へ向けて

動力炉・核燃料開発事業団理事長
林　　政義

燃料サイクルの総合的経済評価と将来展望

コジェマ社（フランス核燃料公社）市場・事業開発部長
J．C．ゲ

原子燃料サイクル戦略と課題

関西電力㈱副社長
飯田孝三

燃料サイクル技術の評価と見通し

英国原子燃料公社（ＢＮＦＬ）副総裁
W．L．ウィルキンソン

原子燃料新時代へ向けて

㈶日本総合研究所会長
岸田純之助

総括コメント：

ＯＥＣＤ原子力機関（ＮＥＡ）事務局長
H．K．シェーパー

── 原子燃料利用体系の展望 ──

── ２１世紀へ向けて ──

（第21回原産年次大会セッション４）

動力炉・核燃料開発事業団

理事長　　林　政義

ただいま議長から紹介を頂きました動燃事業団の林でございます。

今日は，「原子燃料利用体系の展望と課題」というテーマで，イギリスＢＮＦＬのウイルキンソンさん，関西電力の飯田さん，フランスＣＯＧＥＭＡのＪ．Ｃ．ゲさん，日本総合研究所の岸田さん，そして，まとめとしてＯＥＣＤ／ＮＥＡのシェーパーさんから，原子燃料利用体系構築のために，それぞれのお立場から，貴重な講演がなされると思いますが，まず私からは，21世紀に向けての，原子燃料利用体系の展望について述べてみたいと思います。

我が国は，将来的にも工業立国を目指しており，石油，石炭，ＬＮＧ等国内エネルギー資源に乏しい国情から，エネルギー問題を安全保障上の最重要課題として捉え，長期的視点に立ち，原子力を基軸エネルギーとして位置付けているところであります。

又，原子力は高度な技術のシステムから成立っており，そのため，技術集約エネルギーとも呼ばれ，原子力開発を通じて得られる技術の進歩により，広く科学技術への進展，更にはその技術の共有化により国際協調の促進に貢献し得るものであります。

我が国は，基軸エネルギーとしての原子力エネルギーの長期安定供給のためには，ウラン探鉱から放射性廃棄物の処理処分にわたる核燃料サイクルの確立を図ることについて，極めて重要であると考え，原子力政策の基本としているわけであります。

o　まず，ウラン資源問題ですが，世界のウラン資源の動向を見ると，現在の世界的な原子力開発計画の低迷を背景として，ウラン需給は，緩和基調にあり，ウラン価格が低位に留っていることも相俟って，当

面は安定的に推移するものと見込まれております。

一方，長期的には，ＯＥＣＤ／ＮＥＡの報告によれば，自由世界のウラン資源量は確認資源で，130＄／kgU 以下のコストで開発可能なものは 225万tUであり，これは軽水炉ワンス・スルー戦略の場合では，2010年代後半までの世界の需要を満たすものの，2025年迄の不足量は77万tUと推定しております。

また，この確認資源 225万tUの約92%はオーストラリア，アメリカ，南アフリカ，カナダ，ニジェール等の８ヶ国に偏在し，しかも，その入手の安定性は，各国の資源政策等に左右される可能性も十分に考えられます。さらに，1980年以降の主要ウラン鉱床の発見率は，60年代及び70年代に比較して極端に低下しております。

従いまして，我が国としては，21世紀にへ向けてウランの長期安定確保のためには，開発輸入の割合を高めることが重要であり，又，我が国は，2025年までの天然ウラン需要量のうち，自由世界の約９～15%を占めると想定されることから，ウランの大消費国の責務としても，

世界の確認資源を増加させるための着実な探鉱努力が必要であります。

o　次に，核燃料のリサイクル利用でありますが，使用済燃料の再処理によって回収されたプルトニウム及びウランは技術により生み出された準国産燃料であり，これらを利用することは，我が国のエネルギーセキュリティ上からも重要であります。

昨年，原子力委員会が発表した「原子力開発利用長期計画」に於て，再処理－プルトニウム利用路線を再確認したことは，単にウラン資源の有効利用を図り，自国のエネルギーセキュリティ上の観点からだけでなく，世界のＧＮＰの一割以上を占める我が国が，世界的なエネルギー・リソースの効率的配分という観点から，プルトニウムの利用によりエネルギー・リソースの拡大を図るということで，国際社会に貢献していく考え方を示したものであり，大きな意義を持っていると考えます。

o　プルトニウム利用には，核不拡散への周到な制度的，技術的な裏付け，そして国民の理解と協力，更には国際的なコンセンサスが重要で

あります。

我が国は，平和利用を国是とし，世界に先がけて本格的なプルトニウム利用を展開する国としての責任を持ち，そしてプルトニウム利用体系の確立に係わる諸課題を，我が国の高度な技術により克服し，これを背景として，国際社会にプルトニウム利用の有効性を示していくと共に，その信頼を得るべく努力を積み重ねていくことが重要であります。

○　プルトニウム利用の中核はＦＢＲであります。ＦＢＲは，プルトニウムの利用形態に関して，増殖という本質的な特色を有し，ウラン資源の利用効率では，圧倒的に優れておりますが，我が国は，このＦＢＲによるプルトニウム利用体系の構築を積極的に目指すことを基本としております。

動燃事業団は，1992年の臨界を目途に，原型炉「もんじゅ」の建設を進め，これと並行して，ＦＢＲの研究開発とＦＢＲ時代の核燃料サイクルの要となるＦＢＲ使用済燃料再処理等の研究開発を進めている

所であります。我が国としては，プルトニウム利用の展開を図る上から，所要の研究開発を積み重ねることにより，技術的基盤の確立を図りつつ，2020年代から2030年頃におけるＦＢＲによるプルトニウム利用の技術体系の確立を図ることは極めて重要なことであります。

さて次にプルトニウム利用について述べてみたいと思いますが，プルトニウム利用の展開を推進するにあたっては，核不拡散上の国際的責務を果たすとともに，核不拡散と両立し得る平和利用を自ら率先して推進し，実証していくことがきわめて重要なことであると考えます。

我が国におけるプルトニウム利用について，動燃事業団の研究開発は，既に次のような実績と経験を保有しております。

o 東海再処理工場は52年９月のホット試験開始以来，いくつかのトラブル等を克服しつつ運転をつづけ，安定運転の実証を行ってきました。この間の累積再処理量は約 370tUに達し，約2.4tのプルトニウムを回収しております。

o マイクロ波による混合酸化物転換技術につきましては，小型設備での確証試験をもとに，自動化，遠隔化されたプルトニウム転換技術開発施設を建設し，58年10月にプルトニウム試験を開始して以来順調に稼動し，累積転換量はプルトニウム量で約 1.7ｔに達しております。

o 燃料加工に関する技術開発は，昭和41年以来，安全・確実なプルトニウムの取り扱い，ＦＢＲ，ＡＴＲの新型炉及びプルサーマル用ＭＯＸ燃料の製造技術，燃料設計技術，プラント設計，運転及び保守技術等，巾広く確立を図ってきました結果，これまでのＭＯＸ燃料の製造実績は約87ｔＭＯＸに達しております。さらに，これまでに蓄積してきたＭＯＸ燃料製造技術を基に，我が国における最新の自動化技術を結集した，全自動化工場を建設し，現在，プルトニウムを使った試験を開始したところです。

o 高速実験炉「常陽」は我が国初の高速増殖炉として昭和52年４月に初臨界を達成して以来，高速炉に係る技術開発のための種々試験を行い，昨年４月で10周年を迎えることが出来ました。初臨界以来使用した燃料要素本数は約33,000本，燃料最高燃焼度は約50,000ＭＷＤ／ｔに達しておりますが，燃料破損は皆無であります。

また，昭和59年には，常陽の照射済燃料から数10ｇのプルトニ

ウムを回収し，再び常陽にリサイクルすることで，ささやかながら，高速炉を中心とした燃料サイクルの輪を閉じることが出来ました。

o 新型転換炉ふげん発電所は，昭和54年３月の本格運転開始以来８年の運転を経験し，この間ＡＴＲの性能と信頼性を実証し，運転保守技術を蓄積してきました。

ふげんでは，積極的に，炉心はＭＯＸ燃料を装荷することにより，熱中性子炉におけるＭＯＸ燃料の使用実績を重ねてきましたが，燃料取替では，既に装荷体数及び取出体数で夫々ＭＯＸ燃料が 363体，237体となり，最大燃焼度は約18,500ＭＷＤ／ｔに達しており，この間燃料破損は無く，良好な照射実績を示しており，建設が予定されている実証炉，更にはＰｕサーマル利用への展望が拓かれたと思います。

o このように，動燃事業団は，プルトニウム利用の研究開発を着実に進めておりますが，約10年前，東海再処理工場の運転開始に

際し，日米再処理交渉が何回か行なわれ，原子力平和利用と核不拡散の問題に関し，国を挙げて議論がなされました。又ＩＮＦＣＥの場で広く国際的に核不拡散問題が議論され，55年２月には原子力の平和利用と核不拡散は両立できるとの最終報告を得るに到った経緯は，皆様の御記憶にあることと思います。

そして，現在，米国議会における日米原子力協力協定の改訂の審議においても，プルトニウムの本格的利用における核不拡散，安全確保及び環境への影響を含む問題が，議論の中心になっておりますが，我が国としてもプルトニウム・エネルギーを享受するということから，このような問題を真剣に受けとめて，プルトニウム利用を推進していく必要があると考えます。

o したがいまして，原子力平和利用と核不拡散の両立という命題に対し，平和利用に徹し，再処理 ― プルトニウム利用路線を基本に原子力政策を進めている我が国は，更に一層プルトニウム利用の必要性と有効性について国際的な信用を得るべく，研究開発の

推進及び体制の整備を積極的に行うことが，原子力先進国である我が国の責務であります。

o そのためには，核不拡散の有効性の実証といたしまして，保障措置，核物質防護，輸送技術等周辺技術を含めた制度・体制面そして技術面からのトータルシステムを確立することが，プルトニウム利用の内外の合意を得る上で，最も必要かつ有効な方法であると確信しております。

o さて我が国としては，エネルギーの安定供給を確保するため，引き続き一層安全性向上に努めながら，原子力発電を着実に進めるとともに，核燃料サイクルの確立を図ることが必要であると述べてまいりましたが，したがって，原子力発電の運転，核燃料サイクル活動に伴い発生する放射性廃棄物の問題に，適切に対処することは極めて重要なことであります。

o 一般の生活においても，快適な人間生活と，それに伴って必然的に発生する廃棄物の処理・処分問題を如何に調和させていくかということは，人類が解決すべき重要な課題であります。

放射性廃棄物は，一般廃棄物と違って，“放射能”という特徴を有しますが，英知と技術により，逆にこの特徴を利用して適切な方策をとることが可能であり，現在，原子力の便益を享受している我々世代が，責任を持って，放射性廃棄物を科学的かつ社会的に充分適切に処理・処分し，後世代への負担を最低限にしておく必要があると思います。

o 昨年の「原子力開発利用長期計画」において，再処理－プルトニウム利用路線を再確認しましたが，この近い将来の本格的なプルトニウム利用に向かって，特に，使用済み燃料の再処理に伴い発生する高レベル放射性廃棄物の処理・処分を，適切かつ確実に行う方策を確立することは極めて重要であります。

新長計においては，「高レベル放射性廃棄物は，安定な形態に固化し，処分に適する状態になるまで冷却のための貯蔵を行ない，その後，深地層に処分する」ことを我が国の基本的な方針としております。

o 科学技術面の対策，すなわち，研究開発の推進にあたっては，高レベル廃棄物は低レベルと比べてその発生量は少ないものの，強い放射能を持つ物質と，放射能が弱いが半減期の長い物質が含まれているという特徴を十分に考慮し，長期にわたる安全性と人間生活の調和に細心の注意を払って，その処理・処分方法を確立することが肝要であります。

o そのため，早急に具体的な地層処分の目標とその達成のための筋道を明確にし，社会的な合意形成を得つつ，研究開発を推進することが重要であります。

o 高レベル廃棄物の地層処分上の問題は，研究開発面とともに，技術的に対処の見通しのある，この処分対策をいかに実行するかという社会科学的な条件の整備が必要不可欠であります。

すなわち，基準に対する法体系の整備，責任体制の問題，社会・経済的な評価と費用負担，理解を深めるための教育と正しいＰＲ，各産業との共存共栄等の方策をしっかり考え，社会的な合意を得て実行することが重要ではないでしょうか。

o また，放射性廃棄物の処理・処分は，原子力発電を有する国のみならず，それ以外の国々にも深いかかわりを持つ地球規模の課題でありますので，処理・処分方策の概念については，国際的なコンセンサスを得る必要があります。

従って，その研究開発においては，データの共有化や相互補完，

研究手法の確証等，積極的に国際間の共同研究を進めていくことが，必要であると思う次第であります。

o 本年，原子力委員会において，以上のような点を審議すべく，放射性廃棄物対策専門部会及びその下に，技術並びに費用に関する2つの分科会が設置されたことは，時期を得たものと言えましょう。

なお，高レベル廃棄物には，人間生活に有用な貴金属類，すなわち，ロジウム，パラジウム等の白金属元素が多く含まれており，今後の科学技術の進展により，魅力のある有効利用の可能性を秘めている事にも充分留意する必要があります。

さて最後に，21世紀に向けての原子力の役割について，述べてみたいと思います。

o エネルギーの安定確保は将来に対しても人類共通の課題であります。石油，石炭等の化石燃料は限られた貴重な資源であり，消費を極力節減し，より付加価値の高い用途に利用すべく，後世代に残していくのが，現在を生きる我々の責任ではないでしょうか。

また化石燃料はヨーロッパ，北アメリカにみられる酸性雨問題，大気中の炭酸ガス増加に伴う影響等，地球規模での環境問題が論議されつつあり，その影響については未だ解明されていない部分もありますが，影響が出るまえに，対応がなされなければならないところであり，かかる観点からも，先進国として化石燃料の使用については考慮する必要があると考えます。

o 一方，エネルギー需給の展望としては，最近の石油需給は非常に緩んでおりますが，中長期的には逼迫してくるであろうというのが一般的な見方であります。又現在の計画にもとづく原子力開発を進め

るならば，先進国においては石油需要は余り増えないが，発展途上国における石油需要は今後もかなり増大していくであろうと予想されます。

o さらに21世紀のエネルギー源を考えた場合，現在の石油，石炭などの資源依存度の高い形態から，技術集約度の高い形態のエネルギー，高度に加工されたエネルギーの利用へと進むであろうと言われております。

原子力技術は，技術集約度の高いエネルギーの典型であり，21世紀に向けても，極めて広範な技術的可能性を秘めた魅力あるものであり，複合エネルギー源として貴重な役割を果たすものと確信します。

o 21世紀に向かって原子力技術開発を進めるにあたっては，チェルノブイル原子力発電所の事故を契機として，昨今，国内外で安全確保の問題とその重要性に対する認識が，高まっていることを率直に認識する必要があります。しかし，その事によって，我が国のエネル

ギー政策の根本から発する原子力開発と核燃料サイクルの研究開発及びその産業化への計画的努力がゆるむならば，国民は原子力開発の意義に基本的な疑問を持つことになり，ひいてはこれまでの我が国のエネルギー政策の基本も崩れ去ることにつながる恐れがあります。

o 我が国の原子力開発利用は，これまで厳に平和利用のみを目的とする原子力基本法に基づき，安全性に充分留意し，30年以上にわたって進めてきましたが，今後とも，原子力の持つ特徴の原点を見失うことなく，幅広い原子力利用の展開を目指して，21世紀に向けて自信を持って挑戦するべきと考えます。

これまで述べてきたことをまとめてみますと，

o　まず第１は，原子力の将来については平和利用と核不拡散，安全，環境，資源問題等幅広い面を考慮した国際的，全地球的視点からの対応が不可欠であります。我が国におけるセキュリテイ，技術の特徴等も充分勘案しつつ，リーディング・カントリーとして高レベル廃棄物処分などの分野で国際協力・協調を積極的に進めるとともに，広く国際社会へ貢献していくことが重要であります。

第２は，高速増殖炉技術開発を中核としたプルトニウム利用実用化の推進であります。中長期的に見ると，ウラン資源も当然有限であり，より高度な技術を結集し，資源の利用効率を高めた高速増殖炉を中心とした時代の到来は必至であり，これを支えるプルトニウム利用システムの構築は，特に我が国のおかれた種々の環境を考慮すると，国際的な立場上も特に重要な課題であると言えましょう。

第３に，原子力の基盤技術の充実，革新的研究開発の推進，科学技術の進歩による原子力利用の高度化，多様化への挑戦であります。

宇宙，地下空間，海洋等未開拓領域にも原子力の持つ技術的可能性を最大限に活用し，利用の多様化を図り，広く科学技術の進展に貢献していくことが重要な役割ではないでしょうか。

o 時間もなくりましたので，この辺で終わりにしたいと思いますが，動燃事業団は，今後とも原子力開発の推進に対し，プルトニウム利用の技術的基盤を支えるセンターとしての役割を担いうるようプルトニウム利用に関して総合的に研究開発を推進してまいりたいと思います。動燃事業団は，官民連携の場として，また国際協力の場として，その役割を果していきますので，皆様の御支援，御協力を御願いしまして終わらせて頂きます。

御静聴ありがとうございました。

THE 21st JAIF ANNUAL CONFERENCE

Session 4 : Nuclear Fuel Supply System :

Issues and prospects.

A comprehensive economic assessment of the fuel cycle, with a prospective view.

J.C. GUAIS
General Manager
Marketing & Business Development
COGEMA

Introduction

The Japan Atomic Industrial Forum has always stated that the global prospect of nuclear energy system includes both the reactor strategy and the nuclear fuel cycle strategy. The recent, excellent analysises completed by Japanese expert Committees on nuclear power perspectives have clearly underlined this necessity to have a global prospective overview, from fuel supply to power generation.

Let us quote 2 excerpts from these documents :

- *"In a comprehensive nuclear power system, the implementation of the nuclear fuel cycle should go hand-in-hand with the reactor strategy.*
  MITI, September 1986 report : "Nuclear Energy Vision".

- *"For nuclear power generation to continue playing its vital role as the main source of electricity, it is essential to define means to improve its safety, reliability and economy, by a comprehensive examination of not only each individual nuclear power plant, but also the nuclear power system as a whole, including the nuclear fuel cycle".*
  A.E.C., June 1987 report : "Long-term program for development and utilization of nuclear energy".

In fact we could even say that the complete nuclear fuel cycle includes the power generation in the reactor. Anyhow this means that the utilities and the fuel cycle industrials are engaged in the same objective to promote and develop a nuclear energy system, safe and reliable, competitive with other energy generation systems, respectful for the public and the environment.

The whole nuclear energy system starts from the natural energetic material : uranium. Uranium was first identified in pechblende ores in Central Europe, almost exactly 200 years ago. This mineral is a powerful natural resource, which has to be discovered, extracted from the ground, transformed, manufactured, managed, and recycled after use, in the best possible conditions. As mentioned in the MITI's "Nuclear Energy Vision", "Operating a 1000 MWe generating plant for one year requires 30 tons (3 trucks) of nuclear fuel, 1.3 million tons (7 large tankers) of oil, 2.2 million tons (22 large freighters) of coal".

This fantastic energetic content of uranium has made it the strategic resource for a country looking for its energy independence, such as Japan, and some Western Europe countries. Moreover the smooth development of nuclear energy demands a non-restricted circulation between producers and users of the nuclear fuel under its various forms : yellowcake, UF_6, pellets or fuel assemblies, spent fuel, recycled fissile materials, and the resulting final wastes. We have always advocated for the free-trade and regular transportation of the nuclear fuels, provided the technical security measures, and the indispensable international regulation and controls to prevent profiferation risks.

Another specific feature of the nuclear industry is the length of time scales :

- the residence time of nuclear fuel in the reactor core for power generation is usually 3 years ;
- the fuel cycle duration, including manufacturing for recycle, is close to 10 years ;
- building a large power reactor or a major fuel cycle facility requires 6 to 10 years ;
- the time elapsed between first uranium exploration activities and the ore extraction can be 10 years or more ;
- the industrial development of a new technology for the fuel cycle such as enrichment can take 25 years, and 30 years or more for a new reactor type ;
- storage of radioactive materials implies periods of several hundred of years.

Because of these durations, and of the uncertainties associated with the previsions of the great future, including in particular the possible large variations of the exchange rates between the moneys involved in the nuclear market, we have to make the most serious attempts to determine our objectives and the rational ways to attain them. Such strategic approaches have been shown in the above mentioned japanese works of the MITI and A.E.C. Committees. We consider these visions and policy programs as the best examples in the field.

In this paper now, I will first offer some remarks on the front-end of the fuel cycle : uranium and enrichment. My objective is to try identifying the forces behind the evolutions and detect the trends of the industry and the market.

We will then turn to the back-end, where a prospective assessment of the complete closed fuel cycle (with reprocessing/recycling) will be briefly presented, as compared with the open fuel cycle (or once-through option). Some elements of cost comparison between the 2 routes will be included.

1 - Natural Uranium

Since the start of industrial large scale extraction of uranium, 30 years ago, 800,000 Metric tons of U have been produced worldwide (WOCA). Out of this, less than 700,000 Metric tons have already been used, or aro in actual use in the nuclear power plants. This leaves 120,000 to 150,000 Metric tons in inventories both at the producers' places and as utilities stockpiles. Another 600,000 to 800,000 tons will be consumed in the power plants between today and the year 2000. Longer term projections, such as described in the 1986 OECD/IAEA "Red Book", show figures of 2,000,000 to 3,000,000 Metric tons for the WOCA cumulated demand up to year 2015, depending upon the nuclear energy growth rate, and the development of the fast breeder reactor.
Uranium mining industry is relatively young, and modest in terms of quantities produced by comparison to the classical mineral resources : metals, and fossil fuels.
And this industry is experiencing a downward adjustment of global production, a geographic concentration of the sources, and a dramatic reduction of the exploration efforts. These changes are due to a number of reasons ranging from the nuclear power growth slowdown, the international economy crisis, the weakness of US $ and related moneys, government policies and constraints, and some specific structure patterns of the uranium industry and trade.

A few examples of recent and present government or legislative restrictive implications :

- The 5 years stop in the Australian U mining deployment, between 1972 and 1977, associated with the Ranger impact study.
- The restriction imposed in U prospection in some Canadian provinces.
- The 3-mines policy in Australia, and the floor price imposition.
- The US embargo against imports of South African or Namibian yellowcake.
- The upgrading obligation on the Canadian yellowcake.

Moreover, a number of upcoming events bring uncertainties about the future trade of uranium, namely :
- The USA-Canada free trade agreement.
- The limitation of foreign uranium import in the USA for US domestic needs.
- The case in court opposing US miners and DOE.

As a result of these various constraints and uncertainties, the industry faces now some difficulties, including overcapacities in production, over inventories, continuous price decrease trend, industrial recessions and shutdowns, secondary market, and all the features of a hard, difficult market.

The present buyer's market makes the short-term opportunities easy for the consumer utilities. But such a continuing situation could become a threat to the future of nuclear energy basic supply, if a number of uranium mining companies cannot survive to the present low prices.

In the USA, the mining industry is in a difficult situation. After a domestic boom in the 60's, the uranium companies have dramatically reduced their output : 70 % decrease since 1980. By the end of 86, only 4 conventional centers for ore refining and concentration remained in operation, instead of 21 a few years before.
In Southern and Central Africa, as in other producing regions, uranium production is in a constant decrease since the early 80's.

Another serious concern for the future of this industry is the historical decrease of the uranium exploration activities on a global basis, since the late 70's. The OECD/IAEA Red Book reports that in 1985 US $, the exploration expenses for the WOCA have declined from $ 750 M in 1979 to $ 120 M in 1985, that is a reduction of 85 % !
Even if the present level of resources and the large inventories give confidence for the short-term availability of uranium, the partners in the nuclear industry must remember the long delays involved in the exploration activities. A loss of competence and know-how in the mining industry in these years would be detrimental to a restart of discoveries of new U resources all along the 90's.

A last point to make is the present trend to a geographical reduction of both the explorations expenses and the mining industries in a few favorable provinces :
In 1986, only 8 countries have produced more than 1000 Metric tons each.
In the 90's, 90 % of the WOCA supply will come from Canada, Australia, Southern Africa, Central Africa, the United States, and France. Australia and Canada will account for over 50 % of the world supply.

Both partners in the nuclear power system : utilities and uranium suppliers, must contribute to improve the present situation in order to prepare a more secure supply system in the future :

- *The utilities should enlarge their supply base by taking advantage of diversification of sources. Central Africa for instance must continue to represent a major alternate supplier.*

- *The mining industry should maintain a level of effort and money in uranium exploration, including in new places in Africa, South America, and Asia.*

- *Fair prices should be obtained for the long-term procurement contracts, covering the industrial costs, allowing for the indispensable development activities, and providing a reasonable rate of return based on the risk taken. We all know that the resulting price level for long-term supply can easily ensure the competitivity of the nuclear kWh over the fossil fuel generated electricity.*

COGEMA, as a major multinational producer oriented towards the future, will continue to devote a consistent amount of activity in uranium exploration, as well as in the optimum management of the production centers and in the improvement of the exploitation economics.

2 - Enrichment

A sound competition, in a free market environment, is the sign of a healthy industry and trade, ensuring quality services to the customers, and giving incentives for development to the producers.
Unfortunately, today the international competition rules in enrichment remain more or less biased, due to a number of non commercial reasons existing in the USA, such as the use of enrichment services supply for political goals, or the request for long term commitments in absence of clear costing criteria.

Such procedures and uncertainties may worry the customers for the future evolution of services, contracts and prices. For instance what will happen to the DOE SWU prices in some years, if the power needed for the GD plants, is no more available from the then too old coal fired power plants ?
We do think that the actual, if not the only, requirement of the utilities in the enrichment field is to rely upon an efficient technology, a flexible industrial tool, and a responsive marketing attitude. As a prime competitor COGEMA makes every endeavour to meet this requirement :

- *an efficient technology. In terms of the SWU cost in real terms, the EURODIF plant, using nuclear energy, offers the twofold benefit of an uptodate process equipment and a well controlled energy expenditure.*

- *a flexible industrial tool. The plant operations capabilities offer a range of actions, in order to adapt to the changing pattern of the market and of the external conditions : output adjustments to the demand, seasonal power modulations to take advantage from the availability of electricity.*

- *a responsive marketing attitude. The evolutive and more sophisticated demand of the power utilities, fuel managers, is carefully listened to, with the view to supply at all times the most appropriate service.*

To illustrate this point, I may recall here that following the utilities needs for the reenrichment of their reprocessed uranium, COGEMA has planned to operate a large batch of Rep U in the EURODIF plant, in a specific enrichment campaign, in the year 1995-96.

But the future of the enrichment business is also commanded by the results of the vast R & D programs in progress on the advanced enrichment processes, in particular in the laser techniques.
In AVLIS/SILVA, the USA (DOE), Japan (LASERJ) and France (CEA) appear to have the most promising programs, with already a series of good results and confirmations of the process potential in terms of high selectivity.
Then comes now the time for extrapolations in uranium flowrates, laser fluences and recurences, and technological assessment of the system design, the materials, the maintenance and the operations. We know that this necessary step can be tedious and lengthy and will ask for large amounts of money. This will take place in the 90's and will lead to a first industrial deployment by 2000. Commercial SWU costs will only then be really under full control.
The market analyses, associated with the SILVA specific characteristics, conclude that our first application of SILVA enrichment will be in France for reprocessed uranium. By the end of the century, large annual quantities of reprocessed uranium will be produced by the two La Hague plants, and the other reprocessing facilities. As an example, a 2000 tons per year production to be reenriched from 0.8 - 0.9 % to 3.3 - 3.7 %, will need around 1.5 - 2 MSWUs annual capacity. The high selectivity of the SILVA process will authorize to strip the Rep U from its undesirable isotopes (U232 and U236), and this will help an easy fabrication procedure for Rep U fuels.

3 - *Reprocessing/Recycling*

Recycling the used materials is a common practice for mature manufacturing industries such as copper, glass or paper. Conservation of natural resources, protection of the environment, and cost savings, are the usual reasons for the development of such recycling activities.

In the case of a natural material of great value such as uranium, and particularly for the countries with a positive nuclear power program oriented towards the future, but with poor domestic resources, like Japan and the Western Europe countries, recycling is a most reasonable way to improve the security in energy independance. As an example, in a large LWR reactor, recycling both the plutonium as MOX and the residual uranium of a reprocessed reload (24 tons) in a further reload, will save 50 to 60 tons of natural uranium out of the 150 tons needed without any recycling, that is over 35 %.

At the same time, recycling the fissile materials (residual uranium and fission-produced plutonium) greatly optimizes the conditions of the final geological storage of nuclear residues : no plutonium buried in the ground. This can help the whole nuclear industry to gain a better public understanding and acceptance.

Moreover, the consumption of plutonium in reactors, as MOX fuels in present LWRs, then later in FBRs, is a better answer to the legitimate non-proliferation concerns than the storage of this material.

Finally the economic efficiency of the whole nuclear power system is enhanced, when we consider the future development of the reactors types and performances, their fuel management, the evolution of the availability of uranium, and the future technological innovations to be introduced in the fuel cycle.
Any prospective analysis of the nuclear kWh cost, at least its fuel cycle portion, depends heavily on the specific conditions of the country where such analysis is made. This is the case in particular, for the cost comparisons of the so-called open cycle (or throw-away cycle) where the spent fuel is disposed of as a waste, and of the closed cycle with

reprocessing and recycling. So we consider there is not a unique, universal economical preference for one option or the other. Our view as the major company involved in industrial reprocessing and recycling activities, simply relies upon 3 remarks :

* It is a good thing that some research and development be currently pursued in the open cycle : interim storage of spent fuel, proper final conditioning and geological disposal. In particular, there is an interesting program in progress in Sweden, that will bring valuable information and experience on these questions.

* At the present time, the closed cycle including spent fuel reprocessing, wastes conditioning, uranium transformation, reenrichment and fabrication, and plutonium use in MOX fuels, is a wholly demonstrated activity, both technically and industrially. In particular Japan, Belgium, the FRG, UK, and France have accumulated valuable experience on each segment of the fuel cycle back-end, eiher in the fuel cycle industry (reprocessors, convertors, enrichers and fuel fabricators), or in power generation. MOX fuels have been placed in power plants for years and the operations have brought confirmation of the validity and interest of recycling.
  May we stress here the impressive determination of the Japanese plutonium utilization program ? In Japan, the plutonium use is clearly programmed for FBRs, ATRs and the commercial-scale recycling in LWRs. In particular, the deployment of Japanese MOX recycling relies upon a most reasonable schedule, including demonstration tests in a PWR and a BWR, then full scale utilization.

* In the conditions of an advanced nuclear country such as France, we have made a thorough examination of the prospective evolution of the fuel cycle components and the resulting evolution of costs, in order to analyze the fuel cycle cost per kWh, on a discounted basis. The method for such economical calculations has been described in the excellent work published by OECD/NEA in 1985 : "The economics of nuclear fuel cycle". Using this widely recognized approach we have made our proper comparison of the fuel cycle costs associated with the two options

available for the back-end, reprocessing/recycling on the one hand, and once-through on the other. For the recycling route, we rely strongly upon our in-house industrial and operating experience. In particular we can confidently announce significative reductions in prices for reprocessing services, MOX fuel fabrication, and reprocessed uranium recycling, for the second part and late 90's :

- *For reprocessing COGEMA has already mentioned that after the present base-load period, that is from 1999 onwards, a 30-40 % decrease in reprocessing prices will be offered. Quite obviously these favourable conditions will be offered first to the present base-load customers.*
- *In the MOX fabrication field, COGEMA has started the construction of the MELOX facility (100 t/year) in Marcoule. The capacity of this plant, several times the present plants capacity, will entail a substantial benefit in production cost reduction.*
- *For enrichment of Rep U, the laser enrichment technique will offer a significant economic improvement over the present conditions.*

On the other side, for the once-through route, a number of uncertainties remain associated with the future cost evolution, due to the lack of actual accumulated experience. And it is fact of history that actual costs exceed the expected ones.

Based on current figures our economic calculation shows a slight advantage (4 %) in the discounted cost per kWh of the fuel cycle for the reprocessing/recycling route since, in our conditions, the value of the recycled materials exceeds the difference in cost between reprocessing and the once-through back-end.

To summarize, reprocessing and recycling is economically competitive with the one-through option, it keeps open the choices for the future progress of nuclear energy, it protects better the environment, prevents more effectively from nuclear proliferation, and gains a more favourable public acceptance.
Our responsibility towards future generations is to transmit them a safe and efficient nuclear power generation system, with all the questions properly answered, including the final disposal of wastes instead of leaving them with a problem to handle. Proper separation and conditioning of nuclear wastes from valuable fissile materials to recycle, is the rational answer for the long term.

Conclusion

The various actors in the nuclear power industry have responsibilities to :

- *improve the safety of the nuclear installations ;*
- *ensure competitiveness with the alternate energy sources ;*
- *obtain acceptance from the public ;*
- *manage the nuclear energy system in a way which respects the environment.*

In the nuclear fuel cycle, COGEMA as a major company has a responsible strategy by :

- *pursuing an active policy of development in the various steps of the fuel cycle to prepare the future, thanks to the large R & D programs performed by the CEA ;*
- *relying upon a high-tech engineering expertise, in particular with its subsidiary SGN ;*
- *implementing the timely investments in accordance with the market needs, the most recent decision being the MELOX plant for MOX fuel fabrication ;*
- *cooperation with the utilities in view of reducing the nuclear kWh cost through optimization of the fuel cycle expenses ;*
- *maintaining a competitive market with as little restrictions as possible, compatible with the non-proliferation concern ;*
- *promoting a reasonable, safe and demonstrated solution for the back-end of the fuel cycle, which ensures an optimum conditioning of the nuclear wastes, and saves the precious fissile materials, keeping open the promising prospects of the future development of nuclear energy.*

Beyond the present turbulences occurring in the fuel cycle industry and market worldwide, we think that both producers and utilities must recall they work for the same objective : ensuring an improved source of energy to mankind for now and the times to come.

原子燃料サイクル戦略と課題

関西電力㈱ 副社長　飯　田　孝　三

（序言）

只今ご紹介頂きました関西電力の飯田でございます。本日私に与えられましたテーマは、「原子燃料サイクル戦略と課題」ということでございますが、先程、動燃事業団の林さんの方から、「原子燃料利用体系の展望」ということで、主として国の立場から、技術開発のあり方を中心にお話がございましたので、私の方からは、ユーザーとしての電気事業の立場から、お話を申し上げたいと思います。

永野議長さんからもご紹介がありましたように、私は、関西電力の副社長でありますと同時に、わが国の電力会社の連合機関であります電気事業連合会において、原子力に関する方針策定を行っております原子力開発対策会議の委員長でもございますので、そういった観点からお話できることと存じます。

［1．基本的な考え方］

さて、原子燃料サイクルについて考えます場合に、その前提となりますのは、「なぜ原子力を開発するのか」ということでございますので、まず、わが国が原子力を開発する必然性、必要性について、お話申し上げなければなりません。とくにソ連のチェルノブイル事故を契機として、国際的にも、国内的にも、原子力に対するパブリック・アクセプタンスの問題の重要性がますます高まっており、私共電気事業者と致しましても、この問題、即ち原子力開発の基本的考え方をより広く一般に理解して頂くことが目下の最重要課題の1つと考えまして、積極的に取組んでいるところでございます。

（エネルギーと原子力）

エネルギー問題という場合に想い出されるのは、今日あとでお話に

なられる岸田純之助さんのご意見であります。先生によれば、現在は第3次産業革命ということで、18世紀後半からの英国の鉄鋼業を中心とする第1次産業革命、19世紀における近代工業社会の形成、即ち第2次産業革命に対して、今始まりつつある第3次産業革命は、技術の複合化、統合化、融合化等を特徴とするというもので、私も興味深く拝聴したことがございます。第1次産業革命を支えたエネルギーは石炭、第2次産業革命を支えたのが化石燃料による電気エネルギーということでございますが、第3次産業革命を支えるエネルギーについて、先生はとくにご指摘にはなっておられなかったように思いますが、私は、「技術エネルギー」とくに原子力エネルギーが主な役割を担うべきではないかと考えております。

エネルギー資源の有限性については、つとに指摘されているところでありますが、太陽からの贈り物、あるいは遺産ともいうべき地下の天然資源にエネルギーを依存している限り、私共は子孫の資源をも消費してしまうことになりかねません。従いまして、浪費するだけでなく新しいエネルギー資源を生み出していく、といった姿勢が必要でありまして、現在これを大規模に可能にしうるのは原子力をおいてないと考えている次第でございます。

この原子力開発について申しますと、まず第1に国内に資源が賦存する国と、そうでない国とでは、その取組み方におのずから差があって当然かと存じます。たとえば、国内に石炭、石油資源を保有する米国、石炭資源をもつ西ドイツ、石炭と共に北海に天然ガス油田をもつ英国と、これらを殆ど持たないフランスやわが国とでは、原子力開発に対する必要性には、差が生じるのはやむをえないところであろうかと思います。

エネルギーの海外依存度と並んで原子力開発に影響を及ぼす第2の要因として挙げられるのは夫々の国のエネルギー消費の絶対量でございまして、エネルギー多消費の国ほど在来型資源に大きく依存することは許されないということになって参ります。

原子力開発に大きな影響を及ぼす第3の要因は、その国の工業的成

熟度でございまして、これによって、原子力開発に取組みうるポテンシャルに差が生じることになって参ります。原子力開発が社会に受入れられるためには、安全性を絶対的な大前提とし、これに経済性と信頼性が調和したものであらねばなりません。このような原子力開発の姿を外国では「エクセレンス」と称しているようでありますが、「エクセレンス」と一口で申しましても、それを生み出すには、底辺に厖大な産業力、技術力を蓄積していることが不可欠の要件でございますので、現時点で原子力を推進しうる国は限られてこざるを得ないと考えます。

このような理由から、原子力は「技術エネルギー」としてエネルギー資源の制約を克服しうるグローバルなターゲットであるとはいえ、実際の取組みに当っては、夫々の国におけるエネルギーの海外依存度、エネルギーの消費水準、産業力や技術力の成熟度、という3つの要因に応じて、原子力を推進していくのが現実的であろうかと存じます。このようなニーズやポテンシャルが高い国にとっては、原子力を率先して開発していくことにより、世界のエネルギー需給を緩和させること、エネルギー価格が将来高騰する場合の潜在的抑止力となること、石油やＬＮＧを燃料としてではなく石油化学等の原料としてより付加価値の高い利用方法で活用するという所謂ノーブル・ユース化、などについて、先駆的な役割を果していくことが義務づけられていると言っても過言ではないと思います。

また、昨年4月に発表されました国連の「環境と開発に関する世界委員会」の報告によりますと、世界全体のエネルギー消費水準が高まり、化石燃料の消費が増大して参りますと、酸性雨の問題が深刻化することが予測されております他、発生する炭酸ガスによって、21世紀後半には地球の表面が1.5~4.5°Cも温暖化したり、海水面が25~140ｾﾝﾁも上昇するといった見通しが指摘されておりますので、これらの解決についても、原子力発電は大きな意義のあることを私共は認識しておく必要があろうか、と存じます。

（枯渇しない技術エネルギーをめざして）

ところで、原子力は「技術エネルギー」であり、化石燃料の消費抑制に大きなインパクトを与えるとしても、真の意味での資源制約の克服に貢献しうるためには、ウラン資源を枯渇の不安のないものにすることによって、はじめて必要にして、かつ十分な要件になると存じます。

原子力と申しましても、軽水炉によるウラン資源の利用では、370万トン程度とされているウランの確認資源及び推定追加資源はたかだか50年弱で消費してしまうことになり、石油資源の可採年数と大差はありません。軽水炉から出てきた使用済燃料を再処理し、プルトニウムを軽水炉で利用すると致しましても、約2倍の80年程度に延びるだけであり、本質的な解決にはなりにくいと言わざるをえません。従って、ウラン資源をＦＢＲで利用することによって、増殖させるという方策をとることが不可欠となって参ります。このＦＢＲにより、ウラン資源は数10倍にもなり、半永久的な寿命をもつことになり、資源制約を克服することができるわけであります。これは可採年数が30年強の石油、60年弱の天然ガス、170年強の高品位石炭と比べまして桁違いなものでございます。

このような理由から、私共電気事業者と致しましても、軽水炉からＦＢＲへの移行を、できるだけ早く進めたいわけでございますが、軽水炉と経済的に匹敵しうるＦＢＲを実用化することは思いの外難しく、2～3基の実証炉を建設することにより、ステップ・バイ・ステップで新技術の導入を図り、実用炉技術と経済性向上を確立していくことが実際的と考えざるを得ない見通しでございます。

実証炉1号機については、電気事業者としての推進役を日本原子力発電㈱さんにお願いし、動燃事業団さんをはじめとする関係者のご協力をえながら推進していく所存でありますが、その運転開始は2000年代初めになるものと考えられます。その後必要な技術開発とその実証に10数年を要する他、実用炉の計画・建設に10年近くを見込まなけれ

ばならず、そう致しますと、最初の実用ＦＢＲの運転開始は2030年頃にならざるをえないのではないか、と考えている次第でございます。勿論、このＦＢＲ実用化時期2030年頃というのは、現状からみた展望でありまして、技術上の大きなブレーク・スルーがあれば、もっと早まることが期待されるわけでございます。

このようにＦＢＲの実用化はかなり先のことではありますが、先程も申し上げましたように、エネルギーの海外依存度が極めて高く、エネルギー・セキュリティーの確保が不可欠なわが国や欧州の一部諸国にとっては、ＦＢＲによるウラン資源制約の克服を究極的に指向していくことは最も重要な戦略でございますので、ＦＢＲによるプルトニウムの本格的リサイクル時代までの間、プルトニウム利用技術の確立を図っていくことに全力を挙げたいと考えている次第でございます。

ＦＢＲ時代までのプルトニウム利用の方法としては色々なことが考えられますが、私共電気事業者と致しましては、軽水炉での利用を中心に考えているところでございます。この軽水炉という概念には、現行タイプの軽水炉、近い将来の改良型軽水炉の他、21世紀には次世代型の軽水炉も含まれることになろうかと思います。なお、次世代型については、まだ具体的な概念は固まっておりませんが、炉心をより高機能にしたものをイメージしており、転換率が高くプルトニウムの有効利用、ＦＢＲへの円滑な移行という長所をもつと言われている高転換型軽水炉（ＨＣＲ）も1つのオプションになろうかと予測されます。

いずれにせよ、私共電気事業者としましては、炉型開発、プルトニウム利用の両面について、「軽水炉からＦＢＲへ」という基本的な方針の下に、少数炉型主義で対応したいと考えております。その理由は、軽水炉１つをとりましても、その成熟化に３０年という長期を要したわけでございますので、安易に多数炉型主義をとりますと、安全性、経済性、信頼性の3つを備えた「エクセレンス」な原子力開発を確立しにくいこと、プルトニウム利用について国際的、国内的パブリック・アクセプタンスをうるには、できるだけシンプルな路線をとった方がよいこと、などが背景となっております。

とくに、プルトニウムの軽水炉や将来のＦＢＲでのリサイクルにつきましては、世界的なエネルギー需給の一時的な緩和や核不拡散問題の高まりの中で、かなり難しくなっておりまして、リサイクル路線をとる国は、当面特定の国々に限定される見通しでございます。従いまして、これらの国々が技術協力と核不拡散強化の両面で英知を出し合っていかなければ、リサイクルによるエネルギー資源制約の克服という将来の「灯」を消してしまうことになりかねません。このようなリサイクル方針が国内外で十分な同意が得られるよう、私共電気事業者と致しましても、最善の努力を払っていく所存でございます。

［２．戦略と主な課題］

以上のような基本的な考え方に立って、私共電気事業者として、どのような原子燃料サイクル戦略を考えているか、またそれをどのように具体化しようとしているか、につきまして、次にお話申し上げたいと存じます。

（原燃サイクル戦略）

まず原子燃料サイクルに関する戦略についてでございますが、私共電気事業者と致しましては、軽水炉主流時代の一層の長期化を前提としつつ、ＦＢＲ時代への移行の円滑化を念頭において、エネルギー・セキュリティーを飛躍的に高めていくことを目指して、柔軟で、しかも弾力的な戦略を構築していきたいと考えている次第でございます。

現在からＦＢＲ実用化時代の2030年頃までを長期的に展望致しますと、多くの不確実性が予測されますが、その中でリスクとして考えておかなければならないものは、石油やウランの供給における一時的な中断や相当期間に亘る停止、さらにこれらに随伴したり、あるいは独立的に生じる価格の高騰でございます。石油とウランの価格動向は必ずしも一致しておりませず、石油の方がより政治的な影響を受けやすいために、一時的な跛行現象も生じるわけでありますが、長期的な趨勢をみると、ウラン価格は、石油価格動向に引っ張られながら推移し

ていくものと予想されます。石油価格につきましては、現在は 15～18ドル／バーレル の低水準で推移しておりますが、長期的にみますと、「エネルギー経済研究所」等の見通しにありますように、かなり上昇していくものと考えられ、ウラン価格も多少の上下を繰返しながらも、全般的にはこれに追随して上昇トレンドを示す可能性が考えられます。

従いまして、私共電気事業者としましては、ウラン価格動向への対応をベースとし、これにウラン供給の中断・停止の可能性への対応を加味した原子燃料サイクル戦略を組み立てる必要があるわけでございます。

後者のウラン供給の中断・停止、あるいは価格の一時的急騰といった、主として政治的要因に起因する問題に対しては、原子燃料サイクル各段階におけるストック・パイルの活用によって直接的には対応することとなりますが、間接的な対応としても、ウラン供給源の分散、濃縮の国産化率の向上、プルトニウムや回収ウラン利用によるウラン依存そのものの低減といった対策も考慮しなければならないと考えております。

一方、前者のウラン価格が上昇基調を辿る事態への対応としては、プルトニウム及び回収ウランのリサイクル路線、即ち軽水炉からＦＢＲに至る過程でのプルトニウム等の有効利用及び増殖サイクルの確立という中長期的な対策が必要になってくると考えております。

（原燃サイクル上の課題）

以上申し述べました原子燃料サイクル戦略を踏まえまして、私共電気事業者が当面しております具体的課題について、次にお話致したいと思います。

原子燃料サイクルは各段階に亘りますが、その中でも私共は基本目標として、商業的な原子燃料サイクル施設を建設することにより、エネルギー・セキュリティーの技術的及び社会的基盤を確立すること、それらの経済性を同時的に追求していくこと、さらに、未確立である高レベル廃棄物処分のシステムを確立して原子燃料サイクルに対する

社会的な理解を高めていくこと、の3点を掲げ、これを重点的に推進していくことに致したいと考えております。このような基本方針を踏まえつつ、私共が考えております原子燃料サイクル上の課題について、以下に個別に述べてみたいと存じます。

（ウラン精鉱）

まずウラン精鉱につきましては、わが国電気事業者は2000年頃までの必要量について、長期購入契約を中心として確保しておりますが、エネルギー・セキュリティーのため、危機発生時においてそれに対応しうるウラン鉱山の新規開発が出来るだけの余力をもっておく必要があろうかと思います。ウラン鉱山の新規開発には初期的な探査段階から計算致しますと10~13年を要しますが、一定の探鉱段階に達した鉱山であれば、8年間程度で生産に至ることができますので、これで危機に対応しうるだけのウラン精鉱のストック・パイルの手当てと供給の多様化を進めたいと考えております。なお供給の多様化に当っては、供給を受ける相手国の分散といった水平的な多様化を中心としつつ、長期購入契約、スポット契約、開発輸入といった供給方式の多様化－これは垂直的な多様化と言えるかもしれませんが－こういった考え方も取り入れたいと存じております。

（濃縮）

次にウラン濃縮に関しましては、当面1991年に遠心分離法により青森県六ヶ所において 1,500トン SWU／年 の商業工場を運転開始させることに重点を置いております。この工場は当初はマルエージング鋼による遠心機を採用する予定でありますが、経済性を高めるために、1995年頃からはＣＦＲＰによる遠心機を採用致したいと考えているところでございます。これらの技術につきましては、動燃事業団さんで培ってこられた技術開発の成果を積極的に反映して参る所存でございます。この第1工場の他、同規模の工場も将来建設する考えでありまして、2000年代に入った頃には第１、第2工場を合わせた供給能力3,000トン SWU／年 によって、国内需要の 1／3 が自

給できる見通しでございますが、この第2工場にレーザー濃縮法を組み入れられるかどうかが重要な研究課題となっております。

（燃料加工）

第3に燃料成型加工につきましては、軽水炉でのウラン燃料については技術上の問題はほとんどございませんので、今後は経済性の向上に重点を置きたいと考えております。また軽水炉でのプルトニウム混合燃料やＦＢＲの本格実用化までの混合燃料の成型加工につきましては、動燃事業団さんの技術を活用しつつ、民間の活力を生かす方向で進めたいと存じております。

（再処理）

第4に再処理についてでございますが、これは原子燃料サイクル上の要とも言うべきもので、わが国としましては、使用済燃料は再処理し、プルトニウム及び回収ウランの利用を図ることを基本方針としていることは、最初に申し述べた通りでございます。この一環として、1990年代半ば頃に 800ﾄﾝ／年 の商業再処理工場と当面3,000トンの貯蔵能力をもつ使用済燃料貯蔵施設を運転開始させるべく、現在フランス、英国等の協力も得て設計作業中でございます。この工場から回収されるプルトニウムは、ＦＢＲ等の研究開発計画用に用いる他、軽水炉での混合燃料に充当していく考えであります。

この800トン工場によりまして、2000年頃には、国内で発生する使用済燃料の 1／2 程度を国内で処理する体制が整うわけでございます。この六ヶ所工場に次ぐ再処理計画としましては、プルトニウム需要に応じて弾力的に再処理を行うということを基本に致しまして、再処理能力を上回る使用済燃料は、一時貯蔵のオプションを含め、柔軟に対応していくことを考えております。第2工場につきましては、使用済燃料の貯蔵状況、ウラン価格の動向、再処理経済性の進み具合、燃料の高燃焼度化計画の推移などをみながら具体化を図っていく考えでございますが、当面は2010年頃の運転開始を1つの目安と致しております。

（廃棄物処分）

第5は放射性廃棄物の処理・処分についてでございます。このうち原子力発電所から発生致します低レベルの廃棄物につきましては、青森県の六ヶ所における最終貯蔵施設におきまして、1991年頃から処分を開始する予定でございます。

一方、再処理工場から主として発生致します高レベルの廃棄物につきましては、ガラス固化し、再処理事業者が30～50年間一時貯蔵した上で、地層処分することを基本シナリオとしております。この処分が適切かつ確実に行われることについては国が責任をもつこととされておりますが、この実施にかかわる必要な経費は、発生者であります電気事業者が負担することとなっております。

高レベル廃棄物の処分そのものは技術的に可能なわけでございますが、必要となりますのは2030年頃からと、まだ時間的余裕がございます。その間、国民的合意形成の観点からも具体的な実施方策を明確に示していく必要がございますので、今後、固化技術や貯蔵・処分技術の開発について、動燃事業団さんを中心に促進して参ると共に、処分の具体的なサイトについても、先行的に地点調査を行い、将来設立されます実施主体による処分予定地の選定へとつないで参ることになっております。この他、処分に関する国及び実施主体の責任の明確化を図るための法令の整備が必要になって参りますし、処分費用の確保につきましても、処分の具体的方法の確立を展望しながら、確度の高い必要額を算定し、これに基づいて積立方法などの対策に取り組む必要がございます。

（技術開発の進め方）

以上、原子燃料サイクルの確立のための具体的な課題について、個別に申し上げて参りましたが、全般を通じて申せますことは、将来のＦＢＲ実用化時代へ向けて原子燃料サイクルの自立化を図ることが基本的なターゲットであると申せるかと存じます。

このためには、まず技術の確立を図ることが不可欠でございますが、これにつきましては、動燃事業団さんを中心とする国の機関と

私共電気事業者を中心とする民間とが役割分担を行っていくということが、わが国の推進方針であろうかと思います。

技術の開発には基礎段階、原型プラント段階、実証段階、実用化段階の4つが考えられますが、このうち国においては原型プラントまでの段階に力を入れて頂きたいと存じております。この他、国は規制に関する責任をもっておりますので、安全規制や基準化に関する技術の開発も併せ行って頂くことになります。一方、民間におきましては実証段階以降に重点を起きまして、ユーザーとしてのニーズを明確にした上で、大学や国で培ってこられた技術シーズの活用を図っていくことになりますが、この場合、効率性や経済性が重要な判断基準になるかと思います。

このような役割分担を前提と致しますと、原型プラント段階から実証段階に至る過程で、国から民間への技術移転という問題が生じて参ります。原子燃料サイクルにつきましても現在、濃縮、再処理等多くの分野で、早急に技術移転を図っていくべき時期に至っておりまして、動燃事業団さんと民間事業者との間で、共同研究、技術者のシフトなどに関する具体的なお話合いが行われているところでございます。

[3．国際協力の重要性]

さて、これまで「基本的な考え方」、原子燃料サイクルに関する「戦略と主な課題」について、私共電気事業者の基本的な考え方を申し上げて参りましたが、最後に原子燃料サイクルを推進していく上での「国際協力の重要性」につきまして改めて付言させて頂きたいと存じます。

最初にも申し上げましたが、エネルギー需給の国際的な緩和傾向の下で、現在原子力開発に積極的な計画をもっている国は少なくなりつつあり、この中でもとくに原子燃料サイクルを行ってプルトニウム及び回収ウランのリサイクルを実施しようとする国の数はさらに少なくなっております。1973年と1979年に起こりました第1次及び第2次の石

油危機の教訓も、それから長い年月を経るに従って忘れられようとしております。米国のスリー・マイル島での事故、2年前のソ連のチェルノブイル事故によりまして、原子力開発意欲そのものが著しく弱まりつつある観すらみられるところでございます。とくに米国における原子力開発の後退は、原子燃料のリサイクル路線に対して大きなマイナスのインパクトとして働いていると申せましょう。

このような厳しい国際環境の中で、国内に資源がなく、エネルギー消費水準が高いために原子力開発、なかんずく原子燃料のリサイクルを図っていかざるをえない国々は厳しい試練に立たされているわけでございます。これらの国々がこの試練を克服致しますためには安全性の確保に最大限の努力を引続き行うことを大前提としつつ、技術開発や核不拡散強化につきまして、自ら積極的な役割を果していくことが、地道ではありますが基本的な進め方ではないか、と痛感している次第でございます。

たまたま2月に米国を訪問する機会がございまして、米国の原子力関係者と親しくお話することができましたが、その折に感じましたことは、「日米原子力協定」の改訂をめぐりまして、核不拡散問題に対する厳しい見方が広がりつつある、ということでございます。核不拡散の強化の必要性については、私共も全く同感でございまして、今回の改訂も、包括承認問題とあわせて、核不拡散に対する積極的協力が含まれておることを、もっと分り易く一般に理解されねばなりません。

こうした核不拡散といった世界平和を指向した問題は、個々の国々において推進していくのは当然ではございますが、これでは国際的な理解形成にとって限界がありますので、国際的なフレーム・ワークづくりを行い、その中で具体化を図っていくことを考えなければならないと存じます。

原子力の安全面については、現在英国ＣＥＧＢ総裁 マーシャル卿の提案により、原子力を推進する世界の電気事業者が集まる原子力発電事業者国際協会（ＷＡＮＯ　World Association of Nuclear Operations）の組織づくりが行われておりますが、この他に核不拡散問題

をも含む国際的なパブリック・アクセプタンスを増進していくための組織づくりも必要ではないかと考えているところでございます。

このようなフレーム・ワークづくりに際しましては、世界で唯一の原爆被爆国であり、原子力は平和利用以外には絶対用いないことを世界に向かって宣言しておりますわが国としても、官民一丸となって、積極的な役割を果していかなければならない、と考えております。その過程で私共電気事業者と致しましても、全面的な協力を惜しまない覚悟でございます。このことを最後に申しまして、私の講演の締めくくりとさせて頂きたいと存じます。ご静聴、誠に有難うございました。

（完）

FUTURE PROSPECTS FOR THE NUCLEAR FUEL CYCLE

by W L Wilkinson
British Nuclear Fuels plc

INTRODUCTION

1. The industrial scale nuclear fuel cycle is about thirty years old, the component technologies having been largely inherited from earlier military plants. Early development was primarily 'technology-driven' by what was considered to be technically feasible within a particular timescale and with little regard to costs.

2. As nuclear power and its fuel cycle have emerged into the economic field, increasing attention has been paid to the development of processes and plant which reduce costs. Fuel cycle development has now passed from being primarily 'technology - driven', that is where costs are of minor importance, to being 'cost-driven' whereby the principal incentive for technical development is to reduce cost.

3. The desirability of cost reductions would be a driving force for development even if nuclear generation were to be considered in isolation. The economics of nuclear electricity must however, be weighed against competitive means of electricity generation in each country, according to its energy policies. For reprocessing and recycle, perhaps the most important comparison is against the 'throwaway cycle', in which unreprocessed spent fuel is disposed of permanently.

4. FUEL CYCLE COSTS

SLIDE 1 The principal parts of the fuel cycle and their costs are shown in Slide 1 which refer to estimated costs for a PWR, burn-up 49 GWd/tU to be commissioned in the year 2000.

TABLE 1

	P/KWh
U ore	0.22
Conversion	0.02
Enrichment	0.14
Fuel Fabrication	0.05
Spent Fuel Management	0.05
U Credits	(0.01)
Total	0.47

These are life-time costs discounted at 5% with reprocessing assumed to start 25 years after reactor operation. If reprocessing starts 5 years after operation the back end costs would be increased by a factor of 2.5.

SLIDE 1a

The sensitivity of prices to various factors is shown in Slide 1a. (Fig 1)

A more realistic situation however is given in Slide 2.

PERCENTAGE LWR FUEL CYCLE COST BREAKDOWN

SLIDE 2

	REPROCESSING CYCLE %	ONCE THROUGH CYCLE %
Uranium Ore	40	45
Purification & Conversion	2	2
Enrichment	27	29
Fuel Fabrication	10	11
Spent Fuel Transport	2	2
Receipt & Storage	2	8
Fuel Breakdown & Dissolution	8	-
Chemical Separation	8	-
Uranium & Plutonium Finishing	1	-
Interim Waste Storage	2	-
HAW Vitrification & Storage	4	-
ILW Encapsulation & Storage	3	-
Waste Disposal	1	-
Uranium & Plutonium Recycle	-10	-
Spent Fuel Conditioning/Disposal	-	3
	100	100

NOTES

1. Uranium ore levelised price of \$32/lb U_3O_8.
2. Costs based on 25 years operation of fuel cycle facilities
3. Major parameters taken from NEA/OECD Report. The Economics of the Nuclear Fuel Cycle - PWR Reference Case.

5. It is easy to point to the high cost items from the list and suggest that R&D must be done on these in order to reduce the costs. However it is much more difficult to identify known technology which should be applied to the problem and even harder to select areas where radically new technology could, with some assurance, result in cost reduction. This is partly because R&D is a risky undertaking and partly because development of new technology for replacing existing facilities is extremely expensive. Nevertheless it is worthwhile to consider each item in the fuel cycle individually.

URANIUM

SLIDE 3

6. A large contributor to cost is the uranium itself which includes exploration/mining, ore processing and transport. Uranium is very widely distributed, but can at present only be economically recovered where high concentrations are found. Typically, worked ores contain between 0.1 and 0.5%U, although rare (and usually small) deposits may be much richer than this. It is unlikely that the unit cost of either open-cast or underground mining methods can be significantly reduced.

7. Exploration for uranium resulted in new discoveries in the late 1970's and early 1980's just as did a similar need for new oil resources after the OPEC price rise in 1973. Newly found deposits could reduce the cost, if they were relatively high-grade and accessible for transport. Alternatively radical new technologies could contribute to uranium extraction from very low concentrations e.g. from sea-water but this is unlikely.

8. Improvements in the existing technology of ore processing and transport of UOC is considered unlikely to affect economics significantly. We are therefore led to the conclusion that exploration is the key to ~~cover~~ lower uranium prices.

CONVERSION

SLIDE 4

9. Costs of conversion comprise only a small fraction of the total and even a radical improvement in technology will not affect fuel cycle costs significantly. This stage is not therefore important.

ENRICHMENT

SLIDE 5

10. Enrichment comprises about a quarter of fuel cycle costs. Large quantities of material must be processed and, ultimately disposed of as depleted uranium. In enrichment technology, probably more than in any other part of the fuel cycle, the effects of cost-driven development can be clearly seen and have been very successful.

11. Given a common cost of power, diffusion technology will always lose out to more sophisticated ways of enriching uranium e.g. using the centrifuge. The lowest power consumption will come from the laser process AVLIS which expends energy on the U-235 atom only and not on the other 142 unwanted atoms of uranium. However, in practice what is needed is a process providing a product which is cheaper than competitive technologies taking into account all the factors, including capital cost, power consumption, power cost, etc.

12. Whereas the AVLIS process is in energy terms the best, engineering this on the industrial scale poses severe difficulties - which are reminiscent of fusion plant problems which are only now moving towards resolution, after a vast expenditure over many years. The molecular route is much less energetically favourable but poses process engineering problems which are significantly simpler but it does not appear to be as promising as the atomic route.

13. Numerous enrichment techniques have been developed in theory and at laboratory-scale e.g. electromagnetic, nozzle, chemical exchange, laser; but only two have been engineered at the > 10^6 SWU pa industrial scale, namely diffusion and the centrifuge. Of these two, diffusion represents a large proportion of global capacity but has both higher capital and power consumption than the centrifuge and can only be competitive at very large scale and with cheap electricity.

14. Current estimates of the SWU cost of AVLIS are of the order of 20 - 25% less than those for diffusion and the centrifuge. Timescale estimates are difficult to predict but an industrial-scale plant must be unlikely before the year 2000. Furthermore, it is unlikely that the true development cost of AVLIS will be reflected in product pricing, which is similar to diffusion process. Only for centrifuge development has there been a close relationship between development and engineering costs and the product price.

FUEL FABRICATION

15. Fuel manufacture accounts for about 10% of total costs. Cost reduction attempts are beset by two main problems

SLIDE 6

- firstly, a significant impact on fuel cycle costs can only be made through proportionately large savings in fuel manufacturing and, secondly, process inputs and outputs are strictly defined and the manufacturing technology is the best understood of all the fuel cycle technologies. There are a number of caveats to this statement, however. The enrichment process employs UF_6 which can be converted to ceramic UO_2 in a number of ways, each probably capable of some improvement. The laser process, if developed, will use U metal and the route to UO_2 must also be capable of demonstrating savings (indeed the justification for AVLIS may ultimately not be that it is economic with respect to the centrifuge or diffusion per se but that it provides a lower cost route from natural UOC to finished fuel). Major savings have already been achieved (~20%) in converting UF_6 to UO_2 by the invention of the Integrated Dry Route (IDR). Further savings are foreseeable but by means of automation and scale rather than by revolutionary new processes.

16. However the main point is that fuel can be developed for higher burn-ups and ratings, thus reducing the contribution of fuel fabrication to unit electricity costs. This is the main development goal.

FUEL TRANSPORT

SLIDE 7

17. Fuel transport accounts a very small proportion of fuel cycle costs and, although there are substantial savings in absolute terms to be made, for instance, by building higher payload flasks, no significant effect on overall cost is likely.

SPENT FUEL STORAGE

18. Storage accounts for a very minor part of the cost of the reprocessing cycle but substantially more the once through cycle - the difference being the length of storage time, about five years for reprocessing and about fifty years for the once-through cycle. Again only marginal effects on the total costs can be envisaged, whether storage is wet or dry; but significantly greater space utilisation is undoubtedly possible.

REPROCESSING

19. Reprocessing can account for ~~nearly~~ over 20% of fuel cycle costs this could well be an area capable of considerable optimisation resulting in capital and operating savings.

20. The fuel release technique exclusively used in oxide reprocessing is shearing - generally whole element shearing. There are many disadvantages; the mechanical equipment is bulky and complex, it requires frequent maintenance/replacement, it can lead to high fuel losses and a large building is needed. Shearing and dissolution is a costly process accounting for nearly 10% of the fuel cycle costs.

21. There is considerable scope for simplifying the fuel release/process e.g. by laser cutting which has been demonstrated for fast reactor sub-assemblies. If single-pin methods can be devised, capable of the high throughput rates required in a large reprocessing plant then a number of downstream benefits would accrue in addition to reducing fuel losses and the building size e.g. continuous dissolution would be made easier by uniform fuel feeds and elimination of bulky components.

22. Continuous fuel dissolution should need less space and, hence, a smaller and cheaper building than batch dissolution but it requires substantially greater uniformity of feed in order to function optimally. Current designs for continuous dissolvers lack intrinsic reliability and development of maintenance-free designs without moving parts is required.

23. Clarification of dissolver liquor is necessary to remove small cladding and insoluble fission product fines. Once again the principal method using a centrifuge requires bulky equipment and maintenance facilities. Ideally development would centre on a small maintenance free technique which would be more robust, e.g. towards seismic design criteria.

CHEMICAL SEPARATION

24. The basic process employed throughout the world for chemical separation is the PUREX process and it is very likely that this will continue to be the case. There is, however, still considerable scope for further improvements leading to reduction in capital and in the total fuel cycle costs. Particularly important are developments resulting in smaller, more reliable plants and equipment, requiring simpler maintenance, and giving lower effluent levels. There are many possibilities but some examples might be intensification, that is the development of smaller equipment, improved and automated control systems and new flowsheets for processing and co-processing high burn-up, and plutonium - enriched thermal and fast reactor fuels.

25. As uranium recycle, in particular, assumes greater importance there is an optimisation to be achieved between obtaining greater fission product decontamination factors in the solvent extraction process and the extra cost incurred in conversion to UF_6 and fuel fabrication. With higher activity recycled uranium the requirement is chiefly for containment and enhanced automation. In principle, a similar argument applies to enrichment plant, where reprocessed uranium may be re-enriched, but blending of fresh and recycled material could avoid this stage.

PRODUCT FINISHING

26. Uranium and plutonium finishing contribute little to the fuel cycle cost. It is unlikely that a rival will be found for conversion of uranyl nitrate to UO_3 and it is considered that, at best, only marginal process improvements will be made with little effect on overall cost. Development in Pu finishing would also have little effect on overall cost but could have an important contribution in improving the physical properties of the product, giving greater equipment reliability and reducing operator dose. It should also be noted that the Pu in storage will almost

certainly require a purification stage prior to incorporation in fuel, because of the amounts of Am grown-in, and development is necessary.

WASTE MANAGEMENT

27. Interim HA waste storage contributes only a minor 'back-end'cost, this is needed primarily for newly separated HA liquors to decay to the levels required for vitrification. Novel technology is not expected to make a significant contribution to cost reduction.

SLIDE 9

28. However waste treatment is a significant contributor to total fuel cycle costs. Much of the fundamental process development work has been done in identifying the processes for solidification of wastes, that is vitrification for HA liquors and encapsulation in cement for intermediate level wastes. It is unlikely that a radically new technology or matrix will enable significant cost savings to be made and most development effort should be targeted towards lower capital costs, better engineered maintenance free systems and dose reduction. It is to be noted that the number of stores required for encapsulated and vitrified material - and hence capital cost - depends upon the date of final disposal.

FINAL WASTE DISPOSAL

29. It is generally agreed that the sooner a waste repository for final disposal can be made available the better. Although by itself it contributes only minor costs, early provision of facilities could reduce interim storage costs appreciably. Thus, urgent development is required in parallel with the gaining of public acceptance.

FUNCTIONAL DEVELOPMENT

30. In addition to the detailed processes and their associated plants and equipment, there are a substantial number of generic engineering areas which affect all technologies. Two major examples are Instrumentation and Control and Materials. It is considered that there is considerable scope for improvement in these and other areas, for example simulation and modelling, Remote Handling, Risk and Safety Assessment and Vessel and Piping Engineering.

SLIDE 10

DISCUSSION AND CONCLUSIONS

31. The first general point to be made is that whereas improvements to the front-end of the fuel cycle will, not have a great effect on overall costs they can be retrofitted into existing plants without much difficulty. This cannot be achieved in many parts of the back-end without enormous difficulty. Therefore, the back-end plants have to be right first time.

32. The <u>second</u> general point is that reduction in the overall nuclear fuel cycle costs - important in competition with coal, oil, gas, etc - can best be achieved by developments targeted on an integrated view, rather than one in which constituent parts of the fuel cycle are developed in isolation.

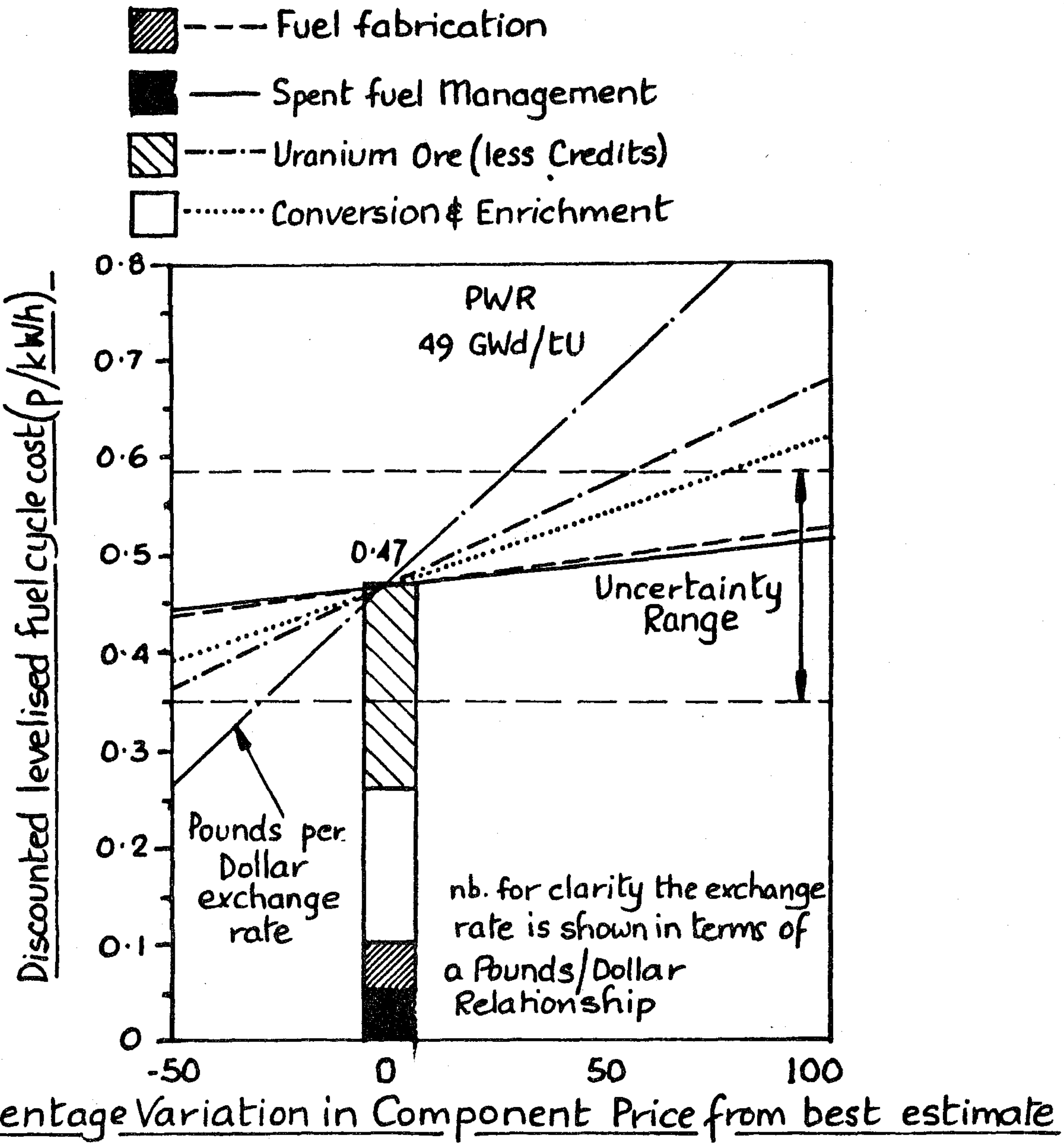
33. The <u>third</u> general point is that the component costs e.g. uranium price, are subject to large fluctuations. The sensitivities of various factors to price changes is illustrated at Fig. 1.

34. The very high capital cost of reprocessing plant and its infra-structure means that relatively few will be built and that they will be operated over lengthy periods - probably in excess of 30 years. BNFL is currently building its Third Generation reprocessing plant, having been in the business for nearly forty years.

35. Reprocessing plant construction and operating costs can be confidently forecast to increase in real terms unless plant and equipment can be made smaller, can be operated with fewer people, and are not subject to unnecessarily stringent safety standards.

36. Taken together, these arguments lead to the conclusion that targeted development work should be cost effective and must be done. The work should be done continuously. A stop-start policy is wasteful of resources and may well be counter-productive.

Fig.1. PWR Fuel Cycle Costs and their Component Sensitivities for Reactor Commissioning in the Shorter Term (Year 2000)



原子燃料新時代へ向けて

財団法人　日本総合研究所

会　長　岸　田　純之助

日本の原子力発電は１９８７年，発電比率で総発電電力量の31.7%，設備利用率も79.2%と，これまでの最高を記録した。原子力平和利用の分野では，世界で第一級の実績をあげる国になった。日本の原子力開発は，さらに一層の成熟を目指して，新たな展開をつげる段階に達したといえる。

１９８７年に作成した原子力開発利用長期計画も，こうした実績を背景にして，基軸エネルギーとして原子力を位置付け，この分野でも国際社会への貢献を果たすべき役割を日本が担っていることを指摘している。第一級の技術的，経済的能力を持つに到った日本は，第二次大戦後遅れて出発した原子力の分野でも，ようやく遅れを取り返して，先発国と肩を並べる段階に達したということである。

今後は自主的に自前の技術の開発に努め，原子力利用が社会にますます定着していくよう努めなければならないのだが，そのためのこれからの具体策を決定するにあたり，以下のような５つの視点が重要だと考える。

第１は，原子力利用に専念する技術先進国として，常に平和利用の観点から原子力技術の有り様を吟味する態度を堅持することである。

周知のとおり，原子力開発はすでに半世紀に近い歴史を持っている。ただ先発諸国の多くは，核兵器の実現という軍事目的から研究開発に着手した。初期の段階では，もっぱら軍事開発に重点が置かれていた。その後，平和利用の技術も実現したが，全体の技術体系を見ると今もなお軍事利用の“尻尾”をつけているという印象を否めない。高濃縮のウラン235を確保し，高純度のプルトニウム239を実現して，性能の良い核兵器を作ることが最優先され，それ以外の技術の開発については，それよりは低い優先度が置かれてきたと受け取れるのである。

核燃料サイクルのバックエンドで特にその感が強い。今では世界で26の国が原子力発電所を持ち，400基の原子力発電所が動くようになっている。しかし，諸外国の使用済燃料再処理に強い規制を加えようとするアメリカの政策は，最近も変わっていない。それは原

子力利用を核兵器開発の角度からのみとらえる心理から抜け出せないでいることの一つの現われといえよう。再処理後の廃液に高レベル廃棄物という名称が与えられているのも，軍事用のプルトニウムを取り出した後の残りは，疑うことなく廃棄物として処分すべきだと考えたことからの命名だといえるのではないか。

だが本当にそう考えていいのだろうか。全体として，これまでの廃棄物の処理処分までを含んだ原子力技術の開発課題のそれぞれに関して，平和利用に専念する国の立場から見ると，まんべんなくバランスが取れた研究開発努力が行われてきたとは言いにくいように思われる。

もともと私は，一般的に平和利用の技術というものは，軍事利用の技術よりは遥かに難しいと考えている。軍事利用の場合は，ある点での性能要求は極めて厳しい。必要な特定の性能の実現に最大の優先度が置かれる。それ以外の技術開発は二の次になる。コストがかさむことはあまり問題にされない。安全性に関しても，国の安全保障という安全性が最優先する。

平和利用の場合はそうではない。平和利用の際必要な性能としては，安全性，信頼性，経済性，維持管理のしやすさ，扱いやすさなどといった様々な性能がバランスよく満たされることが要求される。それによってその技術が社会的に受容性を持てることが重視される。こうした開発における重点の相違があったためか，原子力技術ですでに半世紀の開発の歴史を経ながら，技術開発が最近ようやく緒についたばかりという印象のある分野が残っている。その最たるものが高レベル廃棄物の処理処分の技術だと思われる。

高レベル廃棄物が高レベル廃棄物という名前を与えられながら，その中には鉱物資源として極めて価値の高いロジウム，パラジウムなどの白金属元素が含まれている。仮に日本で現在運転中の原子力発電所の使用済燃料中からロジウムをすべて回収したとすると，日本の年間のロジウム総需要の1200kgの四分の一に相当するロジウムがそこから得られることになる。

ロジウムは貴重なレアメタルの一つで，自動車用の触媒や化学工業などに広く使われている。使用済燃料中のロジウムは半減期が短かく多くの用途が期待されるが，もちろん今のところ，これを経済的に取り出す技術は実現していない。廃棄物として処理処分の計画がたてられることにならざるをえないのだが，これを確定した処理処分方策と考えていいのかどうか。

現在の高レベル放射性廃棄物の処分は，最終的には深い地層への処分という計画になっ

ている。高レベル廃棄物の放射能による危険度は，既存の再処理プロセスではウラン鉱石と大体同じ位になるまでに一万年位かかるため，人間環境から隔離して，その放射性廃棄物の危険の解決を，時間と自然に委ねる方策を取るということである。これまでの経験や知識に基づいた確実な対策としては，こうした方策が選択されることになるということである。だが，一万年というのはいかにも長い年数である。これまでの人類の歴史から考えると，それは気の遠くなるような時間でもある。こうした処分になんとはない抵抗を感じたとしても，それは無理からぬことだといえるのではないか。

高レベル廃棄物を人間環境から隔離して，自然に依存し時間をかけて危険がなくなることを期待するのは，基本的な選択として間違っていないにしても，その時間をもっと縮める方法がないか，少なくとも一桁縮めることはできないか，あるいは数百年のあたりにまで縮めることはできないか，さらに進めて超ウラン元素の消滅処理をすることはできないか。そのような技術的な方策がないかと期待することは，社会的な受容性，パブリック・アクセプタンスといった平和利用の基本線からいって，ごく当然の要求だと考えないわけにはいかない。

これらを含め，原子力を平和利用に専念する立場から，既存の技術体系に不断の吟味を加えることを怠らないようにしなければならない。

第2の視点は，軽水炉時代が当初予想されたのよりも長くなるという現実に立脚し，その後に残されている様々な課題，つまりバックエンドの諸技術なども含め，一層目配りのきいた時間表付きの現実的な開発計画を作りあげる必要が大きくなっているということである。

原子力技術は，これまでいわば二段階に分けて開発されてきた。

第一段階は，ウラン235の利用に力点を置く原子炉の実用化である。この段階はすでに成熟の域に達したといえる。特に平和利用に専念してきた国々は，高い設備利用率で原子炉を運転することができるようになっている。つまり原子力は，ひとまず実用段階に到達しているわけだが，その後に第二段階の開発が残されている。

第二段階とは，高速増殖炉の開発を含む核燃料サイクルの完成である。ところが，この第二段階の成熟には，当初予想されたのよりは相当長い期間がかかりそうな見通しになってきた。

その理由としては色々あげられる。まずウラン資源量の見積りが変化しているというこ

とがある。当初の予想よりは，世界のウラン資源量は，相当大きそうだということがわかってきた。とすれば，ウラン資源のすべてを利用しようという高速増殖炉の実用化をある程度遅らせても，原子力利用には事を欠かないことになる。

実は，高速炉技術を実用段階にまでもっていくには，従来の見通しよりは難しいということもわかってきた。高速炉技術の開発をスローダウンし，あるいはさしあたり高速炉技術の開発は棚上げする国が増えてきている。これはプルトニウムの生産を基礎とした核拡散の可能性に対する一部先発国の強い懸念もまた一つの理由になっているといえるだろう。これは日本にとって難しい時期を迎えたという意味でもある。

日本は資源の極めて少ない技術大国として，高速炉は原子力利用の本命と考える立場にある。だから日本では，商業的な再処理にも積極的に取り組んでいる。他の先発諸国の多くが高速増殖炉計画を中断あるいは遅らせるとすれば，技術先進国として日本がこの第二段階の諸技術の開発に大きな役割を担うということにならざるをえない。これは日本にとっては困難な課題である。

先発国を追いかけ追いつく段階では目標がはっきりしていた。できるだけ早く追いつくことが必要であり，開発のテンポを速めることは，それ自身が望ましいことであった。だが，今では開発のテンポを自身で決めなければならなくなった。先頭を切って走ろうとする国の難しさに初めて直面したといえる。

軽水炉時代が長くなったから，軽水炉自身についても，様々な開発課題を進めなければならない。軽水炉の改良標準化，設計の合理化，建設工期の短縮，購入方法の見直し，品質管理の合理化などを進め，あるいはエレクトロニクスや新素材などの先端技術を活用して軽水炉の寿命を長くし，また定期検査の期間を短縮して設備利用率を高める，また定期検査までの操業期間を延ばすなど，発電コストを下げ経済性を高める課題に一層力を入れなければならない。総発電電力量に占める原子力発電の割合も次第に増えるから，計画的な出力調整も必要になる。その間に生産されるプルトニウムを利用したプルサーマルの発電技術も，実用的なものにしていかなければならない。

そうした第一段階の原子力技術の一層の近代化，高度化への努力にもまして，技術先進国としての日本の第二段階関連の技術開発への努力が，一層強く求められる時期に入っていることを痛感しないわけにはいかない。

軽水炉時代が長くなったということは，第二段階の技術開発について，以前予想されていたよりは長い時間を持つことになったという意味である。

再処理－高速増殖炉路線は日本にとって不可欠なものなのだが，その内容について，持つことができるようなった時間を活かして，より包活的な技術開発の推進が求められているのである。例えば高速増殖炉の燃料の中に，従来は再処理後の廃液中に含まれていた超ウラン元素も含めた混合燃料にし，これらの超ウラン元素の核分裂によって得られるエネルギーも発電に利用し，短い半減期の元素に変えてしまう技術の開発に取り組むことは十分に意義があると思われる。

先発諸国が最初に手掛けた使用済燃料の再処理，すなわちプルトニウムの抽出は，可能な限り高純度のプルトニウム239を取り出し，高性能の核兵器の実現に狙いが絞られていた。それは，濃縮ウランプラントが高濃縮のウランに目標が絞られていたのと同じである。だが，平和利用に使う核燃料はそうではない。ウランといえば低濃縮であり，高速増殖炉の場合も超ウラン元素が含まれていることは何らさしつかえないといえるのではないか。もちろん，それに付随した技術的諸課題が出てくることは予想されるが，人類の超長期の将来に負担を与えなくても済む方策が実現できるならば，それは望ましいことだといえるのではないか。

これらと関連して，第3の視点としては，第1と第2の二つの視点と関連させながら，第二段階すなわち再処理も含むバックエンドについて，考えられるフローの様々なバリエーションを，時間の要素を入れて改めて考え直すことである。再び繰り返しになるが，核保有の先発国でこれまで確立されてきた再処理は，兵器用のプルトニウムの抽出を目的とした技術から出発している。平和利用の立場から見て，それよりもっと賢明な接近法はないかといった疑問を持って当然である。

「群分離」を再処理の過程の中に，僅かな費用超過で付け加える可能性を探求することは，第二段階の技術完成までに得られた時間が多くなっているという観点から十分に意味のあることであり，むしろ必要な研究開発の課題だと考えなければならない。これらを考え合せると，使用済燃料の再処理用のプロセスは，多くの複雑なバリエーションを持ったフローになると思われる。

今では，少なからぬ国が，使用済燃料の直接処分を一つの路線として考えるようになっている。再処理を当面考えない国が増えているということである。日本のように再処理－高速増殖炉路線を不可欠と考える国の場合にも，使用済燃料の全量を直ちに再処理するのか，あるいは一時貯蔵することも必要再処理量という観点から不可避になるのか。高速増

殖炉時代の到来が遅れるとすれば，下北第一工場以降の商業用再処理工場の建設の計画もそれに従って遅れることになるだろうが，再処理工場の処理能力からもまた，一時貯蔵の量が決定されることになる。群分離の過程を含めた改良型再処理のプロセスを開発するという課題も出てくるだろう。群分離のあとでは，現在考えられている高レベル廃棄物処理処分とは違うフローになる。これらの様々なフローの中のどれを基本的な路線とするかは，いわば時間との競争といった性格を持つことになる。

そこで第４の視点として，時間の要素を入れた開発計画を作成することになるのだが，当然のことながら，得られた時間に実現しうる技術進歩をつけ加えて，より高度な燃料サイクルの技術体系を目指さなければならないということになる。時間の要素についていえば，一つは上述の軽水炉の長期化によって得られた時間という要素があるが，もう一つは，高レベル廃棄物のガラス固化から地層への埋め戻し処分までにも，現実に長い時間が予定されている事実にも着目しなければならない。

どの分野の技術であろうと，不断の技術改善が期待されている。これは一つの技術システムを完成したものとして確定しにくくさせるという問題点が伴ってもいる。しかし，少しでも時間が持てるのなら，計画そのものを，その間の技術進歩を入れたシステム設計ができるよう，柔軟性があるものにしておかなければならないと考えるのが当然である。それに今日は，少なくとも先進諸国は，新たな技術革新期に入っていることにも注目しなければならない。それを技術史家は第三次産業革命期と唱えている。18世紀の最後の四分の一世紀に始まった第一次産業革命期，それから100年隔てて電気の技術の出現に特徴付けられる第二次産業革命期が出現した。それが工業化社会の発展・成熟に大きな役割を果した。その後半の段階で人類は原子力技術も手に入れた。そして今、１９７０年代あたりから人類は第三次産業革命期に入った。物質についての技術もエネルギーについての技術も，また新たにつけ加わった情報関連の技術も，大きく発展することが期待されている新しい技術革新期が，この第三次産業革命期である。とすれば，第二段階の原子力技術を完成するために，得られた時間を可能な限り活用するという姿勢を堅持しなければなるまい。技術開発についてむしろ野心的でなければならない時期なのである。

もちろん第５の視点として，第４に挙げた技術進歩の繰り入れは，どの場合でもすでに存在しているシステムとの両立性を，不可欠な前提としなければならない。新たな技術開

発の可能性は常にあるとしても，その実現時期を正確に予定することはできない。ある程度の長期計画を必要とする原子力利用では，差し当たり，確立した技術を前提とせざるをえない。

これは二つの要請があることを差し示すものと理解すべきであろう。一つは，多くの技術者，関係者が従来から長期間努力してきているのだから，新技術の開発計画は，その実績が生かされるように留意したものでなければならないということである。もう一つは，現在の計画は，新たな技術開発が実用化の可能性をもってきた場合，いつでもそれを容易に取り入れることができるような柔軟性を持った内容にしておくことが肝要だということでもある。

以　上

セッション5
軽水炉信頼性向上への努力

＜パネル討論＞

フランス電力庁（ＥＤＦ）副総裁
Ｒ．カール

ソ連原子力発電省第一次官
Ｌ．Ｍ．ワローニン

英国中央電力庁（ＣＥＧＢ）理事
Ｂ．Ｖ．ジョージ

西ドイツ・フィリップスブルク原子力発電会社取締役
Ｈ．Ｊ．シェンク

チェコスロバキア原子力委員会委員長
Ｓ．ハーベル

米国原子力規制委員会（ＮＲＣ）委員
Ｋ．ロジャース

韓国電力公社専務取締役
金　東柱

東京電力㈱常務取締役
池亀　亮

総括コメント：
京都大学名誉教授
柴田俊一

21st JAPAN ATOMIC INDUSTRIAL FORUM

13th to 15th APRIL 1988 — TOKYO

LONG RANGE PROSPECTS FOR LIGHT WATER REACTORS IN FRANCE

by Rémy Carle

Deputy General Manager

ELECTRICITE DE FRANCE

The French nuclear programme is based on pressurized water reactors. On 1st January 1988, thirty four 900 MWe reactors and twelve 1,300 MWe reactors were in service. Eight other units of 1,300 MWe and two of 1450 MWe of the N4 series were under construction.

In 1987, French nuclear power plants produced 251 million kilowatt hours, 70% of France's electricity production. The mean availability in energy terms of the thirty four 900 MWe pressurized water reactors was 80%, for an average age of 6.1 years on 1.1.88. The twelve 1,300 MWe reactors in service, which are much younger (1.9 years on average) had an availability of 70%. All these units appear to be perfectly safe, reliable and economical. The 900 MWe units are used in load following and grid following modes.

The research and development work is oriented in three main directions:

- construction of new reactors;
- improvement of existing reactors;
- definition of the reactors which will replace the existing ones.

The programme for the replacement of conventional power plants by nuclear plants is now finished in France and the rhythm of construction adopted for the new units over the next fifteen years will be determined by electricity requirements. The oldest units in service at present will have to be replaced at the beginning of the next century. Several estimates have been made of the nuclear power to be installed. The diagram indicates the development of nuclear power for a median scenario.

The immediate future: the N4 series

The next reactors to be put into service, at the rate of 1 unit every two years, will be of the N4 series which I presented at the 15th JAIF Conference. This series could comprise about ten units.

The N4 series represents a great advance as regards all the important technological points. For example, the fabrication of the vessels has been improved, and a new steam generator with an axial economizer and using Inconel 690 has been developed. A new turbogenerator has been tested. The control system will make use of the most modern achievements in electronics and computers. Generally speaking, the N4 series embodies all that has been learnt from the TMI accident, particularly as regards the man-machine interface. This improvement involves:

- widescale integration of control and data display facilities, making intensive use of computers,

- a life performance data processing system providing the operator with relevant, easily usable data,
- excellent coordination of operation, maintenance and periodic tests.

The project results in a 5% reduction in the cost per installed kW compared to the 1,300 units. The N4 series can thus be compared to the most advanced PWRs on the drawing board, with the additional advantage that this series is already under construction.

The advanced AFA assembly developed by Framatome uses zircaloy as material for the pin support grid and the instrumentation thimble guides and is accompanied by a gain in the neutron balance. The upper and lower end-pieces are removable, allowing damaged pins to be replaced. Contamination in the primary system is thus reduced.

The good holding power of the cladding allows the burn-up rate to be increased from 33,000 MWj/tonne to 40,000 MWj/tonne, with a uranium enrichment of 4.2%. The best strategy for taking advantage of this is to renew the fuel once a year, replacing a quarter of the core at a time. The annual duration of shutdowns is thus reduced and better use is made of the fuel due to an improvement in the flattening of the flux in the reactor. The saving in the specific consumption of uranium reaches 5%.

The plutonium supplied by La Hague exceeds the current requirements of the fast breeder reactors. Some of the French 900 MWe reactors can take MOX fuel in which 5% plutonium oxide is mixed with depleted uranium oxide. A reload consisting of 16 MOX assemblies was introduced into the Saint Laurent B1 reactor in November 1987. It will be followed by a second one in 1988. Four or five similar reloads are planned every year from 1989 to 1993. This number could increase to ten when the new MELOX factory for the manufacture of MOX fuel, currently under construction, comes into service. We will also study the economic advantages of recycling reprocessed uranium. In 1987 four assemblies using this material were loaded into the Cruas Unit 4, a 900 MWe reactor.

The saving in the amount of natural uranium required to produce the same quantity of electricity is approximately 20% overall as the following table shows.

Year	Reactor Description	Burnup (MWj/tu)	Natural U (t/TWh)
1967	Stainless steel clad fuel as used in the Chooz 300 MW plant	28,500	42.0
1977	17 x 17 fuel with Zirconium cladding and guide thimbles	33,300	24.9
1983	17 x 17 AFA design	34,000	24.4
1987	17 x 17 design	42,000	23.2
1987	17 x 17 AFA design with 30% MOX reloads (recycled once)	34,000	20.2
1995	SSCR – UO_2 PWR + SSCR (Pu) PWR with X1 fuel	45,000 45,000 60,000	17.0 * 10.0 * 22.7 *

* Predicted values.

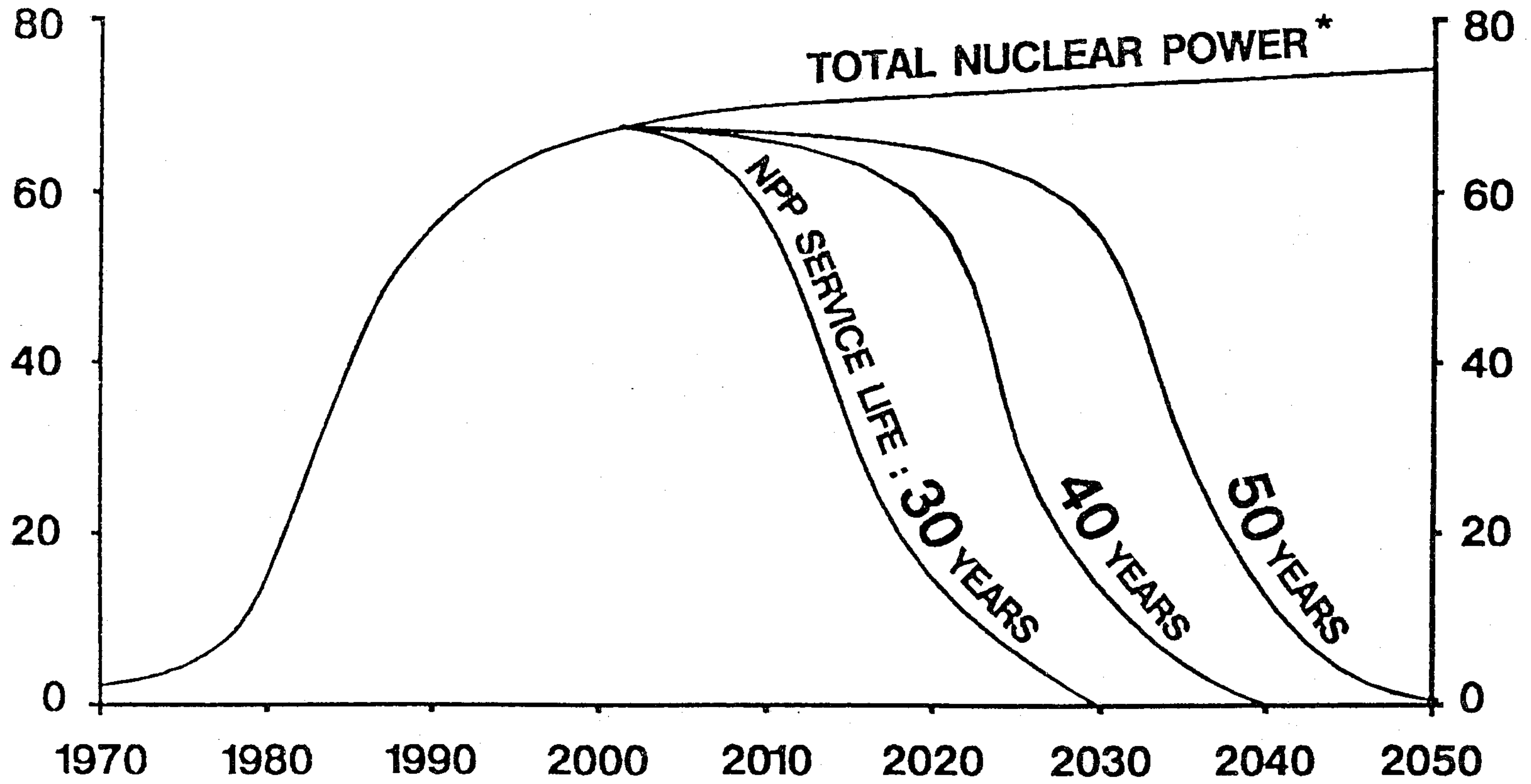
After N4, advanced reactors:

For several years we have been studying the advantages of sub-moderated reactors and spectrum change reactors. The basic studies have been concerned with the core characteristics and their stability as a function of the quantity of plutonium present and of the moderation ratio. We considered using assemblies with uranium enriched to 5%, the Eurodif enrichment limit, and also with MOX fuels. The saving on natural uranium and enrichment work could be as much as 20%. In the coming months the engineering studies will concentrate on the modifications to the operating devices used for the control rod clusters and the rods designed to control the spectrum, the internal upper structures of the reactors and the vessels which are adapted to the devices used to vary the spectrum. Models of the mechanisms have already been constructed.

A parallel study is currently under way on identification of the requirements of the French grid in the next century in order to define the reactor of the year 2000 which will replace the N4. All these studies are geared towards a threefold objective: meeting safety requirements, checking the feasibility of the proposed improvements and quantifying the economic advantages. I have already mentioned the control room developed for N4. The studies are continuing with the aim of defining the areas of application for artificial intelligence techniques and the level of automation of the future plants. The concept of the intrinsically safe reactor has not been adopted. However, the research and development work is being carried on with the purpose of checking that the possibilities of dangerous or unstable configurations have been eliminated, along with those systems known as "intolerant" for which a single failure would be liable to produce unacceptable consequences.

The reactors installed in France at the beginning of the next century will have a lifetime of 30 to 40 years. They will still be in operation beyond the year 2030, at a time when the depletion of world uranium reserves, previously cheap and plentiful, may present a critical problem and it will become necessary to have recourse to fast breeder reactors. Until that time, pressurized water reactors will continue to supply the bulk of France's electricity production.

NEED OF NUCLEAR POWER AFTER THE YEAR 2000
(GW)



*MEDIUM SCENARIO

CONSUMPTION OF NATURAL URANIUM

YEAR	REACTOR DESCRIPTION	BURNUP (MWd/t)	NATURAL U (t/TWh)
1967	STAINLESS STEEL CLAD FUEL (CHOOZ 300 MW PLANT)	28 500	42.0
1977	17 X 17 FUEL WITH ZIRCONIUM CLADDING AND GUIDE THIMBLES	33 300	24.9
1983	17 X 17 AFA DESIGN	34 000	24.4
1987	17 X 17 DESIGN	42 000	23.2
1987	17 X 17 AFA DESIGN WITH 30 % MOX RELOADS	34 000	20.2
1995	SSCR - UO_2	45 000	17.0 *
	PWR + SSCR (Pu)	45 000	10.0 *
	PWR WITH X1 FUEL	60 000	22.7 *

* PREDICTED VALUES

WAYS OF FURTHER IMPROVEMENT OF THE SAFETY AND RELIABILITY OF NUCLEAR POWER STATIONS WITH LIGHT-WATER REACTORS OF BBЭР (PWR) TYPE AND OBJECTIVES OF THE DEVELOPMENT OF INTERNATIONAL COOPERATION IN THIS FIELD

L.M. Voronin

The long-term Energy Programme of the USSR provides not only for the accelerated utilization of economically efficient renewable energy resources, both conventional (hydraulic energy) and non-conventional (geothermal, solar, biological, wind energy), but also for the development of nuclear power engineering the contribution of which is considered as very important.

However dramatic accidents at Three-Mile Island and Chernobyl nuclear power stations have required a new critical analysis of all aspects related to the construction and safety of nuclear power stations.

A thorough study of the causes of the above mentioned and other accidents as well as the implementation of a comprehensive programme to improve the safety of nuclear power stations helped to retain positive attitude towards the development of the nuclear power engineering in the Soviet Union.

Our plans concerning the construction of nuclear power stations have not suffered any significant changes, although certain modifications have been made. All that resulted in a certain slackening in the development of the nuclear power engineering for the nearest future and 25% reduction in commissioning of new nuclear power units planned for the period of 1986-1990.

In 1986 and 1987 7 new nuclear power units with a total capacity of 7.5 million kW were commissioned.

In 1987 the yearly quantity of energy generated by nuclear power stations amounted to 187 billion kW/h which is about 12% of the total quantity of power generated in the country.

By January 1 1988 the installed capacity of nuclear power stations in the USSR was 34.4 million kW. About 50% of the nuclear power stations employ light-water reactors of PWR type. It is planned to increase the total capacity of nuclear power stations by several times by the year of 2000 (the share of power units with light-water reactors will be above 85%).

The long-term plan of the development of nuclear power engineering in the USSR gives preference to nuclear power stations with BBЭP-type (PWR) reactors.

Presently the basic modification of the pressurized water reactor BBЭP is BBЭP-1000. This reactor plant has been employed to design an improved nuclear power station with units of 1 million kW capacity. Major characteristics of a nuclear power unit with pressurized-water reactor BBЭP-1000 are tabulated below.

A nuclear power station with BBЭP-1000 reactors employs the most advanced approaches to the safety of nuclear power stations: two independent reactivity control systems, tight protective containments which confine (localize) radioactive products in case of the maximum accident, anti-seismic equipment and other technical approaches characteristic of power generating units with pressurized water reactors.

Power generating units with ВВЭР-1000 reactors are designed to overcome consequences of various accidents including the maximum design accident which is considered as a spontaneous lateral break in the main coolant piping Dn=850 mm of reactor's primary cooling circuit with two-way coolant escape under conditions of complete deenergizing of the power grid and seismic effects. Nuclear power units with ВВЭР-1000 reactors incorporate safety systems the arrangement of which is based on the principle of three completely independent systems, or channels, every one of which has a 100% capacity in terms of protection functions (i.e. the structure 3x100% is used). Channels of safety systems have independent power supply sources, diesel generators with a capacity of 5600 kW and independent cooling water sources, spray ponds the capacity of which is sufficient for continuous removal of residual heat from the reactor.

Technical approaches to the safety system of a power unit with ВВЭР-1000 reactor are aimed at their high functional reliability. Thus under any emergency conditions which bring into action the safety systems remote control of the safety system will be inhibited to exclude erroneous actions of the operator. Remote control inhibition will be cancelled only upon completion of the functions of this or that machinery (for example: inhibition for remote tripping of sprincler pump will be withdrawn automatically after pressure drop within the containment). To simplify the circuit and ensure a high reliability of the power supply of safety systems, provisions are made in the discussed design of a nuclear power station for standardized loading of reliable power supply diesel generators independently of the type and character of the accident. Due to this approach the programme of stage-wise diesel generator starting can be most simple and reliable, and control of water supply to the primary or secondary circuit or for other protective functions can be excercized automatically by means of automatic actuation of respective valves, pump, etc., depending on the specific pattern of emergency conditions.

Safety systems of BBЭP-1000-based nuclear power stations can be controlled both from the main and stand-by control boards. The stand-by control board can provide control and maintain the reactor and the entire power unit in safety even in case of a failure of the main control board of the nuclear power station. Provisions of the design of BBЭP-1000 power unit actually correspond to Basic Principles of the Safety of Nuclear Power Stations formulated in the report of International Consultative Group on nuclear safety (see IAEA report, JNSAG -3, No 75, Safety series, February, 1988). As we know, similar approaches are being implemented in power units with pressurized water reactors constructed in other countries.

Much effort is also given to minimize exposure doses of personal and environment in the course of operation of a nuclear power station.

Nuclear power stations with ВВЭР-1000 reactors employ primary coolant cleaning system based on high-temperature mechanical filters. Filters are installed on main coolant pump bypass of every of the 4 loops and operate under operating conditions of the primary circuit.

The total capacity of the cleaning system is 4x125=500 m3/h; the filters can handle in an hour a volume of coolant equal to 1.5 volumes of the primary circuit. Granulated sponge-metal titan with grain size 0.5 to 1.5 mm and bulk weight of 1.4 kg/dm3 is used as sorbent.

Experience accumulated in the course of operation of Zaporozhskaya nuclear power station indicates that the high-temperature filters keep a high purity of the core surface whereas the concentration of radionuclides of corrosion origin, for example cobalt 60, in the coolant of operating reactor is much lower than the rated value.

The use of high-temperature filters for coolant cleaning improved radiation conditions during maintenance and inspection operations and reduced thereby the total exposure dose of the power station's personnel. Thus, for example, at Zaporozhskaya nuclear power station the collective exposure dose of personnel operating presently four ВВЭР-1000 units does not exceed the level of 250 rem/year.

The design of a power unit with ВВЭР-1000 incorporates an automatic process control system which is very important in terms of power station's reliability and safety as well as in accident consequence confining.

The automatic process control system covers all systems and equipments of a power unit.

The above mentioned automatic system performs the following functions:

- data acquisition and primary processing;
- data representation on colour graphic monitors in unit control rooms;
- recording of parameters and events under normal operating and emergency conditions;
- computation of nuclear-physical and process parameters and technical and economic characteristics;
- data exchange with station-service computer centre and other subsystems.

Beside these conventional functions the automatic process control system performs the following diagnostic functions:

- automatic realtime identification of emergencies at the power unit;
- group signalling;
- diagnostics of mismatch between the status of actuators and commands issued by the major protections and interlockings;
- periodic automatic centralized testing of control systems of safeguards and and protections of vital equipment.

The first two of the above mentioned functions provide operator with information on the controlled process in a compact and easily comprehensible form.

The second two functions help to maintain automatic control of the vital machinery and safeguards at a high availability level.

A continuous automatic monitoring of conditions of protections and interlockings facilittates timely duplications and necessary maintenance of control circuits i.e. helps to maintain safguards of a nuclear power station permanently in working order and available for operation.

The possibility of diagnostics of individual control channels combined with dialog operation make this function of the automatic process control system especially useful for commissioning or maintenance operations.

As noted above, a set of measures has been developed proceeding from the results of analysis of the serious accidents at Chernobyl NPS, Three-Mile Island NPS and other stations in order to improve the safety of all types of nuclear power stations. These measures were reported by Soviet experts in detail to International conference on indices and safety of nuclear power engineering in Vienna which took place between September 28 and October 2 1987 under the sponsorship of IAEA.

As regards nuclear power units with light-water reactors (PWR type), it should be noted that their safety level corresponds to international requirements, but nevertheless all safety provisions at operating, designed, and constructed nuclear power stations wre analyzed critically anew and a set of safety-improving measures was outlined to be implemented at operating nuclear power stations and at power stations under construction.

The top priorites included measures taken to improve shell resistance to brittle failure (due to elimination of the possibility of comparatively cold water's contact with reactor shell surface and due to reduction of neutron flux to the shell).

It is planned to improve further the nuclear and physical characteristics of ВВЭР-1000 reactor's core and changeover to a higher enrichment, 4.4% instead of 3.3%, which eliminates positive reactivity effects under all operating conditions.

It has been found necessary to improve the efficiency of mechanical reactivity control elements (for fuaranteed suppression of reactivity temperature effect with the help of control rod system elements at coolant temperature drop below 100°C).

Additional provisions have been implemented to improve safety under conditions of minor and medium coolant leaks. An additional hydrogen removal circuit has been provided to remove hydrogen which may accumulate under reactor's roof and in headers of steam generators. First-generation nuclear power stations with ВВЭР-440 reactors are being outfitted with additional passive and active core cooling systems and other additional measure are taken as discussed in the USSR report*.

*)USSR Report: Accident at Chernobyl NPS, a year after. IAEA-C-48/63. Vienna, September 28 - October 2, 1987.

The development and implementations of measures to reduce probability of fuel damaging in the course of accidents is considered very important by the USSR experts.

Thus we have started to implement closed passive circuits for removal of residual heat from the core which reliable prevent nuclear fuel from being damaged for a period not less than 24 hours under conditions of long-time deenergizing of all power sources of the nuclear power station.

The system is based on an air heat exchanger with steam and condensate connections with the steam generator. The heat exchanger removes heat produced by steam condensation into atmospheric air. Under normal operating conditions the system consisting of such heat exchangers is in a wait state and operates under disturbed normal operation conditions accompanied by complete deenergizing. This system can be also used, if required, under emergency conditions without loss of power supply to safety system channels.

In view of possible ambient temperature variations between $-30^{o}C$ and -40^{o}, to exclude spontaneous cooling, provisions are made to control air flow passing through the heat exchanger. This control will be effectuated with the help of special gate valves. To exclude system's freezing in winter, provisions are made for heating up with minimum steam flows. For higher reliability the system is arranged with 100% redundancy.

All nuclear power stations are outfitted with diagnostic/ monitoring systems to monitor the conditions of equipment, piping, and availability of machinery of systems vital for safety.

Beside the above provisions aimed at reduction of the probability of fuel damaging at nuclear power stations with ВВЭР-1000 reactors, system are being developed to ensure the safety of a nuclear power station even in case of heavy accidents when the fuel is damaged. In this case the melt should be reliably confined within the containment.

To avoid excessive pressure rise within the containment, a passive hydrogen post-combustion system to burn hydrogen produced in accidents accompanied by fuel damage will be provided as well as devices for controlled removal of steam/gas medium from the containment via special filters.

Presently a new generation of nuclear power stations with pressurized water reactors is being designed in the USSR. The design features a higher safety and takes into account the following unfavourable failure combinations:

- control rod system failure when its action is required;
- failure of forced coolant circulation through the core or a part of the core;
- long-time deenergizing of all power sources of the nuclear power station;
- complete failure of heat removal from the primary coolant via normal operation systems;
- loss of primary coolant under conditions of long-time denergizing.

New concepts of the so-called ultimately safe reactors are being developed.

The requirements to the nuclear power engineering are much higher than those for conventional power projects.

The top priority is the absolute safety of operation of nuclear power stations.

The accumulated experience indicates that the development of nuclear power engineering requires a proper organization of this complicated industry. The USSR is implementing a comprehensive programme aimed at improvement of design, construction, and operation of nuclear power stations. The programme incorporates provisions for personnel training, strict control at all stages of construction of nuclear power stations and improved management of the nuclear power industry. For this purpose the Ministry of Nuclear Power Industry was formed in the USSR in 1986 and the State Committee for Supervision and Control of Nuclear Power Engineering was reorganized.

Safety problems of nuclear power stations are common for all countries developing the nuclear power engineering. Therefore combined effort and knowledge of experts from different countries could contribute to a faster and more efficient solution of all problems related to the development of a general approach to aspects of further improvement of safety in nuclear power engineering.

To create a new generation of nuclear power stations it necessary and expedient to promote international cooperation which could take advantage of experience in research and development of equipment for nuclear power stations accumulated in different countries. We believe that nations should combine their efforts first of all in the study of heavy accidents at nuclear power stations with pressurized water reactors in order to issue standard international recomendations aimed at improvement of technical approaches and systems which ensure the maximum safety of nuclear power stations.

The USSR, being one of the IAEA constitutors, is continously and actively participating in wide-range and useful activities including the implementation of decisions concerning the establishment of international regulations for the safe development of the nuclear power engineering. The USSR was one of the first countries to ratify the Convention on Fast Warning about Nuclear accidents and the Convention on Assistance in Case of Nuclear Accident or Emergency Radiation Conditions at a Nuclear Power Station.

The Soviet Union takes part in the international nuclear information system. Soviet representatives are active in the International consultative group of experts developing conceptual principles of safety in nuclear power engineering and take part in operation of the international information system of incidents at nuclear power stations. The USSR has decided to enter the World Association of Nuclear Power Producing Organizations.

A close and fruitful cooperation in the field of safety in nuclear power engineering has been established between the member-countries of the Council for Mutual Economic assistance (CMEA).

The USSR cooperates on a bilateral basis with 34 countries including the USA (probabilistic safety analysis), FRG (structure strength, monitoring systems, decontamination of equipment, etc.) and with a number of companies and organizations of Great Britain, France, and other western countries.

Finally, I would like to conclude that the nuclear power engineering has a great potential to provide humanity with electric power and heat.

A successful implementation of the programme of improvement of the existing nuclear power stations and development of new prototypes of reactor plants will render feasible the solutions of problems related to the safe progress of the nuclear power engineering.

Basic specifications of updated nuclear power unit with ВВЭР-1000 reactor

Reactor thermal power, MW	3000-3200
Dimensions and weight of reactor shell:	
length, mm	10,900
diameter, mm	5260
weight, t	325
Number of circulation loops, pcs	4
Quantity of main coolant pumps, pcs	4
Coolant pressure in the primary circuit, MPa	15.9
Coolant temperature at reactor inlet and outlet, °C	289/322
Quantity of steam generators, pcs	4
Saturated steam pressure in steam generators, MPa	6.3
Total steam output of all steam generators, t/h	5880
Dimensions of the reactor core, mm:	
diameter	3160
height	3530
Quantity of fuel-rod assemblies in the core, pcs	163
Quantity of fuel rods in one fuel-rod assembly, pcs	310
Material of fuel rod shell	zirconium and niobium alloy
Quantity of poison rod assemblies of the control rod system, pcs	121

Efficient core operation time between refuellings, h	7000
Quantity of core refuellings during an operating period	3
Quantity of uranium dioxide loaded into the core, t	74.1
Nuclear fuel burn-up rate,	40,000
Make-up fuel enrichment, %	4.4
Power consumption by unit auxiliaries, %	5.5
Unit operating conditions	base-load and flexible

LWR PROGRAMME OF THE UK

Brian V. George
Project and Technical Director
Central Electricity Generating Board
United Kingdom

(Slide 1)

Introduction

Early last year, after a long Public Inquiry, the various authorisations were given allowing the construction of Sizewell 'B' PWR Power Station to go ahead.

We have just heard that the public inquiry for the next station, Hinkley 'C' will start in October of this year. Also later this year we intend to apply for consent for Britain's third PWR power station. Before I describe our strategy in more detail, I will describe the development to date.

Sizewell 'B'

The NSSS itself is the proven Westinghouse four loop design, with an output of 3425 MW(th). The layout is based on the SNUPPS plants built at Wolf Creek and Callaway.

(Slide 2)

Changes have obviously been required to bring the design in line with UK standards and operating practice. These include changes to reflect the difference in the electrical frequency, from 60Hz in the USA to 50Hz here, the provision of two turbines of 660 MW, as opposed to the American practice of a large single unit, and modifications to adapt the SNUPPS design for use on a station located on the coast.

Changes from the basic SNUPPS design have also been required to meet the very stringent UK safety criteria. The area where UK safety regulations have had most effect is the auxiliary systems.

(Slide 3)

Our design safety guidelines require that the overall probability of an unacceptable release of radioactivity is less than 10^{-6} per year. This has generally resulted in 4 way redundancy for equipment necessary for hot shutdown. For frequent faults (defined as greater than 10^{-3} per year) the common-mode failure criteria demand that diverse as well as redundant systems will be required to meet this target. I will now take you through one example of the practical implications of our reliability targets -the reactor shutdown system.

(Slide 4)

Sizewell 'B', in common with international PWRs of the same size, has a control system based on 53 control rod assemblies which fall under gravity on a trip signal. On Sizewell 'B', however, two diverse reactor protection systems - primary and secondary - are provided to trip the control assemblies and to actuate the emergency safety features (including cooling and containment isolation). Either system can interrupt the power supply to the control assemblies causing them to fall. In both cases a 2 out of 4 logic system is employed.

(Slide 5)

Notwithstanding this, a diverse method of shutdown - the Emergency Boration System - has been engineered on Sizewell 'B'. If failure of the control rod assemblies to insert is detected, the EBS injects 7000 ppm boric acid into the system, using the pressure difference between the reactor coolant pump outlet and inlet. Four systems are provided - one to each loop. The system will still work even with loss of off-site power supplies, due to the run down characteristics of the pumps. It can be automatically or manually initiated to mitigate the consequences of failure to insert control assemblies following reactor trip to limit "return to power" following steam line breaks.

JAPANVISIT/BVG

Even with these diverse and redundant means of trip, we have additional protection, an inherent characteristic of the PWR is that it has a negative temperature coefficient. This means that power reduces if the fuel and reactor coolant temperature increases. We expect to show that the reaction will shut itself down without exceeding pressure boundary failure parameters.

(Slide 6)
An important factor in determining the overall risk from Nuclear Power Stations is human error. It must be demonstrated that the possibility of human error will not significantly affect the overall reliability of the safety functions. Much work has been carried out on the design of the control room itself to ensure its ease of operation from an ergonomic point of view to minimise the chance of incorrect action and maximise the chance of correct action.

Instrumentation and alarm systems are designed to minimise the possibility of operator confusion or error. Where necessary and practicable, features will be incorporated into the design to prevent potentially unsafe incorrect operator action. Such features consist, for example, of interlocks which prevent particular actions or disconnect certain controls until a defined series of actions has been carried out.

To this end, a full scale mock-up has been built.

We carry out our own development work where the need is identified to ensure that equipment of high quality is specified. A major problem on
(Slide 7) all types of process plant is the correct operation of valves. Because of this the CEGB has set up three test rigs at their research laboratories in Marchwood, Southampton to test potential candidate valves.

This slide shows one of the rigs.

JAPANVISIT/BVG

(Slide 8)

The increasing complexity of design of nuclear power stations has been matched, by the demanding requirements of quality assurance standards. In the UK, compliance with British Standards has resulted in the establishment of a QA programme which covers design through to decommissioning to provide adequate assurance of quality.

(Slide 9)

The reactor pressure vessel is subjected to an extensive programme of non-destructive examination to ensure it is free from defects of structural concern and to confirm that the necessary high quality has been achieved. In addition to the suppliers manual ultrasonic inspections automated ultrasonic inspections are carried out on behalf of the CEGB on both base materials and on welds at several stages of manufacture. Following the hydrostatic test a further automated inspection is also carried out utilising the in-service inspection equipment.

The overall programme involves detection and sizing of defects by redundant and diverse techniques thereby ensuring high reliability of inspection. All the ultrasonic inspections are independently validated. This programme is an important part of our strategy to demonstrate that components whose failure is assumed to be incredible will not affect the overall risk targets.

(Slide 10)

Follow-on Stations

Although it is still early days to judge the outcome of such a major project, the progress of work to date is obviously a very welcome and hopeful indicator of future progress. However, it is not just Sizewell which will concern us, but also a number of follow-on stations.

JAPANVISIT/BVG

New generating capacity is needed on the CEGB's system for two main reasons: to replace old plant and to satisfy an increasing demand.

This slide which shows a breakdown of the CEGBs generating capacity as a function of fuel type and one way in which this 'plant mix' might be changed with time.

To have this capacity available by the year 2000 requires that the application for consent for the last of these units be made no later than about the end of 1990; given this time scale there is no practical alternative to that of replicating Sizewell 'B'. In fact we have applied for planning permission for Hinkley Point 'C'. A Public Inquiry is scheduled to start on 4 October 1988.

Some changes will be required - the most obvious perhaps being those resulting from different site conditions and local hazards.

(Slide 11)

A method of maximising the cost advantages of replication would be to build two identical stations on one site, where this is possible.

Building two stations of the same type identical in all respects on the same site clearly has a number of operational advantages. These include:

- common spares holdings
- access to a single simulator - so that operating staff are capable of switching from one half of the site to the other without further training
- shared maintenance staff
- shared maintenance equipment

The first opportunity to do this in the UK will occur at Sizewell, where it is planned to build a further station as part of the family of follow on stations.

JAPANVISIT/BVG

(Slide 12)

Second Generation PWR

Assuming that Sizewell 'B' and the follow-on stations are built to cost and time and that they operate satisfactorily, there are still incentives to design and build a second generation of PWRs.

These are:

- Reduced generating costs
- Operating flexibility
- Increased Safety

(Slide 13)

International Cooperation

International cooperation would be put to best effect where cost savings can be achieved or improvements made in the technical database by the exchange of information.

One area likely to be the focus of international attention is concern over the effects of low level radiation. There is currently a range of differing opinions worldwide regarding these effects, for example whether low level radiation can cause leukaemia in young children. This focus of attention will apply both to worker exposure and exposure of the general population.

Feedback from the experience of the large numbers of staff in the world's LWR utilities in a variety of exposure types, rates and total doses would provide a good data base for future studies.

JAPANVISIT/BVG

Another area of interest is computer code development. There is of course already significant involvement from many countries in the assessment of codes such as TRAC PF1/MOD1 and RELAP5/MOD2 through ICAP (International Code Assessment and Applications Programme). This programme has revealed strengths and weaknesses in these codes. Generally the codes used for licensing purposes (such as NOTRUMP or WCOBRA-TRAC) date from the early 1970's and are simplified models giving bounding conditions.

Thus the emphasis is likely to change to the development of these codes, also with significant involvement from many countries. In some instances this will involve manpower or financial contributions, in others it may involve output of the kind received from experiments such as the LOFT reactor at the Idaho National Engineering Laboratories in recent years.

As you are all aware there is a well developed series of networks for operating experience feedback including for example, UNIPEDE, OECD, IAEA and EPRI. As a result we have found, in general, that operational experience is readily available from a large number of nuclear reactors.

This willingness to cooperate, which has been shown by utilities worldwide, makes a significant contribution to improving the safety and performance of nuclear reactors. There may be scope to further strengthen these links in the future.

It is also possible that exchanges of information could be used to establish methods of minimising construction times.

Information exchange of this kind could improve the performance of LWR's both in construction and operation and would promote even higher standards of safety. International cooperation will also assist in demonstrating to the public that the benefits of nuclear power far outweigh the risks.

JAPANVISIT/BVG

Presentation for the Panel Session by H.J.Schenk, F.R.G. April 1988

Present and Future Endeavours in Germany to Improve the Safety and Reliability of LWRs

Mister Chairman, Ladies and Gentlemen,

First of all I would like to thank the organizers of this conference who have honoured me again with the invitation to participate in this panel discussion group. It is a pleasure for me to be in Japan and join your annual conference.

The topic of our discussion should cover efforts for further increase in reliability of LWRs.

I like to start with the status of reliability and safety of the nuclear power plants in Germany and then I will describe our efforts for further improvements.

A: Present Characteristics of Plant Reliability and Safety.

At the end of March '88, there were 12 PWRs, 7 BWRs and 1 THTR in operation with a total capacity of more than 21 000 MWe (Fig. 1).

The first of three Konvoi units was handed over to the utility for commercial operation at the beginning of April. The construction time from the German equivalent of "rock inspection" to commercial operation was 61 months which is far shorter than for previous plants and could be achieved partially due to improvements in German licensing procedure since 1980.

Electricity production by nuclear power plants has grown very rapidly. Over 15 years, from 1970 to 1985 the average annual growth rate was 22 %. Nuclear energy accounted for 36.6 % of total electricity production in 1987 (Fig. 2).

In four German utilities nuclear power makes up more than 65 % of their production. Therefore some units have been operating in the "load follow operation mode" for several years. The possibility of frequency control has also been successfully demonstrated.

The time availability of nuclear power plants continues to be high (Fig. 3). The average for the past 3 years was about 86 % (85 % for PWRs and 88 % for BWRs).

...

In 1987 the average capacity factor was about 79 %. This lower value was mainly caused by the "load follow operation mode" in several plants. The plants Mülheim Kärlich (PWR) and the gas-cooled THTR are not included in this data as they have been in operation for less than one year.

About 9-13 % of annual down time are accounted for by refuelling and annual inspection, approximately 1 % is due to malfunctions. We experienced about 1 scram per plant and year. The number of additional shutdowns caused by malfunctions amounts to about 1-2 per year and plant (Fig. 4).

About 2 % of the additional shutdowns (Fig. 5) were caused by electrical defects and about 3 % by mechanical defects.

In the next three figures the safety status of the plants is characterized by some typical values:

First, the number of incidents to report to the Authority in 1987 was about 17 per plant. None of these had high safety related importance. There was no serious accident in our nuclear plants (Fig. 6).

The average release rates of radioactivity was very low in recent years (Fig. 7). As an example the 1350 MW PWR in Philippsburg (KKP II) released 20 Ci of noble gases and less than 1 m Ci of Iodine in the year 1987. The licensed limits are 30 000 Ci/a noble gases. This is a clear indication of the high quality of fuel elements, the tightness of the pressure systems and of the filter systems.

The annual radiation exposure of the operating personnel has been drastically reduced to about 50 manrem per year in newer plants by optimization of water chemistry, employment of lower Co-base alloys and plant design for easy maintenance and repair(Fig. 8). In KKP II the annual personnel exposure was 39 manrem in 1987, the 3rd year of operation.

We are confident that such low figures can be maintained in the future and will be realized in the Konvoi plants as well.

The higher values for the BWR plants are due to the fact that Co-alloys have so far not been eliminated and that the feedwater is not pumped through a filter system in some BWR plants completely.

To conclude this short report on plant reliability I would like to point out the main reason for the high safety and reliability status of our plants, as I see them (Fig. 9):

Our plants are designed taking into account a broad spectrum of design accidents according to the defence-in-depth principle and using many failure-tolerant features. The degree of automation is determined by:

- the requirement that safety actions of the operators should not be nesseccary during the first 30 minutes following an accident and - the requirement to ensure a reliable operation of complex components by the operator even in case of defects.

High quality of components is assured by stringent quality control during the manufacturing process and by repeated in-service inspection (ISI) during the lifetime of the plants. The qualification of the operators is an important factor also.

Good accessibility to components facilitate maintenance and repair as well as ISI work. Our PWRs are designed in a way which allows the exchange of heavy components easily. By an optimized chemical treatment we have reduced personnel exposure values and the corrosion rate in the components considerably.

B: Further Improvements of Plant Safety and Reliability.

Although the Safety status of our nuclear plants is very high, and this is confirmed by the licensing authorities, the discussion of possibilities for a further reduction of the risk of hypothetical severe accident is going on (Fig. 10).

The probability of a severe core meltdown accident is acceptably low, even taking into account only the safety systems to prevent such a severe accident. Therefore, the use of all available systems to cope with an accident was up to now not included in the training of operators and not described in procedures in the past.

Some time ago it was decided to prepare accident management (A.M.) procedures for an effective use of all systems available in case of an accident with failed safety systems.

Accident management procedures have to consider the different events leading to severe accidents. It is also necessary to distinguish between measures available early enough to cope with severe accidents and measures which only mitigate the results of severe accidents.

In the course of this discussion, it turned out that with a few, but particular additional systems the effectiveness of accident management measures would be much higher and complete. It was therefore decided to install some new components.

Before I give some examples of such new installation, I would like to describe the logic diagramm the operator has to follow in case of a plant accident (Fig. 11).

If the operator is successful in identifying the type of accident, the plant is brought into the long-term safe condition by means of event-oriented procedures according to step-by-step programs contained in the operating manual.

In case an accident cannot clearly be associated with one of the above-mentioned event-oriented procedures, then the operator has to follow the symptom-oriented procedures.

If, for example, one or more plant parameters assigned to safety objectives run outside their limits, they have to be brought back into the safe range by taking symptom-oriented measures, thus ensuring that the plant is put into the long term safe condition.

If the safety goals cannot be fulfilled with symptom-oriented procedures because of failed safety systems, then accident management procedures have to be taken to fulfill safety goals by utilizing relevant possibilities of the plant.

In this case, it will be considered permissible:

- to select configurations and operating modes which have not been scheduled originally for plant operation,

- to intervene in engineered safety features (e.g. in the reactor protection system) and

- to ensure that the main safety goals, i.e. to keep the fuel cooled and to maintain the containment integrity, are fulfilled. In order to achieve such goals, it may be unavoidable to start the depressurization of the containment using a special filter system.

The detailed conditions for accident management measures are derived from realistic assumptions for system effectiveness and best-estimate analyses of accidents into core meltdown events.

In order to explain this concept some examples of accident measures presently under discussion are briefly described (Fig. 12):

In our plants we have a highly redundant back-up emergency power supply

- Auxiliary power from the Turbine Generator

- Auxiliary power from at least two independent grids

- two independant emergency diesel sets of 4 diesels each.

In addition, we are preparing possibilities which enable us to stop a station blackout after 2 hours at least and to enable long-term residual heat to be removed.

Battery power supply required for providing the necessary information, communications and emergency lighting must be ensured continously as a supporting measure. This measure is an indispensable prerequisite for all further A.M. actions in case of station blackout. Solutions for this problem are

- battery capacity for at least 2-3 hours,

- switching off unnecessary consumers,

- possibility of external supply.

A further additional measure to prevent a severe accident is the possibility of A.M. procedures for primary side "bleed and feed".

In PWR's secondary side "bleed and feed" will be initiated in case of total failure of the nuclear feedwater systems while the primary system is intact in order to prevent the high pressure core meltdown path.

Steam generator feed has to start within 1.6 h in case of failure of the regular feedwater supply.

The "bleed" is performed by the following manual actions

- depressurization of two steam generators via the preheating pipes by blowing into the feedwater tank (up to ca. 6 bar).

- blowdown via the steam generator blowdown control valves to reduce pressure in the steam generator below feedwater tank pressure.

Feeding is done by injecting feedwater out of the pressure charged feedwater tank (max. 350 m^3) into the free-blown steam generator. By maintaining the feed for nearly 4 h, the decay heat will be removed out of the primary system.

After depressurization of the feedwater tank the further feedwater supply can be provided by mobile pumps, for example by fire fighting pumps which can inject water out of additional water resources via flexible hoses into the feedwater supply system.

For all events with an intact primary system the secondary bleed and feed is sufficient to prevent high pressure core meltdown. This shows that the secondary bleed and feed is of absolute priority to us, although the necessary measures are rather complicated, numerous have to be performed within a time of between 45 min and 1 h only.

In PWRs primary side bleed and feed measures have to be taken in case of a small leak in the primary system and an additional failure of those systems or system functions respectively which are necessary to cope with such an accident. The prevention of a high pressure core meltdown can be achieved in such extreme cases with primary bleed and feed.

For example the depressurization of the primary system has to be initiated in less than 1 h depending on the dimension of the leak in case of

- failure of the automatic 100 °C/h shutdown system

- failure of the pressurizer spraying system

- unavailability of the steam generator heat sink

- unavailability of the high pressure safety injection system

The objective is to reduce the pressure in the primary system below the coolant injection pressure of the high pressure injection system, the accumulator injection pressure or the low pressure injection system in order to be able to use their water inventory and to keep the primary system at a sufficiently low pressure. We think that additional feed measures, such as the injection of water directly to the primary system, are not required as long as the accumulator inventory is able to cool the core with water until power supply and/or the low-pressure safety injection systems are available again. In several of our PWR nuclear power plants, primary-side bleed and feed measures will be possible by retrofitting additional pilot lines for the individual pressurizer valves only. If it is not possible to stop the course of a severe accident, procedures should be on hand to mitigate the consequences of the accident (Fig. 13).

If progress of core meltdown cannot be stopped, the energy of the molten core will produce a pressure rise in the containment. The pressure design limit of the containment will be reached after approximately 4-5 days.

In order to preserve containment integrity, depressurization should be made possible. A valve system could be used for discharging the steam/air/hydrogen mixture of the containment atmosphere through a filter unit to the vent stack. The retention factor for aerosols is in a range of 99.9 %. The filter equipment will be available at the plants and could be coupled on demand, or will be installed permanently. The system is designed to reduce the pressure in the containment vessel to half of the design pressure within 2 days. The compensation of the water loss in the containment should be provided. Such depressurization measures have been realized already or are under construction.

As a second example I would like to mention the inertization of the BWR-containment with nitrogen. This was decided as a permanent measure in our BWRs because of the fast production of hydrogen by a core meltdown.

This hydrogen problem probably does not require any additional measures in our PWR containments because of their size and their design. Nevertheless, different possibilities to solve this problem, for example by electrical ignition devices in the containment or by catalytic materials in contact with the containment atmosphere have been investigated.

After this description of the accident management measures I would like to make some remarks on development trends for nuclear power plants (Fig. 14).

The improvement of LWR economy continues to be an important goal. In Germany we are trying to reach it by the development of high burn-up fuel and reprocessing. In addition, the further development of the high temperature reactor will be important.

Very important also, I think, are further improvements in failure tolerant features of the safety-related components in nuclear plants. In this connection, possible improvements in the man-machine interface should be mentioned. In highly complex automatic systems, the possibility to control the system by an operator, has to be maintained in case of defects in the system. There is still ample potential for applications of computers in nuclear plants.

In Germany a number of monitoring systems have been developed to detect faults in the plant at a very early stage so that severe damage can be avoided. Examples are the "Loose part monitoring system", the "Vibration monitoring system" and the "Leak monitoring system". (See Nuclear Engineering International March 1988). The fatigue monitoring system is designed to monitor on-line events and transients during plant operation and the resulting structural loads induced by thermal and pressure loads thus indicating to what degree design margins have been used up by plant operation. Extension of plant lifetime is possible by on-line monitoring of design margins, preventive maintenance as well as exchange of components.

With respect to development trends for the future (Fig. 15) the following can be said: a realistic possibility for higher economy could be the high conversion reactor, which is presently being developed. Basic feasibility of this new reactor system is expected to be demonstrated in the near future. There is an interest in reactor systems for special applications such as small and inherent safe systems for heat production and last but not least in the usage of intelligent computers in connection with digitalized I&C. Certainly, the further reduction of the risk of severe accidents will remain in the center of discussion on safety and reliability of nuclear power plants in Germany.

Fig1

Capacity of nuclear plants in Germany at the end of March 1988

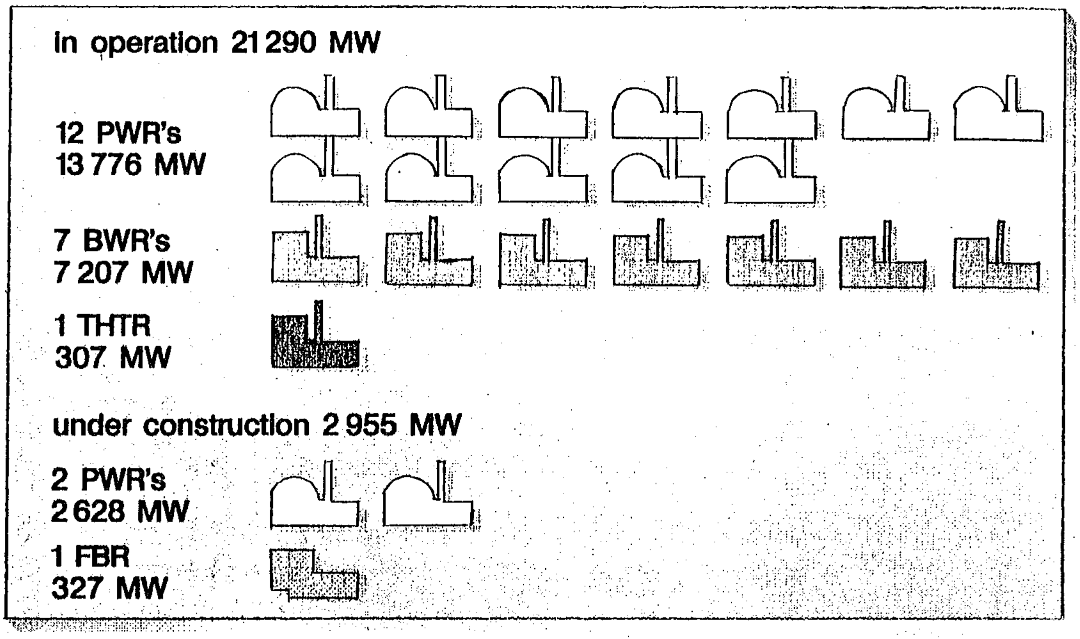


Fig2

Electricity production by nuclear power plants in Germany

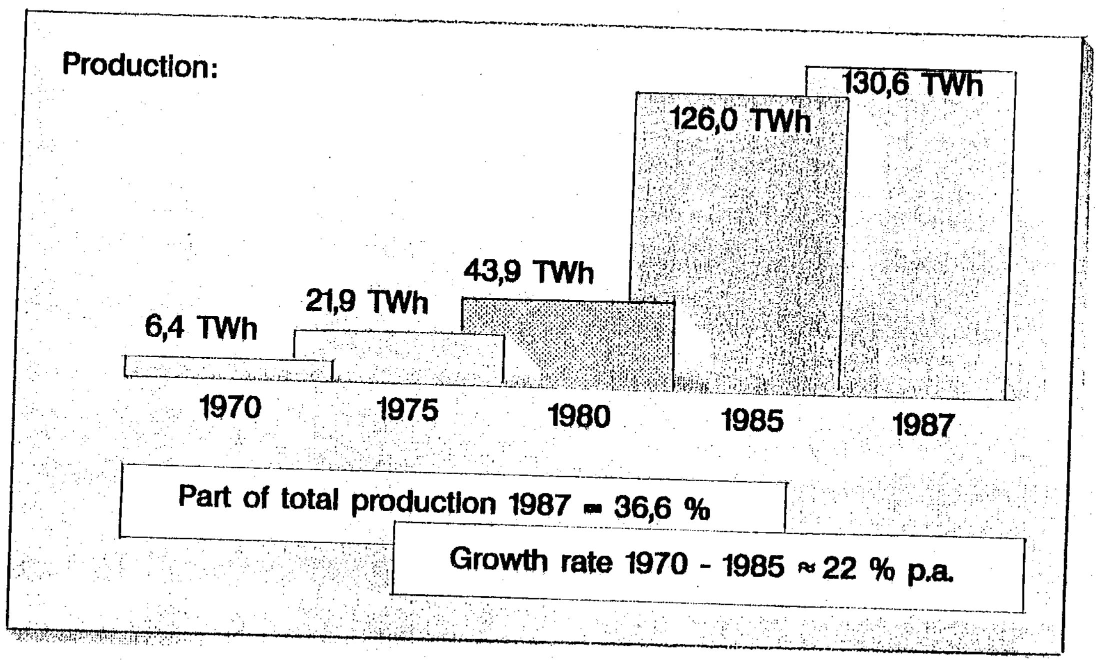


Fig 3

Time availabilities of NPPs in 1985 - 1987

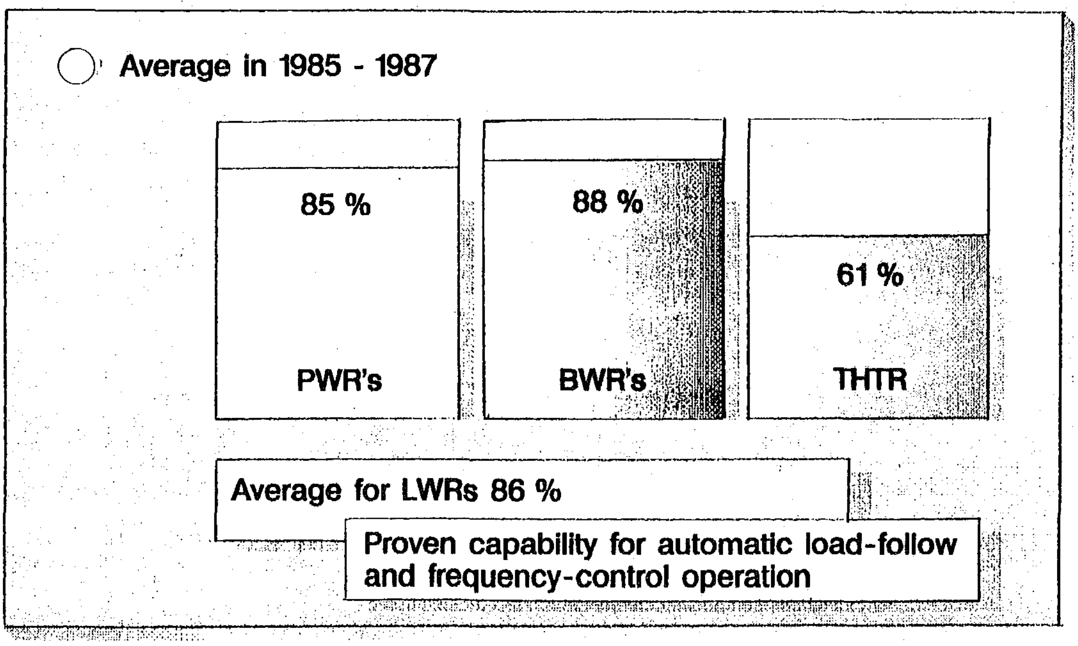


Fig 4

Main groups of non-availability

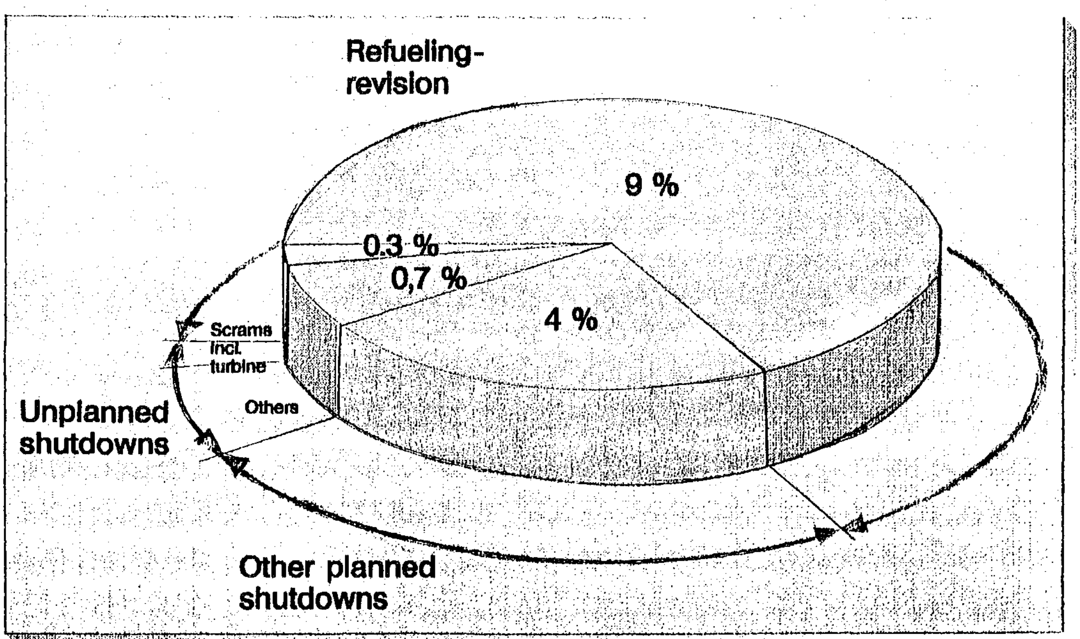


Fig 5

Main reasons for non-availability

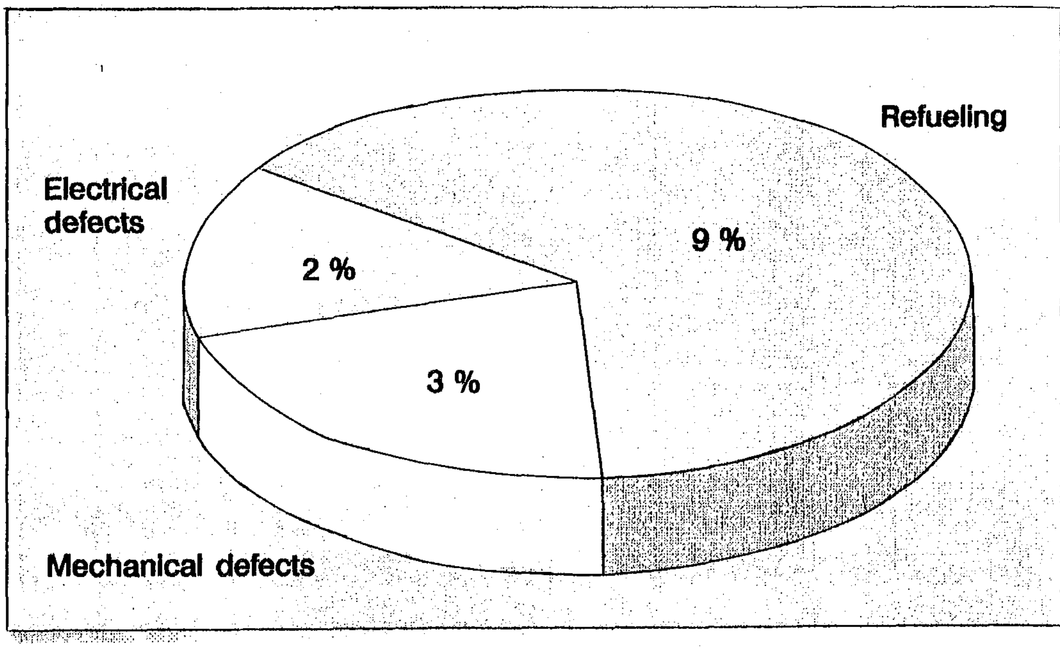


Fig 6

Number of incidents to report 1986

Cat.	Notification	Countermeasures	%
1	Immediate	Safety	0
2	Interim	Check safety	3
3	Normal	Operational	95
4	During construction	Before fuel loading	2

Fig7

Average release rates of radioactivity (1982-1986)

Gaseous release	PWR	BWR
rare gases	210 Ci/a	320 Ci/a
Jodine	0.6 m Ci/a	7,3 m Ci/a
Aerosols	1,7 m Ci/a	7,5 m Ci/a
Liquid release		
exc. Tritium	61 m Ci/a	58 m Ci/a
Tritium	328 m Ci/a	24 m Ci/a

Fig8

Typical radiation dose in a 1300 MW plant

for PWR:	in total	50 manrem/year
	during refueling	45 manrem/year
for BWR:	in total	150 manrem/year
	during refueling	75 manrem/year

Fig 9

Main reasons for the safety and reliability of the plants

- ○ Broad spectrum of design accidents
- ○ Defence in depth design
- ○ Failure tolerant features
- ○ High quality
- ○ Good accessibility of components
- ○ Good possibility for repair or exchange components
- ○ Optimized chemical treatment
- ○ Reliable man-machine interface
- ○ Experienced, well trained operators
- ○ Application of current experiences

Fig 10

Accident-Management (AM) to reduce the risk of severe accidents

- ○ Preparation of AM-procedures for an effective use of available systems
- ○ Additive measures to cope with severe accidents
- ○ Additive measures to mitigate severe accidents

Fig 11

Emergency-procedure guidelines

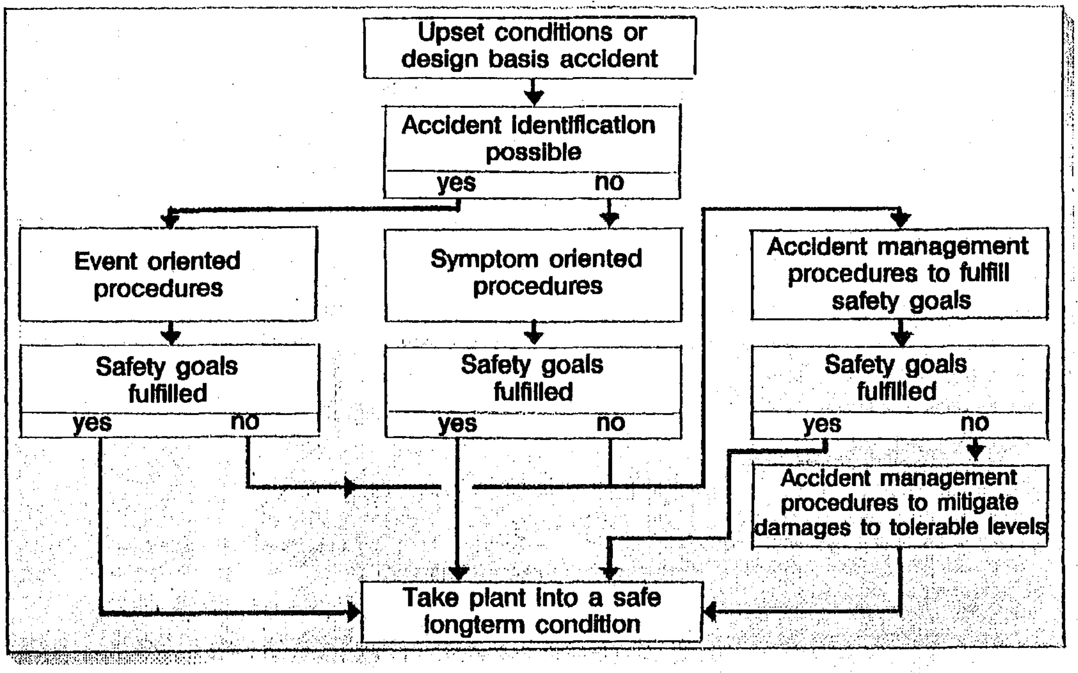


Fig 12

Examples of additional measures to cope with severe accidents

- Measures to reduce duration of station black out
- Measures to avoid loss of battery supply
- Feed and bleed (Secondary, Primary)

Fig13

Examples of additional measures to mitigate the consequences of severe accidents

- Possibility to depressurise the containment using a special filter system
- Inertisation of BWR-containments
- Hydrogen combustion in PWR's

Fig14

Current developments for NPP

- High burn up fuel elements
- Improvements in fault-tolerant features
- Improvements in man-machine interface and computer usage
- Consequent aging control
- Extension of plant lifetime
- Reduction of radioactive waste

Fig15

Development trends for the future

- Further reduction of the risk of severe accidents
- Use of artificial intelligence
- High conversion reactor
- Reactor systems for heat production

ANALYSIS OF SOME SAFETY AND RELIABILITY CHARACTERISTICS OF CZECHOSLOVAK NUCLEAR POWER PLANTS

S. H a v e l

Chairman, Czechoslovak Atomic Energy Commision Prague, Czechoslovakia

1. THE NUCLEAR POWER DEVELOPMENT IN THE CSSR

Structural changes in the utilization of energy sources in Czechoslovakia are characterized by a marked decrease of the consumption of liquid fuel and coal and by an increase in the consumption of gaseous fuel and production of nuclear power. This development is not only owing to economy but it is also an ecological necessity. The costs of the coal mining are growing and the quality of the coal deteriorates so that large emission of sulphur dioxide should be expected when burnt under common conditions.

Czechoslovakia is therefore oriented on intensive construction of nuclear power plants (NPPs) which are now used mainly for covering the growing demands of electricity. In the near future the nuclear sources will supply a growing amount of heat into centralized district heating networks. The development till 2005 is shown in Figure 1.

Figure 1: Production of electricity and heat from nuclear sources in Czechoslovakia till 2005.

The development of nuclear power in Czechoslovakia is based on the construction and operation of the Soviet PWR-reactors-VVER. At present 8 VVER-440 (440 MW(e)) units are in operation at two sites (Jaslovske Bohunice and Dukovany), 4 others VVER-440 are now under construction (NPP Mochovce). They should be put into operation stepwise by 1992. Thus the development of the 440 $MW_{(e)}$ units should be finished und the alternate 1000 $MW_{(e)}$ units will be constructed. The construction of 4 VVER-1000 units was started since 1984 at the site of NPP Temelin, which should go into operation stepwise from about 1992 to 1998. Two other sites have been selected for 2xVVER 1000 with expected construction start after 2000.

On the basis of Soviet documentations the Czechoslovak manufacturers are producing heavy components of NPPs (in accordence with the CSSR standards) such as reactor pressure vessels with internal structures and safety systems, primary circuit pipes, steam generators and pressurizers, turbogenerators and other secondary circuit components. Part of them are exported to some other countries, empolying the VVER NPPs.

The fuel assemblies are delivered by the USSR and the spent fuel is returned to the USSR after several years cooling-period. Only special equipments are imported and assemblied under the supervision of the suppliers' experts (mainly from the USSR). The portion of foreign deliveries decreased from 41 % for the first two VVER-440 to 16 % for the other units of the same power. It should decrease to about 10 % for the VVER-1000 NPPs. - Start-up, operation and maintenance are carried out by Czechoslovak organizations. (1)

2. SAFETY OPERATION INDICATORS OF THE VVER 440 UNITS

All VVER 440s' have six loops, isolation valves on each loop, horizontal steam generators, rack and pinion type control rod drives, hexagonal fuel assemblies containing

126 fuel rods and hermeticaly sealed low inertia pumps. Each steam generator produces 450 t/h steam 4,6 MPa and they are supplying 2x220 MWe steam turbines. The average core power is rather low, i.e. 84 $kW.l^{-1}$, what gives this reactor a fairly high DNBR (departure from nucleate boiling ratio) of the value of about 2.

The gross electric efficiency depending on the temperature of water in the cooling towers ranges within 30 - 32 %. The selfconsumption of electricity produced at the NPP was about 7,6 %; as a result of rationalization this value was decreased within last year by about 1 %.

The VVER 440 NPPs are used in the national grids in the base load.

The indicators of the Czechoslovak NPPs operated for more than 1 year, expressed by the most common used coefficients, i.e. the load factor (LF) and the time utilization factor (TUF) for individual years, are shown in Figures 2 and 3. (1)

Figure 2: Load factors of the Czechoslovak VVER-440 NPPs
Figure 3: Time utilization factor of the Czechoslovak VVER 440 NPPs

The mean value of the load factor of all VVER 440 units during the period from the start of commercial operation by the end of 1986 (i.e. reactors operated more or at least 1 year) equals to 0,75. Accordingly is the time utilization factor of these reactors 0,82. Both these figures prove a good level of the reliability of the Czechoslovak VVER 440 NPPs. (2)

The load factors are highly affected by planned outages for periodic inspections and potential repairs, which are performed simultaneously with refuelling operations. The programme of planned periodic inspections encompasses mainly the in-service inspection of some 80 parts of primary and secondary circuit equipments with the periodicity differing from 1 year (exceptionaly) to 4, 5, 6 and 8 years. As an example the pressure vessel inspection can be introduced, with a basic four-years check-up cycle: every year 1/3 of inserted fuel is to be replaced by a "fresh portion", the rest being restructured according to the needs of neutron flux adjustment. This outage time is 49 days and it covers some 5000 NDT and in-service operations. Each fourth year the so called "extended periodic inspection" takes place with a planned outage of 84 days, when not only all fuel assemblies but also all the internal structures are to be removed and after about 9000 NDt and inspection operations again reassembled.

Table 1 shows standardized time-requirements (in days) for operations performed during planned periodic inspections (PPI) and extended periodic inspections (EPI) on equipments of the primary circuit of the VVER-440 (1). These figures are in general about twofold higher compared to planned outage times for Westeuropean PWRs because of higher extent of the tests' being performed. Thus the mean yearly losts of the production were up to now about 14 %.

Table 1: Standardized time requirements (in days) for operations performed during planned periodic inspections on equipments of the primary circuit of the VVER-440

For planned periodic inspections about 90 % of the time requirements scheduled in Table 1 are usualy spent whereas in the case of extended inspections the real time agrees with that scheduled. As also shown in Table 1, a decrease of prescribed time is envisaged for individual operations and thus for the whole inspection as a result of the growth of the skill and experience of the personnel and as a consequence of improved technics, development of sophisticated measuring devices and maintenance equipments etc. (1)

Unplanned outages caused by technical failures, expressed in the percentage of losts of the load factor, reached 3,3 % for the whole period of the VVER-440 NPPs operation. Similar value for losts due to maintenance was 2,7 % what is even lower than the figure foreseen by the CSSR standards (i.e. 3,8 %).

Outages caused by technical failures during operation are assessed and analyzed in details by the so called "Failure committee" established at each operated NPP. These commitees are not only recommending remedial actions, they also have to identify basic causes of each failure. So was for instance found-out in 1986 at the NPP Jaslovske Bohunice that the human factor share on technical failures was about 1 % with equivalent lost of energy output 0,04 % on units I and II. In the same time span the human factor shared 13,3 % on technical failures of units III and IV of the same NPP, with corresponding output losts of 33,4 %. The relevant "failure commitee" found the reason for such a big difference quite easy because it was caused by a repeated repair of a steam generator tube by an outside supplier.

For the same period as mentioned above the human factor share on technical failures on units I and II of the Dukovany NPP was 7,2 % with equivalent energy output lost of 3,2 %. The analysis for the whole period of commercial operation of the four units of the Jaslovske Bohunice NPP led to a conclusion that the human factor share on technical failures did not exceeded 5 %, what is a very favourable value.

Another characteristic used for assessing the operational reliability of Czechoslovak NPPs is the number of scrams of the units during the commercial operation due to the action of so called fast emergency protection systems. Following specified equipment failures or upon violations of setpoints by critical plant parameters, the emergency system responds by reduction of power or by complete shutdown (scram) of the reactor. Depending on the degree of hazard represented by the emergency signal, the emergency system performs its protective functions with various levels of intensity.

Table 2 shows the number of reactor scrams on the commercialy operated VVER-440 units, caused by the action of the fast emergency protection systems; figures in parenthesis show the part of them caused by the secondary circuit. It can be seen that this part is representing more than 65 % of the total.

In most prevalent part of them (94 %) - the protective function of emergency protection systems was preceded by the closing of the fast - acting turbine valves. This logic, common for all VVER-440, is used as a conservative approach to the assurance of units' safety. - As it can be seen from the table, the mean number of reactor scrams due to the action of fast emergency protection systems is about 3,7/year and after 3 years of operation of the units I and II. of the Bohunice NPP this value was about 2/year, what is a very satisfactory figure.

Table 2: Number of emergency scrams of commercialy operated Czechoslovak VVER-440 units.

The results of the operation of the Czechoslovak NPPs characterized by their reliability, preparedness and safety, are fully compareble with the worldwide figures(3). Stabilized realiability figures are achieved already in the 2nd year of commercial operation. The share of individual parts of the stations on failures is very similar to figures reported by other countries for PWRs,i.e.

- primary circuit equipments	15 - 20 %
- secondary circuit equipments	25 - 30 %
- electric equipments, artmatures, pipes	35 - 45 %
- auxiliary heat equipments	15 - 20 %.

Even if the operational results are very positive from the view of reliability, a high attention is paid to questions such as good functioning, service life control and safety indicators of important NPP components. In addition to own internal analysis made by the stations an international experience exchange is assured by active participation in the IAEA Systems PRIS (Power Reactor Information System) and IRS (Incident Reporting System).

3. DATA BASE OF THE VVER-440 NPP OPERATIONAL DATA

An important prerequisite for the assurance of reliability of NPP equipments is a good database of operational data, their evaluation and the feedback of these analysis on the improvement of equipment design, production and operational utilization. A good co-operation is necessary between the producers and operators.

An analytical data base system was formed in the CSSR in early 70's for the classic steam power plants. Using these experience a similar system was established for VVER NPPs (formerly called "Reliability Information System" - SIS, recently inovated as ISIS). ISIS takes fully into consideration the uniform standardized characterization in design documentation, the CSSR standards as well as international recommendations by CMEA, Interatomenergo, IAEA and ISO. The ISIS has a legislative force in the CSSR because there are 14 concerns taking part on the design and production of equipments of NPPs what means about 120 establishments and factories (3,4).

Primary informations from the NPPs encompass

- failures
- defects
- maintenance
- tests of safety systems
- operation and outages of reactor and turboaggregates
- operation and outages of equipment assemblies
- operational loads of the primary circuit components
- operational loads of the turboaggregates
- operational loads of the secondary circuit components
- material chracteristics of important component etc.

The ISIS is now in the development stage; the autonomous subsystems are formed which are interconnected. With view to trends of nuclear power development in the CSSR, the completion and implementation of the fully functioning ISIS is of a big interest and therefore the work on it is highly favoured.

4. LIFE EXPECTANCY OF NPP COMPONENTS ASSESSMENT AND PRELIMINARY STUDY OF NPP LIFE EXTENSION IN CSSR

The conception of residual life expectancy identification of the components of the VVER units is based on these main issues (3):

1) The development and implementation of a computerized data base system (LSIS) of data needed for calculations of the residual life expectancy of the reactor components.

2) The development of methods, algorithms and computer programmes for determining strains, damages and residual life expectancy of NPP components and continual improvement in accordance with further development of scientific findings.

3) Systematic evaluation of residual life expectancy of critical nodal points of selected NPP components, operative evaluation of influence of nontypical operation characteristics on the residual life expectancy and the incidence of material defects.

The question of the data base was already discussed in the previous chapter. The relevant methods, algorithms and computer programmes were developed stepwise. Taking into account the operational conditions of selected NPP components (pipe - networks and the pressure components of the primary and partialy also the secondary circuit), attention is paid to life assessment at low-cycle fatigue, defects' incidence and growth and the atteining of static strength criteria. To enable calculation of this character it is necessary to gain, within others, also figures of the component strains.

Even if it is not easy to have data like these available, some very promissing assessments of this kind were already performed by implementing the specific developed programmes on analysis of important NPP components. As an example an analysis of the main-closing valve body can be introduced, with very high demands on safety and reliability with view to component strain and low-cycle fatigue. Another important excercise was the assessment of the limitation of the wall thickness reduction of heat-exchanger pipes of the WER-440 steam generators. Both these assessments gave important results for the determination of the residual life expectancy. The described methods are laborious, their results give, however, important support for the assessment and assurance of reliability of sensitive NPP components.

The first Czechoslovak VVER-440 units will come to the end of their planned life very shortly after the year 2000. The construction of new fossil power plants is not planned, so the only alternative is to extend the power production on nuclear sources. This means, of ccurse, that not only the lost part of energy due to old plant decommissioning should be covered but the foreseen demand as well. Without the life extension of the first generation of NPPs, the construction of new NPPs should be considerably expanded, to cover CSSR national economy demans. A few variants of the Nuclear Power Programme Development were therefore analysed (5) to assess the impact of Nuclear Power Plant life Extension (NUPLEX) by applying the economic criteria used in the country with "central planning economy".

Three scenarios were analysed in a recent study (5), i.e:

Scenario 1. The decommissioned NPPs should be replaced by new units of a higher capacity.

Scenario 2. After the 25 years of operation, the NPPs of this first generation should be shut down for refurbishment for a period of three years. One extra 1000 MW (VVER-1000) must be available to replace consecutively the capacities of NPPs shut down for refurbishment.

Scenario 3. The 25 years operation period should be extended to 30 years without refurbishment. After these 30 years the refurbishment takes place and another 10-20 years life extension is considered individually for each unit with respect to its technical conditions.

Under specified conditions the flow of expenses and incomes were assessed for each of the above scenario. As the comparative basis the scenario No. 1 was taken and optimization criteria were analyzed for each of the three variant. Differences were chosen between the discounted operational expenses of the basic and the other scenarios.

For the basic scenario the specific investment costs of new plants (i_a^z [crowns/MW]) are the main characteristic, the other two being characterized by the specific cost of refurbishment (i_o^i [crowns/MW]).

Comparative calculations have shown that, in the scenario 2, the shorter life extension (10 years) can be efficient up to the ratio of $i_a^z : i_o^i = 1 : 1,2 - 1,1$; whereas by 20 years life extension this ratio is lower, i.e.: $i_a^z : i_o^i = 1 : 1,2-1,1$. Thus the efficiency of the longer life extension was confirmed. - Similar results were obtained for the comparision of the scenario 3 with the basic variant: The longer the time of life extension, the more effective it is, if-of course - the refurbishment expenses do not increase considerably due to extended operation without refurbishment.

The described study (5) confirmed that the NPP life extension is a way to an effective electricity production that must be seriously considered in the long range planning and relevant support should be given to this programme in the near future.

In the context of the life extension analysis also some assessment were made (6) concerning the refurbishment of obsolete components at the Czechoslovak NPPs. If the foreseen refurbishment is technicaly viable, the economic effectiveness can be assessed by analysing the ratio of specific investment costs of the new plant and the specific investment costs of the refurbishment. Further factors which have to be taken into consideration are - within others- the time of the shut - down and the higher maintenance expenses of the refurbished source, if any. Any assessment of the life extension involves a deep analysis of the technical conditions of the equipment and the determination of the nodal points which could be of the highest importance for such a decission.

Details of the above shown study can be found in the reference (6), here only some results will be short y discussed: Based on the figures given by EPRI (7) the direct and undirect costs of the pressure vessel refurbishment were assed to be about 80 mil. US $ (in US $ 1979-80). For further calculations a 50 % reserve was add to this figure what brounght the total costs to a sum of 123 mil US $. In 1980 cost of an installed kW for a 1000 MW NPP was 1017 US $. kW^{-1}, so the costs of the pressure vessel refuabishment could amount about 12 % of the investment costs. From these about 16 % represents costs of the collective dose, thus with deduction of this part the costs of the refurbishment work itself shoul be roughly equivalent to the costs of a new pressure vessel. Compaired with the figures from the construction of the Jaslovske Bohunice NPP, the costs of the pressure vessel delivery and assembling could be about 9.4 % of the investment costs (or 6,6 % of the total costs).

For the assessment of the steam generator refurbishment no relevant figures were found as in the case of the pressure vessel. Therefore a conservative presumption was made that the replacement of the old steam generator by a new one under "radioactive" conditions could be 10 times more expensive than the analogous operation on the new station. Under these circumstances the costs of the steam generator refurbishment could reach about 3,8 % of the investment costs of a typical VVER-440 (or about 2,7 % of its total costs).

In the case that the pressure vessel should be refurbished and all the six steam generators as well, the costs could amount about 13,8 % of the investment costs of the VVER-440 NPP.

If also all other important nodal systems should be replaced, the costs of such a "complete refurbishment" should reach about 27 - 30 % of the NPP investment costs. In this pesimistic case the specific investment costs of the NPP refurbishment are about 3500 Kčs.kW^{-1} (this gives the ratio i_a^z/i_o^i = 4,286 (6). The costs are acceptable and also in this case the 20 years life plant extention would be economicaly favourable.

5. THE IMPACT OF NPP OPERATION ON THE PERSONNEL AND THE ENVIRONMENT

General trends to decrease the radiation exposure of the personnel during routine work at the NPP is not only a result of recommendations of the ICRP and the effort of the supervisory governmental body to keep the radiation doses as low as reasonably achievable (ALARA), it is also important from the view of economy. At sufficiently low collective doses the highly qualified personnel can be used for some additional work which can be performed without any overexposition of the individuals. In the oposite case some additional personnel is necessary, what can always cause some complications and higher expenses.

The collective dose differs not only with the type of reactor but also in individual countries. Concerning the type of reactors, as a rule the dosis are usualy higher at BWRs compared to PWRs.

On the basis of data collected from different sources a comparison was made of the collective dose equivalents of the personnel related to the produced energy [mSv.GW^{-1}.h^{-1}] on the NPPs with VVERs in different countries (8).

Table 3: Comparison of the mean collective dose equivalents of the personnel related to the produced energy [$mSv.GW^{-1}.h^{-1}$] on the NPPs with VVERs in different countries.

The highest values were reported from the Bulgarian NPP-Kozloduj, the lowest from the Czechoslovak NPP - Jaslovske Bohunice and the Finish NPP - Loviisa, of course, these figures are differing in years. It could be in general expected that the colective dose equivalents would grow with the length of the NPP operation life due to increasing contamination of the internal surfaces and there might be also expected a sizable influence of the maintenance and repair works. On the other side the growth of the skill and experience of the personnel application of remote controled devices etc., can contribute to collective dose equivalent reduction. It can be deducted from the figures in Table 3 that the radiation load of the personnel of the Czechoslovak NPPs with VVER-440 is on the level of the best NPPs worldwide.

Another indicator of the quality of the NPP operation, which is supervized very strongly in the CSSR is the release of radioactive emission into the environment. It can be generaly said that these releases are very low from all operated VVER-440 units (9,1).

For instance in the site of Jaslovske Bohunice where 4 VVER-440 units are in operation the radioactivity release into the environment in 1986 represented 61 TBq in the form of gases, aerosols and low-active water. The comparison of real emission with authorized limits is very positive: so were the real emissions of radioactive noble gases max. 4 % and emissions of radioactive aerosols 0,02-1,3 % of the authorized limits. Mean annual releases of tritium into the hydrosphere from units I and II of the Jaslovske Bohunice NPP achieved 15,7 % of the authorized limit and 60 - 80 % from units III and IV where much stronger limits were designated. The total releases into the hydrosphere from all four units were under 20 % of the authorized limits. The total sum of releases from these units into the environment in 1986 was 42 GBq. For the Dukovany site (where, of course, the last unit was put into operation only in 1987) the total radioactivity emissions were lower. - The achieved levels of this indicator are very satisfactory and they are a good evidence of careful performance and responsible operation of the Czechoslovak VVER-440 units.

6. MANAGEMENT OF RADIOACTIVE WASTE FROM OPERATION OF NPPs WITH VVER

The first Czechoslovak NPP were put into service without being equipped with a comprehensive radioactive waste (RAW) management system. The liquid waste treatment was limited to the concentration through evaporation. The concentrates and spent ion-exchange resins were strored at the NPP site in steel tanks, the solid waste in concrete storage bins. The capacity of tanks was determined for the 5 years's operation of power plant. In the course of this period the Czechoslovak policy of a safe management of RAW from NPP was formed gradually. Great nation-wide importance attached to this problem is well documented by the fact, that it was several times on the agenda of the government, which also decided on ways it will be settled.

The philosophy of the accepted policy is a comprehensive treatment of all RAW types set out to reduce the waste volume and to transform it in an optimum form from the viewpoint of safety during treatment, transport, and final storage of disposal.

The Czechoslovak policy comprizes the following engineering approaches:

- concentrated liquid RAW are solidified by a suitable method right at the power plant site and packaged into 200 l steel drums (bituminization with the application of bitumen or emulsified bitumen; calcination connected with bituminization or cement solidification; cement solidification);

- solid wastes are classified; non-combustible wastes are pressed into drums and combustible wastes are incinerated, ash residues and fly ashes mixed with suitable bonding agent and packaged into drums,

- drums with solid and immobilized liquid waste are temporary stored at the site of NPPs after the regional RAW repositories will be available (now in construction), the drums will be transported in shielded transport containers over there.

The regional repositories which are now in construction are of the shallow-ground type. For the site selection, design, construction, and operation of a repository of this type, the IAEA recommendations were widely accepted. With respect to the location of our NPPs two regional repositories were selected being a part of NPP Dukovany and Mochovce.

Although liquid waste is so far transported in many countries, e.g. in USSR or GDR, a philosophy was adopted in our country, according to which the liquid RAW transport from the NPP to the repository on public communications represents unnecessary hazard and will not be carried out. Rightness of this decision is supported by the last IAEA recommendations eliminating transport of low- and intermediate-level RAW in the liquid form.

Although the technological processes necessary for safe management of RAW from NPP operation are at present available in ČSSR and the respective equipment is manufactured, research and development work on new processes is continuing.

In the region of liquid RAW immobilization which is considered as being the most important, supercalcination and vitrification processes for low- and intermediate-level RAW are under development.

Out of several alternative schemes tested, a process was selected consisting in adding inexpensive glass-forming admixtures (as, e.g. some alumosilicates and silica) in the liquid concentrate, homogenizing and dosing slurry thus formed in a continuous furnace with a direct electrical heating (Joule heat). Nearly the entire process is managed already with the exception of the final operation, where a decision is to be made on the form of the final product.

Project of a plant with a capacity of approximately 1 ton glass a day is expected to be finished within 2 years.

7. CONCLUSION

Experiences and results of the VVER-440 NPP operation are confirming the reliability and safety of the Czechoslovak VVER-440 units. Fairly low frequency of failures did not develop in any case into a danger of potential radioactivity release into the environment. A very important factor of safety was the thermohydralic stability of the reactors of this type. Analysis of the operational experience are used for improvment of the equipment and of the operation itself.

The Czechoslovak nuclear safety policy as applied on the NPPs takes three main determining components as a basis:

- quality of the equipment,
- quality of the personnel,
- quality of the operation.

The safety requirements for all these three items are set down statutory by relevant laws which must be strictly respected. The Czechoslovak Atomic Energy Commission (CsAEC) was authorized to supervise the nuclear safety by a law entred into force in 1984 when the State regulatory body for Nuclear Safety of Nuclear Facilities at the CsAEC was constituted. This State regulatory body for nuclear Safety together with the Public health service and the State technical inspection for safety of work and technical facilities are realizing independent profesional inspections aimed to the main common interest to protect the human health and lifes.

REFERENCES

(1) HAVEL, S. - BERÁNEK, J. - KOZÁK, M. - KEHER J.
"Light water reactors VVER-440 in the CSSR - Characteristics and Safety". Jaderná energie, 34, 1988, No.1,p.1 (in Slovak).

(2) SKJÖLDEBRAND, R. - WHITE, D.
"The IAEA Power Reactor System and its possible use for improving Plant Performance." Proceedings, IAEA Symposium on Nuclear Power Plant Availability, Maintenance and Operation, Munich, 20-23 May 1985, p. 17, IAEA, Vienna, 1985.

(3) KAČMÁRY,Š. - KUBÁNYI, J.
"Reliability of the VVER NPPs." Jaderná energie, 33, 1987, No. 7, p. 247 (in Slovak).

(4) LEICMAN, J.
"Use of the Reliability Information System for Nuclear Power Plant Reliability Improvement". Proceedings, IAEA Symposium on Nuclear Power Plant Availability, Maintenance and Operation, Munich, 20-23 May, 1985, p. 3', IAEA, Vienna, 1985.

(5) NOVÁK, S.
"NPP Life Termination and possibilities of their Life Extension". Jaderná energie, 33, 1987, No.3, p. 81 (in Slovak).

(6) NOVÁK, S.
"NPP's main components replacement for the life extension". Jaderná energie, 33, 1987, No. 6, p. 206 (in Slovak).

(7) "Extended Life operation of Light water reactors: Economic and Technological Review", Vol. 1: Summary. EPRI, NP-2418, June 1982.

(8) NOVÁK, S.
"Comparison of nuclear power plant personnel collective dose equivalent". Jaderná energie, 33, 1987, No. 5, p. 186.

(9) MORÁVEK, J. - BURCLOVÁ, J. - KAPIŠOVSKÝ, V. - PIETRIK, I. - SLÁVIK, O. - ŠTUBŇA, M. - ŠUJAK, P.
"Improvement of the radiation safety of nuclear power plants operation." Jaderná energie, 33, 1987, No. 7, p. 266.

(10) HRON, M. - KRETT, V. - NEUMANN, L. - METKE, E. - POLÁK, V. - HLADKÝ, E.
"Management of Radioactive Waste from operation of Czechoslovak NPPs with VVER Reactors." IAEA International Conference on Nuclear Power Performance and Safety, Vienna, Austria, 28 Sept. - 20. October 1987, IAEA-CN-48/267.

Table 1

Standardized time requirements (in days) for operations performed during planned periodic inspections on equipments of the primary circuit of VVER-440 NPPs

Operation	Time requirements			
	Standard - 1986		Envisaged - 1990	
	PPI	EPI	PPI	EPI
1. Reactor cooldown	4	4	2	2
2. Reactor dismantling	8,5	8,5	8	8
3. Refuelling	19	-	12	-
4. Fuel carry-out	-	12,5	-	10
5. Disassembling of reactor internals	-	4,5	-	3
6. Pressure vessel NDT	-	19	-	16
7. Reassembling of reactor internals	-	4,5	-	4
8. Fuel fill-up	-	12,5	-	10
9. Reactor reassembling	8,5	8,5	8	8
10. Hydrostatic test	4	4	3	3
11. Pressure build-up test	1	2	3	3
12. Start-up	4	4	3	3

Table 2

Number of emergency screms of commercialy operated Czechoslovak VVER-440 units

Unit	year							
	1979	1980	1981	1982	1983	1984	1985	1986
Bohunice I	13(8)	3(3)	3(3)	2(1)	0	2(2)	3(1)	0
Bohunice II		10(6)	5(3)	4(2)	2(0)	2(2)	2(1)	1(1)
Bohunice III							8(2)	4(4)
Bohunice IV							2(1)	1(0)
Dukovany I							8(7)	4(4)
Dukovany II								2(2)

Note: Figures in parenthesis show the part of srams caused by secondary circuit.

Table 3

Comparison of the mean collective dose equivalents of the personnel related to the produced energy $[mSv.W^{-1}.h^{-1}]$ on the NPPs with VVERs in different countries

NPP / years	CSSR Jaslovske Bohunice	Bulgaria Kozlodui	GDR Bruno Leuschner	USSR Novo-voronezh	USSR Kola	Finland Loviisa
1974		0,39	0,22			
1975		1,44	1,85			
1976		0,92	0,52	0,9	1,2	
1977		0,50	0,26	0,6	0,9	0
1978		2,11	0,49	0,8	0,9	0,31
1979	0,018	1,50	0,79	0,8	0,9	0,49
1980	0,25	1,08	0,46	0,6	0,7	1,46
1981	0,32		0,54	0,7	0,1	0,25
1982	0,54					0,26
1983	0,36					0,23
1984	0,17					0,31
1985	1,0					0,16
1986	0,26					

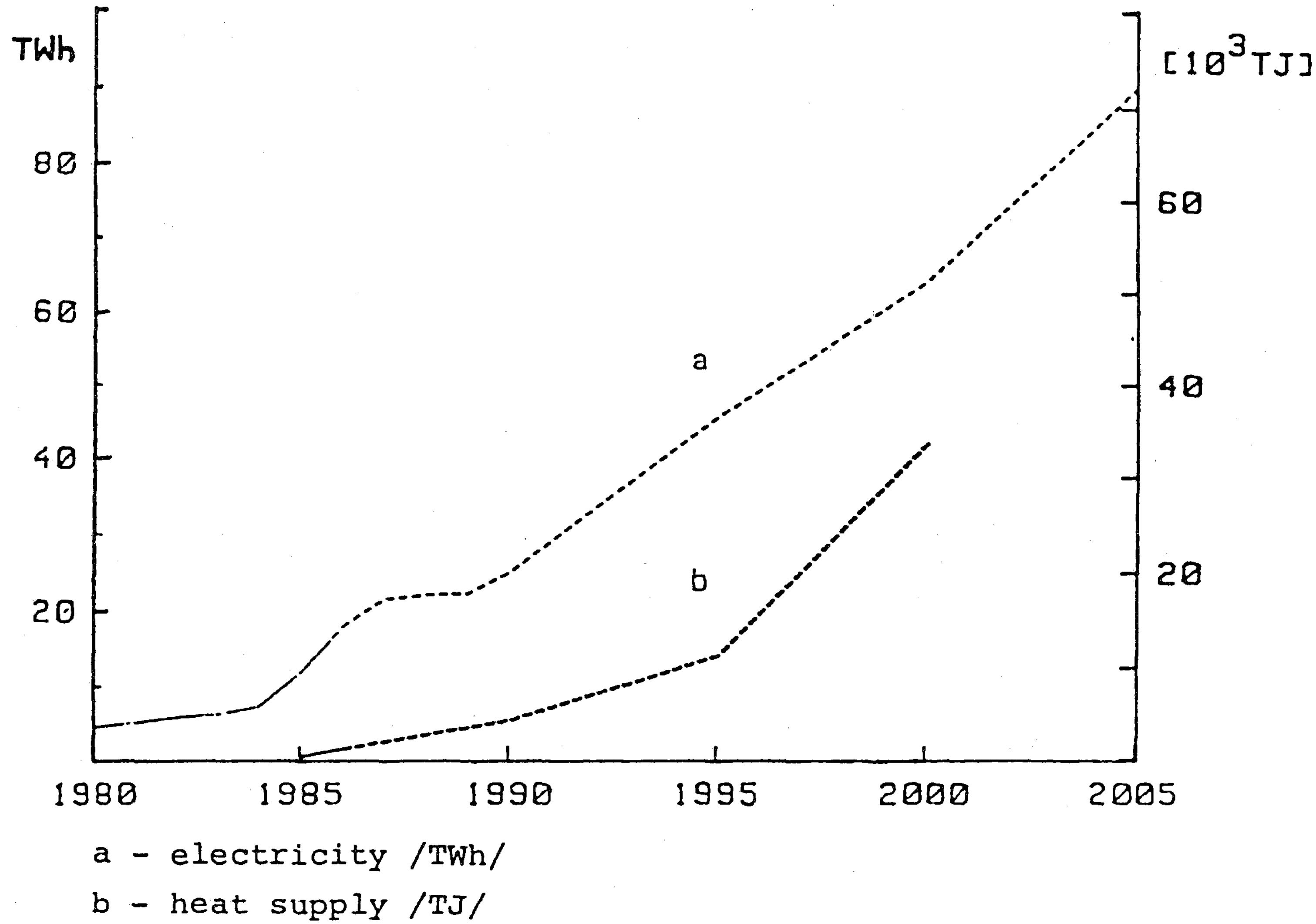


Figure 1 Energy production in nuclear facilities in Czechoslovakia

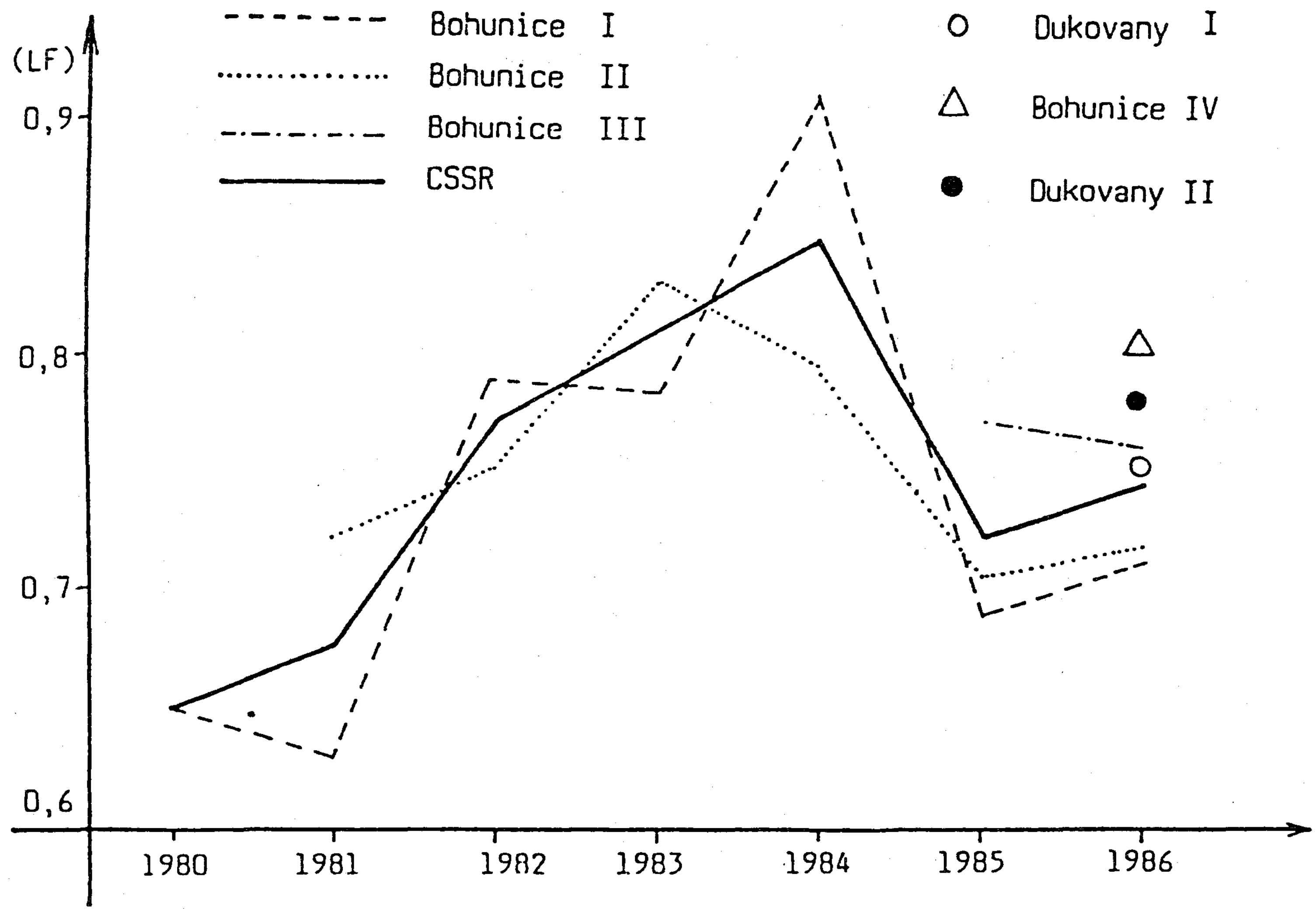


Figure 2 Load factor /LF/ of the Czechoslovak VVER 440 units

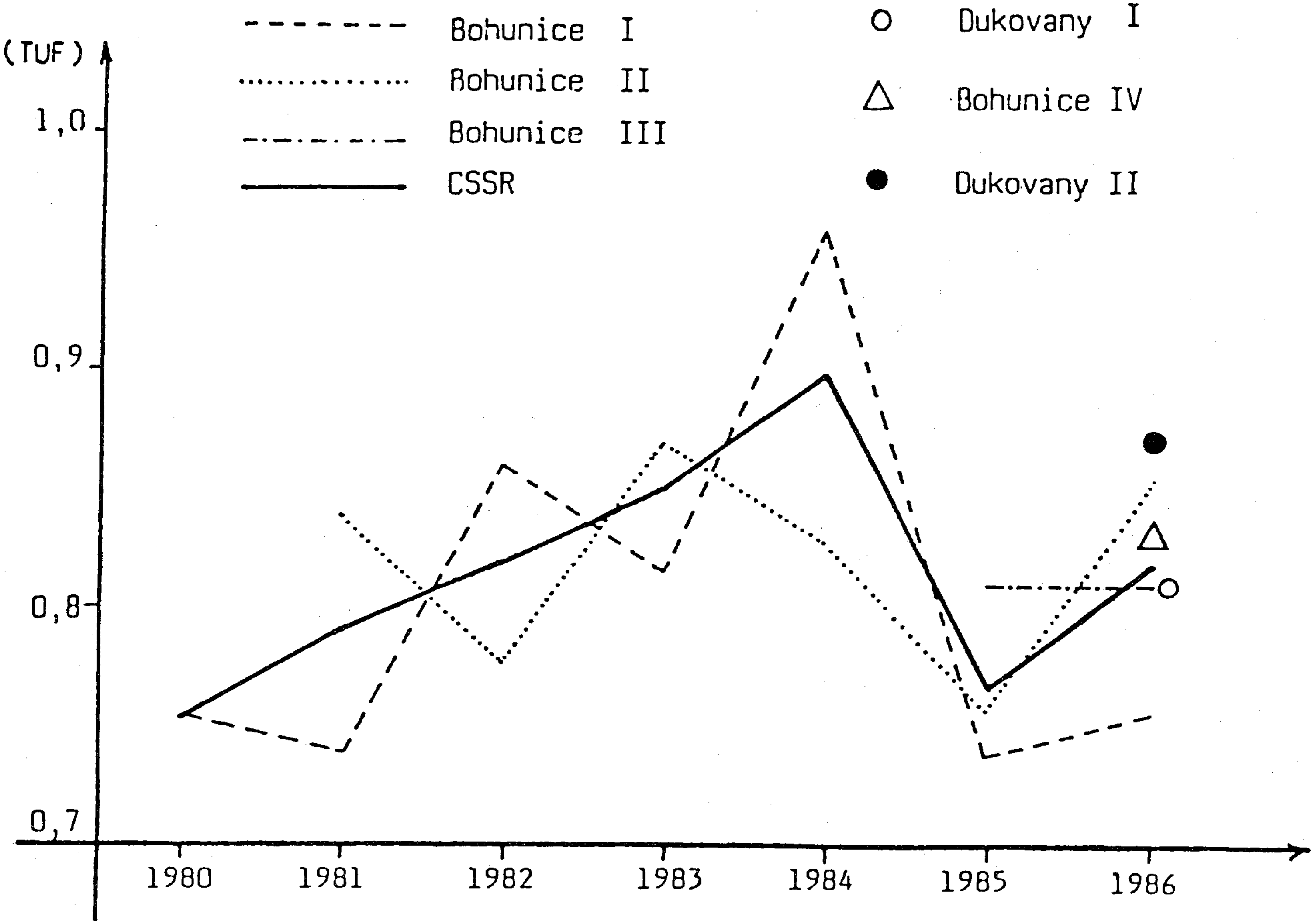


Figure 3 Time utilization factor /TUF/ of the Czechoslovak VVER 440 units

LONG RANGE PROSPECTS AND SHORT RANGE OPPORTUNITIES

Commissioner Kenneth C. Rogers

U.S. Nuclear Regulatory Commission

PRESENTED AT

21ST JAIF ANNUAL MEETING

TOKYO, JAPAN

APRIL 15, 1988

Good afternoon, ladies and gentlemen. It is a pleasure to be with you today and participate in this important international dialogue on nuclear power.

I came to my position as Commissioner less than one year ago after thirty years as a research physicist and engineering educator, chief executive of a technological university, and a member of the Board of Directors of a nuclear utility. While I am new to the world of government regulation, I have been involved quite closely, for a number of years, with nuclear technology and the challenges of operating both pressurized water reactors and boiling water reactors by a commercial electric utility. It is from those vantage points that I project what will be happening in the US in the near term as part of the transition to the next generation of nuclear power plants.

At this time [redacted] there are 110 nuclear power plants licensed for operation in the US, and 9 plants remain under active construction. In 1987, US operating nuclear plants generated 455 thousand giga-watt hours representing 17.7 percent of the electrical generation in the US. Thus, although there are no new orders, there is an inventory of reactors - in fact, the world's largest inventory (approaching a half trillion dollars investment) - which will be operational for several decades. For the longer term, the US has an ongoing development program on Advanced Light Water Reactor (ALWR) designs and continuing research efforts on Liquid Metal Fast Reactors (LMFRs) and Gas Cooled Reactors (GCRs). The US nuclear power situation has both similarities to and distinctions from those of other nuclear countries. The similarities suggest that the US and other nuclear nations may learn from each other's technological initiatives and experiences; the differences relate to the US need to chart a somewhat different regulatory course. Among the important factors which I think will shape the US future are the following:

- The US has very few power plants still under construction and none planned. Thus, regulatory and utility management attention is being devoted to operations. Utility and regulatory attention to the problems of operating reactors will permit improvements and solutions to operational problems that have occurred in the US nuclear program.

- The US has an older nuclear plant inventory, on the average, than does the rest of the world. Whereas nearly two thirds of the power plants in the rest of the world are under 10 years old, in the US, about two thirds are over 10 years old. Thus, the US is now beginning to face problems of aging reactor systems and components, decisions on extending or renewing existing operating licenses, and decisions on decommissioning.

- The US nuclear industry has included several vendors, numerous architect-engineers and engineer constructors, and many utilities. This diversity has resulted in a large number of design variations. We lack the design standardization that some other countries have achieved, and therefore effective regulation is more difficult for us.

- The performance of US nuclear power plants in recent years has lagged behind that of other nations, most notably Japan. However, reviews of a limited number of safety-related performance measures in US reactors for 1984 through 1987 by the Nuclear Regulatory Commission (NRC) and a larger number of general performance indicators by the Institute of Nuclear Power Operations (INPO), show a steady improvement in many measures, including scram rates, safety system actuations and personnel exposures. In addition NRC reports analyzing significant events indicate a downward trend in the number of serious event precursors over the same period. These data and other qualitative measures demonstrate that the overall performance of nuclear plants in the US is improving. These trends must continue. As they do, both the safety and economics of nuclear power plants will improve. The capacity factors achieved in Japanese nuclear power stations are approximately 20 percentage points higher than average US practice. This differential translated to an equivalent electrical capacity would represent a US investment of conservatively $50 billion.

- The US has the good fortune of relatively abundant supplies of a variety of energy resources, including both uranium and fossil fuels. Until now, these indigenous fuel supplies have allowed us to defer long term decisions about nuclear power. Nevertheless, US energy resources are not unlimited; in fact, recent findings of the US Geological Survey suggest that our fossil reserves might be 40 percent less than previously believed. The US may never have to rely heavily on any one resource, but we will soon need to address the question of building or not building a next generation of nuclear power plants. At that time, the option of a nuclear commitment will depend, not only on our resources, but also on environmental, health and safety and economic performance. As electric demand increases, additional pressures for nuclear generation in the US may well develop.

Other speakers in this session have referred to new plants options incorporating advances in technology and operational concepts. Since the US will not be building new plants in the near term, our present regulatory agenda does not emphasize regulatory issues regarding siting approvals, design approvals, and construction inspections. We do, of course, share an interest in efforts mentioned to improve existing reactors. Emphasis on operating reactors will remain the central theme of the US regulatory process.

In describing my view of the evolving US nuclear future, I will address three areas I think important: first, the way US regulatory activity is evolving to meet the requirements of operating reactors; second, the management and operational changes the US industry will need to make, and third, the modifications that could be made to existing reactors to improve their safety and performance. We can draw on both the new ideas developing in nuclear plant design and existing technologies not yet applied to the nuclear industry. Then, finally, I will outline where I see the US going in terms of the next generation of nuclear power plants.

AN EVOLVING REGULATORY APPROACH

The regulatory activities required for the monitoring of day-by-day operations are quite different from those necessary to establish and verify that a plant has been designed and constructed properly. As the immediate future in the US evolves with an almost total emphasis on operations rather than on design and construction, our regulatory reactors practice is changing.

One important element of this change is that the NRC must establish safety performance standards (that is, outcomes) that all licensees understand and are required to meet. Such standards are currently being explored both inside and outside the NRC. Within the NRC the requirements for plant-referenced simulation facilities for licensed operator testing and requalification in new NRC regulations are an example. These requirements represent less prescriptive regulation for utilities with acceptable simulation facilities and training programs accredited by the INPO. The NRC no longer specifies training program content and instructor qualifications. Moreover, operators are now tested, observed, graded, and evaluated by both utility and NRC personnel. NRC judges the INPO accreditation process and criteria to be of high standards; therefore we can satisfy our safety responsibilities by reviewing testing results rather than by prescribing specific training requirements.

Other initiatives are going on outside the NRC. The Massachusetts Institute of Technology (MIT), for example, has examined how the industry might comply with a regulation for loss-of-offsite-power that specifies an expected frequency of core damage rather than specific hardware requirements or allowable outage duration. Such approaches require confidence in the data base and the probabilistic models. If current studies prove positive, they can lead to performance standards that require a common high level of safety, while encouraging innovation which takes into account particular characteristics of the plant. This approach would allow individual licensees to define the most appropriate way to achieve these requirements. NRC could approve the approach, make it part of the license, and hold the licensee accountable for achieving the required outcomes by way of the procedures and plans that they themselves have developed.

The NRC must avoid the pitfall of overly simplistic quantification of licensee performance measures. It is tempting to set up scoring systems and check lists. However, these may generate meaningless numerical ratings in lieu of the essential factor of experienced human judgment. For example, Probabilistic Risk Assessment provides numerical results, but does not take into account the quality of plant management, the single most important factor in achieving performance excellence.

And finally, the NRC must foster a point of view that emphasizes a total systems concern. The greatest overall safety sometimes requires balancing competing special technical requirements and then making the best systems engineering judgment. Optimal overall balance may require accepting suboptimal performance for certain components of the system, viewed in isolation. Thus, the rendering of systems level judgments can be misinterpreted or misconstrued by those whose area of special concern cannot be totally satisfied if the safest possible overall situation is to be achieved.

This systems approach is particularly evident in the severe accident area. Following the Three Mile Island Accident in 1979, the NRC initiated a major effort to review existing US plant designs and establish possible risks to the public. These efforts have led, over the years, to numerous changes in NRC regulation, and recently, to the Commission's Severe Accident Policy Statement in 1985, subsequent policy implementation plan in 1986, and the Commission's Safety Goals in 1986. These initiatives have been guided by the agency's Severe Accident Research Plan (NUREG-0900), and supporting program elements such as the Source Term Reassessment Effort (NUREG-0956) and the Reactor Risk Reference Document (NUREG-1150) issued in draft form in February 1987. The final version of NUREG-1150, scheduled for Commission consideration later in 1988, is expected to constitute a key technical base and methodology for implementation of Commission severe accident and safety goal policies. The Commission intends to require its utility licensees to examine their plants in accordance with its Severe Accident Policy statement within an Individual Plant Examination (IPE) program using either an Industry Degraded Core (IDCOR) methodology approved by the NRC or conventional state of the art probabilistic risk assessment techniques. The IPE program is scheduled to begin this year and extend for an approximate two to three year period. This systems level review will identify possible risk contributors for each plant so that eventually all plants can be modified if necessary to conform to the Commission's Safety Goals. At the conclusion of this program we expect to finally achieve closure of the severe accident issues.

KEY AREAS FOR INDUSTRY EMPHASIS

The safe operation of a nuclear plant requires a management commitment at the highest levels, a disciplined and thoroughly professional approach, a carefully constructed and competently staffed organization, and continuous training of all key players. The importance of the managerial contribution to safety and what that contribution must include, are emphasized in the final draft of the IAEA International Safety Advisory Group (INSAG) document, "Basic Safety Principles for Nuclear Power Plants," which was released a few weeks ago. I'd like to quote some of their key observations:

> The phrase 'safety culture' refers to a very general matter, the personal dedication and accountability of all individuals engaged in any activity which has a bearing on the safety of nuclear power plants. The starting point for the necessary full attention to safety matters is with the senior management of all organizations concerned. Policies are established and implemented which ensure correct practices, with the recognition that their importance lies not just in the practices themselves, but also in the environment of safety consciousness which they create. Clear lines of responsibility and communication are established; sound procedures are developed; strict adherence to these procedures is demanded; internal reviews are performed of safety related activities; above all, staff training and education emphasize the reasons behind the safety practices established, together with the consequences for safety of shortfalls in personal performance.

In addition, the INSAG report concludes:

> Open attitudes are required in such staff to ensure that information relevant to plant safety is freely communicated; when errors of practice are committed, their admission is particularly encouraged. By these means, an all pervading safety thinking is achieved, allowing an inherently questioning attitude, the prevention of complacency, a commitment to excellence, and the fostering of both personal accountability and corporate self-regulation in safety matters.

In the US, recognition of these truths will require significant organizational changes in some utilities. A nuclear power plant cannot be treated as just another electricity generator in the utility's inventory. Recent actions within the industry indicate that this fact is generally becoming recognized. Greater responsibility for nuclear operations will have to move to the very top levels of the management structure. Management at all levels will have to evidence a commitment to the highest standards of excellence and professionalism, an unflagging attention to procedure and detail, and the strictest concern for safety matters. Ultimately such commitments will ensure economic benefits for the utility as well as safety to the general public.

A related area which needs additional industry emphasis is that of maintenance. The NRC has found plant maintenance to be far more critical to overall safety, as well as to achieving high reliability and capacity factors, than we had previously thought. In addition, plant material readiness offers one of the very best measures of overall management effectiveness and commitment to excellence. Lack of a comprehensive maintenance plan is evidence of a lack of in-depth thinking about the plant and a careless attitude towards safety. Good maintenance programs include attention to corrective, predictive, and preventative activities and ways of allocating resources sensibly to each of these.

The NRC is currently developing a new regulatory framework for maintenance. At the same time, US utilities are engaged in a major effort to upgrade their maintenance programs. These efforts are being led by efforts of the utility-sponsored groups, Nuclear Utility Management and Resources

Committee (NUMARC), and INPO, to define good maintenance practices, to develop mechanisms for self assessment, and to provide assistance to individual utilities in developing and assessing their programs. This strong industry initiative may demonstrate that NRC leadership in this area is not required. The existence of 110 different plants in the US requires customization of maintenance procedures and is best addressed through a nonprescriptive, outcome oriented approach to regulation. However, the importance of maintenance is such that if a nonprescriptive approach is taken, then it must be accompanied by strong regulatory oversight and formal rules for measuring outcomes, with penalties for nonperformance.

Another key to safe and reliable plant operations is the routine monitoring and use by the licensee of real-time data on all aspects of plant status, including parameters which provide immediate and continuous information on the current condition and performance of the plant. While the US nuclear power industry does monitor plant status, the use of modern instrumentation, control and information systems technology is limited. Without in any way minimizing the importance of the human being in nuclear operations, or the importance of strict attention to procedures and detail, I do think there is more opportunity for the use of high technology in supporting functions. The introduction of more creative and innovative applications of existing and readily available technology to monitoring and control can significantly enhance safety. Comprehensive monitoring during reactor operation of the acoustical noise and vibration spectra emitted by the plant's components can benefit both safety and availability, by using the information these signals provide about the condition of critical components.

A number of successful uses of such measurements have been achieved. One recent example is that of a utility for which NRC accepted neutron noise measurements as evidence of the condition of thermal shield supports, thus allowing the plant to continue operating until the next scheduled inspection outage. Also, improved monitoring, control, and understanding of the relationship between water chemistry and materials properties can have very important effects on long-term reactor performance and reliability. Finally, more extensive in-situ monitoring of reactor components in-service can help to better identify materials degradation so that action can be taken in a timely manner.

Another change already taking place is a greater emphasis on simulation. Simulation is, of course, valuable for training; it is also becoming more and more useful for diagnosing certain kinds of events and conditions, for generating data for human factors applications, and for testing alternative designs. The capabilities of simulators have improved significantly in recent years, and some utilities will need to upgrade their facilities, to maintain physical and functional fidelity, and to expand the range of situations for which the simulator can be used. In the US some utilities are using their plant simulators to conduct the annual emergency response exercise: this can provide a high degree of plant realism, since accident conditions do not have to be simulated in the main control room while the plant is operating at full power.

OPPORTUNITIES FOR APPLICATIONS OF ADVANCED TECHNOLOGY

Research and development related to improved reactor components, to technological questions connected with plant lifetimes, and to advanced LWR designs can identify useful improvements for incorporation into existing reactors. While, of course, some of the more advanced design concepts represent fundamental changes that could not be introduced directly into an existing system, others might be usable in currently operating reactors.

It is well worth looking at such possibilities to take advantage in the near term of selected advanced technologies and designs which might improve operational safety, reliability or efficiency. Certainly, advanced designs for discrete components or systems ought to be considered whenever an existing component system is to be replaced for any reason. For example, steam generator replacements can take advantage of the higher reliability that is likely to derive from the use of modern developments in materials science and thermo-hydraulics modelling techniques, and replacements for defective valves in the primary system can benefit from new valve designs incorporating advanced materials. Replacements of major elements of control rooms can take advantage of advances in solid state electronics and digital systems, and of advanced computer capabilities, as well as of new knowledge about human factors. The introduction of artificial intelligence and expert systems technology clearly could assist operators and help to prevent human error. Advanced logic systems and boards can be retrofitted to perform better, and automated surveillance of their functionality can be incorporated.

THE NEXT GENERATION

In looking ahead, I see an opportunity for the US to make significant changes in the next generation of plants to correct or reduce some of the problems that have plagued our programs. The most important will be a strong move toward greater standardization and design simplification. The US program has suffered particularly because of the multiplicity of reactor designs in use. The NRC is presently developing policies and rules appropriate for the review and licensing of standardized designs.

I believe there will be far fewer design variations in the next generation of US reactors than there have been in the past. Beyond those designs, advanced reactors may be smaller in size and therefore able to incorporate passive safety features. There are fairly clear safety advantages to having systems that do not depend as much on mechanical components or human performance.

Another significant change likely in advanced designs is a move toward modularity. Modularity appears to have several advantages, which include greater opportunities for factory fabrication of systems, control of construction costs, improved quality of construction, and easier regulatory oversight of these activities. Modularity also enables the utilities to match their growth in capacity more closely to the growth in demand.

SUMMARY AND CONCLUSION

In conclusion, I see the US, in common with other nations, engaging in a variety of management, regulatory, and facility improvements in the near term to improve and sustain the nuclear option. For the US, this activity will almost exclusively involve existing reactors; for other nations, both existing and future reactors may be involved. I see all the nuclear nations moving toward a more uniformly high level of performance, although a more internationally consistent approach to operations and regulation is much more problematical. In every nation the particular national culture and current nuclear status will dictate different approaches. Nevertheless, I see, in common with others in this session, a strong benefit to greater international cooperation and exchange of information, particularly on matters relating to safety. Therefore, I appreciate the opportunity I have had today to hear of the plans of other nations and to address you on what I see as near term US nuclear power prospects. Thank you.

Endeavors to Improve the Safety and Reliability of Korean Nuclear Units

by

Dong Joo Kim
Vice President, Technology Development
Korea Electric Power Corporation

The development of Korean nuclear power projects was accelerated due to the oil crises in the 1970s to substitute imported oil, which was a major energy source for electricity at that time. Now we are proud of supporting the domestic economy through cheap and stable supply of electricity.

At present, seven nuclear units are in operation with total capacity of 5,716 MW. The overall capacity factor of nuclear units in 1987 was 79.9 %, which is very high considering the relatively short operating experiences. The nuclear share in total electricity was 53.1 %. Three Korean units were included in the top 25 nuclear units in the world for their high capacity factor in 1987.

In addition to the seven operating units, Ulchin Nuclear Units 1 and 2 are under startup test to begin their commercial operation this year and in 1989. Construction work for Yonggwang Nuclear Unit 3 and 4 will start this year for completion in 1995 and 1996, respectively.
Therefore, the nuclear power in Korea will play an increased role for the sound development of economy in future.

Although stable supply of electricity at reasonable price can be definitely assured with the nuclear units, Koreans tend to become more critical of the nuclear option due possibly to their ambiguous fear for and confusion with nuclear weapons. Such a trend has become more evident since the Chernobyl accident and the current democratization process taking place in the Korean political scene.

In spite of the remarkable growth, our nuclear capability is still limited when compared to advanced countries. Since commercial application of fast breeder technology is likely to be postponed in spite of the concentrated efforts in many advanced countries, Korea has no choice but to rely on the LWR technology with improved version even in the early part of the 21st century.

In order to advance the LWR technology, leading nuclear countries placed great emphasis on standardization of nuclear power plants, to satisfy regulatory requirements on nuclear safety and to incorporate more safety margins in design and operation. Innovative design such as microcomputer-based control and instrumentation, human engineering and robotics are positively applied.

Before explaining the Korean efforts to upgrade the LWR reliability, I would like to mention the domestic situation involving nuclear energy.

Firstly, we have two types of water reactor, PWR and CANDU. The NSSS suppliers include AECL of Canada, Framatome of France, and Westinghouse and Combustion Engineering of U.S.A. The diversity in reactor types and suppliers has brought much difficulty in establishing our own regulatory terms on reactor safety and in managing nuclear projects. Also, manpower training and systematic buildup of domestic capability have been adversely affected.

Secondly, we rely on the import of energy resources. In case of an unexpected future energy crsis, energy supply in Korea may be jeopardized, thus disturbing the overall economic structure.

Thirdly, although the majority of the general public still stands for nuclear energy, criticism and suspicion are growing to threaten the strong acceptance basis of nuclear development.

Therefore, aiming at achieving the energy independence through nuclear option, the Korean strategy is not only to absorb advanced reactor technology but to secure public acceptance.

Now, let me describe our efforts to maximize the utilization of the operating units.

Several years ago, KEPCO developed a special plan to improve the capacity factor to 75 % or above by 1991. To achieve this goal, we have adopted high burnup fuel to extend the refueling interval to 15 months or so to raise the capacity factor by 3 %. Preventive maintenance and fortified surveillance is emphasized to reduce the forced outages and to reduce annual refueling period.

In order to raise the safety level and to provide post-accident capability, TMI action items have been incorporated into our units either in operation or under construction. A few remaining items such as Safety Parameter Display System, Emergency Response Facility, and Post Accident Sampling System are currently under design.

As an endeavor to identify and correct the deficiencies of the equipment, plant control systems and operating procedures in terms of reliability and safety, we have set up the methodologies of probabilistic reliability analysis to perform analysis of any level. For instance, major safety systems including the shutdown systems # 1 and 2 of Wolsong Unit 1 is being assessed this year. These analyses will be applied to PWR units also in 1989 to find the shortcomings of the safety systems.

Kori Unit 1, the first power reactor in Korea, once suffered the fuel damage due to flow-induced vibration, which has been solved by upflow modification of reactor internals.The unit has also experienced the problem of water chemistry which has resulted in plugging of tubes of steam generators and main condenser. In order to rehabilitate the performance of the unit, steam generator tubes are sleeved and condenser tubes are replaced during the extensive overhaul of this spring.

Another major effort to improve and advance the LWR performance in Korea is a project to standardize a 1,000 MWe PWR for the future nuclear units.

Four-year long Phases 1 and 2 studies ended last year to analyze domestic and foreign experiences and to formulate an overall project plan. Reference to the standardizing unit is Yonggwang Units 3 and 4. Designs of the reference units will be largely adopted in standardizing units. Major equipment including the NSSS and T/G will be the same as those of the reference to utilize the fabrication capability and the buildup of experience to the maximum content.

Phase 3 began this spring to develop design requirements of the ulitity and to draft standard safety analysis reports. Phase 4 and 5 will perform the basic and detail designs of the Korea Nuclear Units 13 and 14, which will be put into commercial operation at the end of 1990s.

Now let me talk about the public acceptance in Korea.

From the beginning of the nuclear age, concerned governmental authorities, social organizations and KEPCO have performed many public relations activities. The activities include plant tours, operation of exhibition centers, symposium on nuclear energy,publication of booklets and films and others, which have been effective for securing strong support of the general public. Several recent surveys have revealed that about 80% of Koreans acknowledge and support the necessity of nuclear power.

The Chernobyl accident, however, has given much impact to the general public in spite of the geographical distance. In addition,as the standard of living is improved,the general public has become more keen to the biased critical reports by several journalists in the mass media.

In order to keep the public acceptance on nuclear option,we feel it necessary to organize and systemize the on-going public relations activities in a single tone and to develop new activities and methodologies.Therefore, a comprehensive program is being drafted through active co-participation of concerned parties.

In conclusion, we are trying to improve the performance of LWRs through various ways including the standardization project. Yet, it is true that we are still at the beginning stage in this field, which means the necessity of international cooperation. We will willingly share our experiences with other countries and will participate in international efforts to improve the safety and reliability of LWRs.

セッション５「日本における軽水炉信頼性向上への努力」キーノート

東京電力㈱常務取締役　池　亀　亮

軽水炉の先駆けとして、日本原子力発電の敦賀１号炉が運開して約２０年たっております。昨今の情勢から、今後も軽水炉時代が長期化することについては岡部議長の紹介にあった通りと考えております。今日までの推移は、米国軽水炉技術の導入から始まりその定着を図った前半約１０年間、信頼性向上のために技術改良に取り組んだ後半約１０年間の一連の努力の結果と言うことができます。この約２０年間の努力を振返りつつ、現在および今後の計画を論議することは有意義であると考えております。なぜならば、信頼性向上のために行われている努力を明確にすることによって、人々の原子力に対する正しい理解を深めることができると考えるからです。

本日はこのような観点から、信頼性向上を含むいくつかの項目について、今まで努力してきたこと、今取り組んでいることなどについて、順を追って紹介させていただきます。

始めに、今までの努力の結果、成果が明らかになった項目のうち４点について紹介させていただきます。

第１点目は安定運転の確保に関してです。日本の原子力発電所の設備利用率を見てみると、年々上昇傾向にあり、ＳＣＣ対策あるいはＳＧ対策で利用率の落ちた１９７７年度の約４２％から、１９８２年度に約６８％になり、１９８６年度には約７６％に、１９８８年度では約７７％に上昇しました。この要因には、運転期間の長期化やロボット利用などによる定検期間の短縮、事故停止の低減（特に１９８６、１９８７年において、事故停止率は０．３回／炉年程度と低水準に保たれています。）並びに、計画的な機器の保守点検等が上げら

れると思います。これらの良好な実績をもとに、長期的な連続運転が可能なように条件整備も進めているところであります。

第２点は、教育訓練です。運転員については、運転訓練センターにおけるフルスコープシミュレータを利用した各種訓練のほか、各発電所に設置する学習用小形シミュレータによる基本操作の学習を計画しています。また、保修員については、技能訓練センターにおける研修などにより、教育訓練を行っています。

第３点は、ひばく低減対策です。低コバルト材の採用・クラッド発生抑制対策・自動化機器の採用、作業員への放射線管理の指導助言、モックアップ訓練等の教育によりひばく低減化を図ってきています。この結果、柏崎刈羽１号機の第１回定検では、２０マン・レム以下という、極めて低い線量を達成することができました。

第４点は、放射性固体廃棄物管理です。発生面では、廃棄物となるイオン交換樹脂を必要としない非プリコート型フィルタを採用したり、焼却処理・プラスチック固化等で容積を減らす等の対策を採っています。

また、貯蔵面では、青森県の下北地区に低レベル放射性廃棄物の貯蔵施設が設置され、１９９１年より操業開始の予定となっております。

次に、現在、取り組んでいることについて述べます。

初めに、改良型軽水炉の開発ですが、従来型軽水炉に比べ、より一層の安全性、信頼性向上と同時に設備利用率向上、作業員ひばく低減、コスト低減を目

指しました。これらの目標のため、運転経験、国内の自主技術並びに国際的協力を柱に、メーカと電力が共同してこの開発を進めました。

改良型ＢＷＲについて述べますと、既に、東京電力の柏崎刈羽６、７号機に採用が決まっておりまして、１９９６年、１９９８年運転開始を目指し、この４月から設置許可申請手続きに入る予定でございます。インターナルポンプの採用により、外部原子炉再循環系配管がなくなり、原子炉格納容器がコンパクトになり、耐震性および経済性が向上しました。改良型制御棒駆動機構の採用により、水圧駆動に加えて、電動駆動方式も採用されたため、制御棒駆動源の多様化が図られました。鉄筋コンクリート製格納容器の採用により原子炉建屋がコンパクトになり、耐震性が向上しました。さらに、電気出力は1356ＭＷと従来型ＢＷＲに比べ一回り大きくなっております。設備利用率８６％、ひばく線量５０人・レム／炉年以下、建設単価は従来型に比べ約２０％安い等の優れた性能を有しております。

この様に、多くの関係者の協力のもと開発された改良型軽水炉は、信頼性のより高い軽水炉として、今後の我が国の原子力発電の主役となるものと考えております。

第２点は、燃料の改良についてです。ここでは、高燃焼度化とプルサーマル計画について述べます。

まず、高燃焼度化ですが、ＢＷＲでは、集合体最高燃焼度４０，０００ＭＷＤ／Ｔの燃料を去年の秋から装荷し始めており、さらに５０，０００ＭＷＤ／Ｔの燃料を１９９１年後半を目標に実用化する予定となっています。

ＰＷＲでは、現在の３９，０００ＭＷＤ／Ｔを４８，０００ＭＷＤ／Ｔにする計画が１９８９年後半に実用化を目標に進行中です。

もうひとつは、プルサーマル計画です。ＢＷＲでは、ＭＯＸ燃料体２体を１９８６年度に敦賀１号炉に装荷し、その特性等を確認中であり、ＰＷＲではＭＯＸ燃料体２体を美浜１号炉に装荷する予定となっています。

また今後の計画として、１９９０年代前半を目途とした実用規模実証計画を経て、１９９０年代後半の本格利用に移行することとしています。

第３点は、長寿命化です。原子力発電所の長寿命化研究が１９８５年から８年計画で進められています。研究では機器などの重要度を分類したり、監視すべき機器を明らかにすることから始め、評価手法の確立、監視装置の開発、経済評価が検討されています。

第４点は、マン・マシン・インターフェイスです。２月のＩＡＥＡの会議でも確認された様な、機械を使う人間の側に立ったシステム設計、人と機械の役割分担、運転と共に保守作業におけるヒューマン・ファクターの重要性あるいはマン・マン・インターフェイスの重要性等の課題について、現在、電中研などの機関で検討しているところです。

次に日本で話題になっている出力調整運転について紹介します。現在のところ、日本ではフランスの様に出力調整運転を日常的に行う計画はありません。しかし、将来に備えて段階的に試験を実施し、こうした運転を円滑におこなえるように諸準備を進めていくことは、運転の信頼性を求められる原子力発電にとって重要なことであると考えております。実施された試験はいずれも良好な結果を得ていますが、最近、これら試験をチェルノブイル と同等の試験であるとした反対運動が展開されました。この反対運動を通じて、チェルノブイル事故が正しく公衆に理解されていないこと、即ち、低出力、試験、人為ミスとい

う３つの言葉がチェルノブイルのキーワードとなって、事実と遊離した形で、人々の心の中に焼付いてしまっているということを痛感した次第です。このような経験に基づき、原子力に対する一般公衆の正しい理解を得るにはどうしたらよいか、電力側の一層の努力が必要と考えられます。

最後に、国際協力について述べます。

日本では、電力会社間あるいは電力・メーカ間で、各レベル毎に設計、運転、保守に関し、多くの情報交換の場が設定されております。電力会社毎の考え方、実行の方法について相違点があり、他社の情報は自社の改善に非常に役立っており、これが日本の原子力発電の実績が優れている大きな要因となっていると考えております。原子力発電所の運転者の間で、国際的な情報交換を行うことは、多くの利益を相互に与えるものと考えております。

このような意味で、ＩＡＥＡの活動を補完するものとして、ＣＥＧＢマーシャル総裁提案の「国際原子力発電事業者協会地域センター構想」に対し、日本の電気事業者は積極的に賛同しております。第１回アジア地域の意見交換会を東京で２月に開催し、韓国電力・台湾電力・パキスタン原子力委員会・日本の電気事業者が出席して、アジア地域センターの設立に向けての努力を確認したところであります。

以上いろいろな点について述べてきましたが、軽水炉の信頼性向上のためには、いずれも重要なテーマであり、今後とも我が国が、国際的な協力をしつつ、一層の努力を傾けていく必要があるものと思っております。

SESSION 5 Keynote Speech

Efforts for Further Enhancement of Reliability of LWR

Ryo Ikegame

I am Ryo Ikegame of Tokyo Electric Power Co.

It is about 20 years since Tsuruga-1 reactor of Japan Atomic Power Co. came into operation as the first commercial light water reactor (LWR) in Japan. In view of the present situation, the era of light water reactors is expected to continue for a long time in future, as Chairman Okabe has noted. The past 20-year period up to the present may be divided into the first decade of years when technology for LWRs introduced from the United States was established in Japan and the second decade in which energetic efforts were made for technical improvement for a further enhancement of the reliability of LWRs. It would be meaningful to discuss present and future plans, looking back on our efforts made in the past 20 years. I believe that the public may deepen their correct understanding of nuclear power, by being informed our efforts made for reliability improvement.

From this standpoint, today I would like to discuss our past and present efforts in regard to reliability improvement and other areas.

First, I would like to give explanations on four items in which successful results have been obtained so far through our efforts.

The first is the securing of steady operation. The capacity factor of nuclear power plants in Japan has been yearly on the increase. The capacity factor, which dipped to about 42% in fiscal 1977 due to counter measures for SCC or SG problems, rose to about 68% in fiscal 1982 to about 76% in fiscal 1986, and to about 77% in fiscal 1988. The main reasons for this increase are extended operating cycles, the reduction of refueling outage due to the utilization of robots, reduction of forced outage (particularly, the rate of forced outage was reduced to 0.3 times/reactor year in 1986 and 1987), and planned maintenance and inspection of equipment. At present, efforts are being made on the basis of this favorable performance to create conditions for long-term continuous operation.

The second concerns education and training. As for operators, they are trained in various necessary training items using large-scale simulaters at operation training centers. Furthermore basic plant operation training with the use of small simulators for education is planned at each nuclear power station. Maintenance staff are trained according to their training programs at technical training centers.

The third point concerns measures against radiation exposure reduction. Efforts have been made for this purpose by introducing materials with less cobalt content, decreasing the crud, adopting various automation equipment, giving assistance to subcontractors in regard to radiation protection and training with mock-ups. As a result, a very low exposure of 20 manrem of the first periodical inspection was attained at Kashiwazaki Kariwa-1.

The fourth point is related to solid radioactive waste management. The volume of radioactive waste is reduced through adopting non-precoated type filters to stop generating radioactive resin waste, introducing incineration treatment and plastic solidification, etc.

For the storage of radioactive waste, it is planned to build a low level waste storage facility in the Shimokita district in Aomori Prefecture, which is expected to start operation in April 1991.

Next, let me explain some items we are tackling at present.

First, I will give explanations on the development of an advanced light water reactor, which is designed to be improved in safety and reliability, capacity factor, reduction of radiation exposure and construction cost as compared with the conventional LWRs. In order to achieve these purposes, nuclear reactor manufacturers and electric power utilities jointly promoted this development work on the basis of operational experience, technologies accumulated in Japan and international cooperation.

As for advanced BWRs, Tokyo Electric Power Co. has already decided to adopt them as its Kashiwazaki Kariwa-6 and -7 units, which are planned to go into commercial operation in 1996 and 1998, respectively. Our company will file the application of the nuclear reactor establishment permit to the government in April this year. The adoption of reactor internal pumps (RIPs) will eliminate the external recirculation piping, and enable to make reactor containment vessel compact, resulting in improvement of their aseismic characteristics and economic parameters. Futhermore, control rod driving power sources will be diversified through adoption of an electric drive, in addition to a hydraulic piston drive. The adoption of a reinforced concrete containment vessel (RCCV) will make the reactor building compact and improve its aseismic characteristics. The electric output of the units is planned to be 1,356 MW each, which is larger than that of conventional BWRs. The capacity factor and the radiation exposure are expected to be more than 86% and less than 50 manrem/year, respectively, and the construction cost, dollars per kW, is expected to be 20% less than that of conventional BWRs.

In this way, advanced LWRs which have been developed through the cooperation of all parties concerned, are expected to play a leading role in future in Japan's nuclear power generation.

The second item concerns the improvement of fuel. I will explain this matter with special reference to high burnup fuel and utilization of Pu in LWRs.

As for BWRs, we started to load high burnup fuel with a maximum assembly burnup of 40,000 MWD/T in the autumn of last year, and plan to load a high burnup fuel with a maximum exposure of 50,000 MWD/T in the latter half of 1991.

As for PWRs, a plan is under way to increase maximum burnup from the present 39,000 MWD/T to 48,000 MWD/T in the latter half of 1989.

Regarding the utilization of Pu in BWRs, two mixed-oxide fuel assemblies were loaded in Tsuruga-1 in fiscal 1986 to study their characteristics. As for utilization of Pu in PWRs, two mixed-oxide fuel assemblies are planned to be loaded in Mihama-1.

Full-scale Pu utilization is expected to start in the late 1990s after a large-scale demonstration project which is planned to start in the first half of the 1990s.

The third point is the life extension of nuclear power stations. An eight-year plan for the life extension of nuclear power stations started in 1985. This study program covers a wide area, beginning with the classification of equipment and parts according to their importance and clear definition of equipment which should be put under surveillance, and including the task of establishing evaluation methodologies of life extension, development of surveillance equipment and economic evaluation.

The fourth point is man-machine interface. The Central Research Institute of Electric Power Industry and other organization are doing research work on user-oriented system design, clear definition of the roles of a man and a machine, and the importance of human factors in maintenance as well as in operation, and the importance of man-man interface, whose importance was confirmed by the February meeting of IAEA.

Next, let me speak a few words about load following operation, which is now a hot issue in Japan. As the matter stands at present, Japan does not have a plan to carry out a load following operation on a day-to-day basis as it is done in France. However, we consider it important for nuclear power generation, which is required to be reliable in operation, to conduct tests for the purpose step by step in case of future need so that we may be able to carry out such operation smoothly. All the tests so far conducted have shown favorable results. However, recently an opposition movement was developed, with its leaders charging us with conducting the same tests at Chernobyl. We were made keenly aware through the opposition movement that the Chernobyl accident was not correctly understood by the public, namely the three key words of the Chernobyl accident -- low output power, tests and human mistake -- were implanted in the minds of the public as fixed ideas divorced from the facts. In view of the above experience, I think it is required of the power utilities to make increased efforts to win public acceptance of nuclear power plants.

Lastly, I will briefly outline our international cooperation efforts.

In Japan, there are many meetings and vehicles of information exchange on design, operation and maintenance between electric power utilities, between electric power utilities and makers on various levels of positions. Different electrical power utilities have different policies and methods of practice, and information on other utilities is useful for mutual improvement. I consider this to be one of the factors for the excellent performance of nuclear power plants in Japan. I also think that international exchange of information among the operators of nuclear power plants will bring great mutual benefits to them. In this sense, Japanese electric power utilities positively support the idea of regional centers of the World Association of Nuclear Operators proposed by Lord Marshall, Chairman of CEGB. Then the first meeting to exchange views on establishing and operating the Asia Regional Center of the World Association of Nuclear Operators was already held in February in Tokyo.

Beside Japanese utilities, the Korea Power Corporation, the Taiwan Power Company, and the Pakistan Atomic Energy Commission attended the meeting, and recognized the need to make efforts for the establishment of the Asian regional center.

The items I discussed above are all important ones for the reliability improvement of LWRs. I think it is necessary for us to make increased efforts for the solution of these problems in future, too, while promoting international cooperation.