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**Series:** Bromley, D. Allan, Files  
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**Folder Title:**  
Physical Sciences: General (1) [7 of 7] [1992]

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"Document Control"

TYPE: ACTION DOCUMENT NUMBER: 9201758  
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS  
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FROM: MOORE, W. Henson: DEPUTY CHIEF OF STAFF TO THE PRESIDENT

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 05/11/92

SUBJECT: HE IS FORWARDING A COPY OF HIS LETTER TO MR. J. PAUL  
PLEASANT IN WHICH HE SUGGESTS MR. PLEASANT MEET WITH  
DR. BROMLEY.

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: PHYSICAL SCIENCES ASSIGNED:

ACTION  
REQUIRED: AS NECESSARY

Attended DAB meeting with Prof. Furukawa  
+ talked privately for ~ 3/4 hrs. with him.  
Per DAB's request:  
1) Will contact DOE to see interest in  
molten salt + provide pt. of contact  
2) KAE/LIS to contact MIT (Mr. Gray) to  
see if any interest.  
JSS 6/9/92

\*\*\*\*\*  
SENDER'S DUE DATE:  
OSTP DUE DATE: 06/01/92 STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT:

\*\*\*\*\*  
COPIES TO: D. Allan Bromley

\*\*\*\*\*  
WHITE HOUSE TRACKING #: CONTACT PERSON:  
PHONE: EXT:  
REMARKS: ASSIGNED TO PHYSICAL SCIENCES PER DAMAR.

For Lee Schroeder - I believe the mtg  
with Furukawa is scheduled for Monday or  
Tuesday  
KAE 6/7/92

OSTP RECEIVED: 05/18/92  
FILE: P-PHYSICAL SCIENCES

DEPT RECEIVED:

CENTRAL FILES:









1758

THE WHITE HOUSE

WASHINGTON

May 11, 1992

RECEIVED

92 MAY 18 P 1: 50

OSTP  
MAIL ROOM

Dear Mr. Pleasant:

I have received your recent letter requesting a meeting with Professor Kazuo Furukawa of the Institute of Research and Development at Tokai University in Japan to discuss Japan's and the world's future role in the production of plutonium for the utilization of commercial energy.

While I continue to be most interested in these matters since I have come to the White House from the Department of Energy, due to the different kinds of assignments in which I am now involved, I would like to suggest Professor Furukawa would be better served by requesting a meeting with Dr. Allan Bromley.

As you are probably aware, Dr. Bromley is the Assistant to the President for Science and Technology. I have discussed your request with Dr. Bromley's office and they would welcome hearing from you.

With kindest personal regards, I remain

Sincerely yours,



W. Henson Moore  
Deputy Chief of Staff  
to the President

Mr. J. Paul Pleasant  
President  
Energy Frontiers International  
11472 Ehren Street  
Lake View, California 91342



# Energy Frontiers International

J. PAUL PLEASANT, President

To Bromley

Henson Moore  
Presidential Advisor  
The White House  
Washington D.C.

April 14, 1992

Professor Kazuo Furukawa, Institute of Research and Development, Tokai University is one of Japan's leading nuclear physicist. He has taken a public leadership role advocating that Japan, and the world, avoid the production of plutonium in the utilization of commercial nuclear energy.

Professor Furukawa is the leading exponent of THOREM-NES, a Accelerator Molten-Salt Reactor concept utilizing thorium. This concept will require a close cooperative effort with the Oak Ridge National Laboratory.

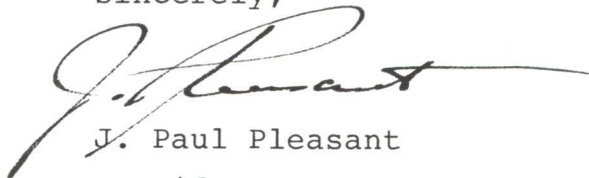
Professor Furukawa will visit the United States in June and has expressed a strong desire to meet with you, or staff, in Washington D.C. on June 10 or 11.

Enclosed are copies of recent correspondence. The correspondence reflects a developing international interest in this nuclear energy project.

I believe it is most important to the long-term interests of the United States that Japan avoid an energy future based upon plutonium. I strongly urge that Mr. Furukawa be granted a personal opportunity to discuss his vision of Japan's energy future.

Please advise if this meeting can be scheduled.

Sincerely,

A handwritten signature in dark ink, appearing to read "J. Paul Pleasant", with a long, sweeping horizontal line extending to the right.

J. Paul Pleasant

President

ENERGY FRONTIERS INTERNATIONAL



Mr. J. Paul Pleasant  
President,  
Energy Frontiers International,  
11472 Ehren St.,  
Lake View Terrace, California 91342  
U.S.A.

FAX : 818 890-4336

11th April, 1992

Dear Mr. Pleasant,

Thank you very much for your letter of 1st April, 1992, by which I have been encouraged so much.

Our movement is quite successfully growing. We have prepared a new Tokyo-office, and everything is progressing everyday. I cannot explain simply. I have to see you as soon as possible.

Now I have decided to participate in "Citizen Ambassador Program": Nucl. Fuels Management Delegation to the Commonw. of Indep. States (Moscow, Chelyabinsk, Kiev, Chernobyl), which will start on 13th June, 1992 from New York.

cf.: Ms. Kathy White,  
Project Coordinator  
People to people Cit. Amb. Program  
Dwight D. Eisenhower Building  
Spokane, Washington 99202

FAX: 509-534-5245  
TEL: 509-534-0430

Honorary Chairman:

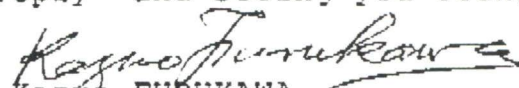
President George Bush

[ Half month ago, I was timely elected as a Foreign Member of Ukrainian Academy of science.]

Therefore, starting here on 31th May, and touching LLNL etc., I want to see you on 3rd June, 1992 at Los Angeles. Is it all right for you ?

After visiting ORNL [Director, Dr. Trivelpiece] including many friends (hoping to see Dr. A. Weinberg, too), I want to see Mr. Henson Moore on 11th or 10th June at Washington. (If impossible, to his staffs !). I should be very much obliged if you would kindly help me on it.

Looking forward to getting your reply and seeing you soon,  
Sincerely yours,

  
Kazuo FURUKAWA

Prof. Kazuo FURUKAWA  
Inst. of Research & Development,  
Tokai University,  
Hiratsuka, Kanagawa 259-12,  
JAPAN

FAX: 463-58-1203



TOKAI UNIVERSITY  
INSTITUTE OF RESEARCH & DEVELOPMENT

1117-Kitakaname, Hiratsuka, Kanagawa, 259-12 JAPAN

Phone 0463-58-1211 Ext. ~~2298, 2299~~ 5300

Fax 0463-58-1203

Mr. J. Paul Pleasant  
President,  
Energy Frontiers International,  
11472 Ehren St.,  
Lake View Terrace, California 91342  
U.S.A.

9th March, 1992

Dear Mr. Pleasant,

Thank you very much for your letter of 2nd March, 1992 and copies of letters indeed.

I am quite waiting the successes of these actions. Please report me soon by Fax [ 463-58-1203 ]. I also want to know your Fax number, please.

Could you imagine now Japanese are also quickly understanding our opinion (good for all peoples) among top peoples or opinion leaders.

My next essay <sup>was</sup> ~~will~~ be published <sup>day</sup> ~~tomorrow~~ on the leading Newspaper: ASAHI (5 M copies ?) much discussing on Pu: "Let extinguish the fire of Pu", they chosen this title. On 1st March, timely, Mr. Torii, a Editorial Writer of Japan Economy NP[Nihonn KEIZAI] presented quite clear essay: "New Nuclear Energy Way", quite following our way, he said, and really Ministry Foreign Aff. & Tokyo ELEC. Power Corp. are appreciating these proposal now.

Asahi also wrote a similar editorial on 22th Feb. titled "Re-examine the Pu policy". Therefore I sent them the above second essay. Tokyo E.P.Co invited me on the end of this January.

I am meeting with Mr. K. Tanigawa, Minister of Sci. Tech. Agency on 10th March. Socialist Party has invited me for a lecture to rebuild their energy policy on 18th March.

Looking forward to seeing you near future,  
Sincerely yours,

  
Kazuo FURUKAWA

P.S. Please tell me your Fax number and the air-port for seeing you.  
(How to go there ?)





12月  
1992  
3/1

## 中外時評

### 世界中で使われる原子力を

#### 「長期計画」改定、技術戦略示せ

論説委員

鳥井 弘之

原子力委員会が、わが国の原子力政策の基本となる「原子力開発利用長期計画」の改定作業に入らうとしている。原子力を巡る情勢は大きく変化しており、新しい時代の中で原子力をどう位置づけ、行くかが世界の関心事になっている。今回の改定作業は、それに対するわが国の回答であり、従来の改定と比較にはないほど重大な意味を持っている。

地球環境問題は原子力を考える上でも重要な要因になる。化石燃料の消費によって発生する炭酸ガスが地球温暖化の原因になると考えられ、六月にリオデジャネイロで開かれる地球サミットに向かつて、二酸化炭素の排出抑制に関する議論が続けられている。省エネルギーなど地道な努力も必要だが、それだけで、抑制の目標を達成できるわけではない。

世界のエネルギー需要は、省エネとが出来るのだろうか。言い換えれば、世界の多くの国が原子力に頼ることを無条件で賛成できるかどうかになる。

まず考える必要があるのは核の拡散の問題である。原子力発電所の勢いで伸びると予想され、二酸化炭素を排出しないエネルギー源として必要になる。それに答える最も有力な候補が原子力である。昨年のロンドン・サミットでも原子力の重要性が経済宣言に盛り込まれたように、原子力に対する期待は大きくなっている。

タンなどの核爆発国もある。IAEAは、爆発国に対して特別査察が出来るように、査察制度の見直しを進めているが、これにも限界があり、核の拡散を完全に防ぐことが出来るのだろうか。言い換えれば、世界の多くの国が原子力に頼ることを無条件で賛成できるかどうかになる。

わが国の原子力発電所の安全性は世界でも最高水準にある。安全が保たれている背景には、広島と長崎の経験、国民の教育レベル、文化、経済状態など様々な要素がある。世界の中でもわが国と同じような安全性が確保できるとは限らない。世界の現状を見れば、原子力施設が戦火を浴びることも考慮しなければならない。

こう考えると、原子力に対する期待は大きくなるのに、現在の原子力は、長期的に世界という視点からは、その期待にたえない資格が無いように思われる。期待にこたえるためには、プルトニウムなど核兵器につなげる懸念を伴わない原子力が必要だ。厳重な管理をしながらも安全な原子力が生まれる。これらの条件を考慮した新しい原子力に関する技術的進歩もいくつかある。

日本の原子力利用は、ウラン濃縮、軽水炉、使用済み燃料の再処理など、欧米の路線をまっとうしている。しかし、将来の世界に対して日本が責任を持つなら、世界中で使われる原子力技術の開発に日本が取り組むべきであろう。技術はすぐには完成しない。その意味で現在の軽水炉を否定するわけではなく、技術の完成をまって、わが国の原子力利用も、徐々に新しい技術体系に切り替えて行けばよい。

今や、日本は世界の将来がどうあるべきかを考え、それを世界に訴えていく立場にある。技術開発も日本のためという視点だけでは不十分である。原子力について言え、それが平和利用に導く。日本の立場の証明にもなる。長期計画では、当面の核不拡散やプルトニウム利用をどう考えるかも重要だが、長期的な技術戦略も検討する必要がある。

※ ※ ※  
原子力はこの期待をたえず、主権人民共和国（北朝鮮）パキスタンに示している。

※ ※ ※  
もう一つの問題は、安全の確保である。チェルノブイリの原子力事故によって、事故の被害が一国の中に止まらず、周辺にも大きな影響を与えることが認識されるようになった。一方、東欧などの事態が明らかになるにつれて、旧式原子力炉が運転されていることも判明している。

※ ※ ※  
また、原子力に対する期待は、現在の原子力に対する期待は大きくなるのに、現在の原子力は、長期的に世界という視点からは、その期待にたえない資格が無いように思われる。期待にこたえるためには、プルトニウムなど核兵器につなげる懸念を伴わない原子力が必要だ。厳重な管理をしながらも安全な原子力が生まれる。これらの条件を考慮した新しい原子力に関する技術的進歩もいくつかある。

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# 論点

私たちは、来世紀に向かっている環境およびエネルギー対策を、太陽エネルギーに頼るならば最良と思つてゐる。だが何ぶん密度が低く不規則なので、補助が特殊目的から抜け出すのは困難であらう。

の面において、全世界で喜んで使つてもらえるものでなければならぬであらう。

東海大学教授



お和男 古川

今の化石燃料時代からこの太陽エネルギー時代への橋渡しをどうするか？ 一部の人は核融合に期待しているらしい。しかし、ITER (国際熱核融合実験炉) の推進者たちも、実用化は四、五十年先という。もし実現して世界エネルギーの二割を供給し始めたとしても、二、三割を占めるのは再来世紀初めになってしまう。

中に少なくとも七千万から一兆kW・年の電力を生産することが必要である。これでも、化石燃料の使用で増え続ける世界の炭酸ガス放出率は、二〇六五年によつて増勢が止まる程度である。過去の原発発電総量はわずか二十億kW・年に過ぎず、その数百倍の生産は、とても既存の軽水炉の改良程度で追いつけることではなからう。ではどうしたらよいのか？

それはウランの代わりに「トリウム」を利用する道がある。さらに固体をよめて液体の溶融塩核燃料利用に移るのである。米国のオークリッジ国立研究所の人々が、この基礎研究をまとめ推進を始め、一九五八年頃から、筆者も生涯の仕事と決めた三十年以上努力してきたが、ようやく来世紀世界に展開するにふさわしい具体構想が

核燃料は自給自足できるので、余剰燃料が不要で制御棒なしに出るかも知れない。核燃料の路上輸送は、運転始めと終わりの二度だけでよい。燃料は空気・水と反応しない常圧の最も安定な液体である。冷えれば燃料塩はガラス状に固化し、放射能閉じ込めに最良で、水に溶けない。廃棄物についても、まず一番やっかいな超ウラ

単に運ばない。検知・監視はきわめて容易である(従つて、燃料は液体にして遠隔操作され、作業員は被ばくをまぬかれる)。

このほか、この炉は小型化できる利点をもつ。既存の大型原発と必要に競争せず、小型炉から次第に世界に展開していけばよい。技術成熟に、立地に有利である。米・仏・伊などには、かねがね

## 今こそ有望な「トリウム」燃料

固まつてきた。しかも前記の課題すべてを解決する見込みがある。

安全性に関しては、炉が破壊されても過酷事故(炉心溶融・再臨界など)が想定できないくらい安全である。ガス状の放射能は常に除去されており、事故時に放出されるものはほとんどない。炉内は裸の黒鉛(空間の九〇%占有)とすきまを流れる溶融塩燃料だけから成り、フタなしの単純なタンクが本体である。

元素類がほとんど生まれな。燃料をいじり回さないで、低レベル廃棄物を激減できる。

核拡散・核テロ対策では、トリウムの利用によりプルトニウム廃絶が可能である。トリウムは核分裂性の人工ウラン<sup>233</sup>に変えられて燃やされるのであるが、これは必ず強烈なガンマ線を伴い、テロリストは致死量を浴びてしまう。遮蔽(しゃへい)するには厚さ三十センチの鉛の容器が必要で、簡

一刻も早く開発したいという仲間がいる。最近、ロシアの研究所が挙げて共同したいと動き出した。開発途上国でも、現にチェルノブイル災害に懲りて原発を拒否していたトルコ政府機関までが、一緒に検討させてほしいと言つて来ている。インド・インドネシアその他にも熱心な仲間がいる。

このような新しい炉は開発費が大変なうとよく言われるが、逆である。その証拠に、オークリッジでは実にわずかの資金と最高二百人の陣容で、すでに実験炉が立派に運転され、技術基盤はできているのである。最小限の新技術実証には、約十年の年月と国連が今世紀内に必要という環境対策費一兆の千分の一ぐらいがあれば十分と思われる。経済性の高さも十分推察していたに過ぎないであらう。

(核エネルギー論)





TOKAI UNIVERSITY  
INSTITUTE OF RESEARCH & DEVELOPMENT

1117-Kitakaname, Hiratsuka, Kanagawa, 259-12 JAPAN

Phone 0463-58-1211 Ext. 2298, 2299, 5300

Fax " - " - 1203

Mr. J. Paul Pleasant  
President,  
Energy Frontiers International,  
11472 Ehren St.,  
Lake View Terrace, California 91342  
U.S.A.

18th February, 1992

Dear Mr. Pleasant,

Thank you very much indeed for your letter[and beautiful stamps] of 14th January(February ?), 1992.

Your statements all are quite agreeable and encouraging me. I am sorry for my silence, but I did a lot for Th. Partially I shall report you, as Th is on time:

0) Please tell me your Fax No.. Mine is 463-58-1203.

1) Th fuel cycle promotion by HTGR is natural for USA. However, the age is shifting, and really a new era. Your country has the base of MSR tech.. Comparing them, HTGR is an incomplete set, especially concerning "fuel processing", really. I discussed severely on it with Professor Schulten[Julich] 3 years ago, and off course, with other severals including EdF chief engineer (cf. II-5 section of our blue book prepared by the help of EdF.).

2) So long I am hoping for DOE to move on MSR development using ORNL, with which I have a deep connection as you know. I prepared a very easy approach than ORNL-MSBR, and can distribute all over the world. I enclosed our newest report here. ORNL peoples are supporting me.

I am very happy if you would couple with me to prepare the international coopo.system for th-MSR development. Would you please explain our idea to Mr. Henson Moore[ what is his previous career ?], because the several groups in the world are more and more supporting our proposal:

3) For example:

Now Russian Inst. for Theo. & Exptl Physics, Moscow [2500 persons, responsible for N. Weapon head incineration] is officially cworking in our direction.

Turkish Atomic E. Authority President presented his hope to study more on our system cooperatively (already progressing in partial). Please understand it means that this tech. is very attractive for developing countries, too. In recent, India, Indonesia, Czecho., Israel, --- are hoping to know more.

Will you know a week ago Indonesia nearly gave up PWR after

long examination choosing coal.

Japan is now more understanding the difficulty of LWR siting. Two days later (20th Feb.) the Japanese biggest conservative Newspaper "YOMIURI" is publishing an invited energy essay of mine in 9 million copies.

4) I have to explain more in detail. Could we meet together near future? Where is your town? Last year I missed to visit USA, but this year have to go, at least visiting LLNL, EPRI, Los Angeles, LANL?, ORNL, Tennessee Univ.. Which period is suitable for meeting you?

Would you have a connection with the former President Carter, who was a reactor fuel engineer and really promoted to use Th than Pu strongly! (I am also not impossible to find it.) Senate of Tennessee (who) should move to use ORNL more for not only USA but also the world, don't you?

I shall move more now. Please help me.

Looking forward to seeing you near future,  
Sincerely yours,

  
Kazuo FURUKAWA

P.S. I heard that Dr. Clark Gibb, the head of ETEC, Canoga Park, has an interest on MSR. More than 20 years ago, I had a deep connection with LMEC and Atomic International. I am writing him, too.



Institute of Research & Development  
Tokai University  
Kitakaname, Hiratsuka  
Kanagawa 259-12 JAPAN

VIA AIR MAIL

Mr. J. Paul Pleasant  
President,  
Energy Frontiers International,  
11472 Ehren St.,  
Lake View Terrace, California 91  
U.S.A.



*To Mr. J. Paul Pleasant,  
with the compliments of Kazuo Furukawa*

## Thorium Molten-Salt Nuclear Energy Synergetics

Kazuo FURUKAWA, Alfred LECOCQ, Yoshio KATO  
and Kohshi MITACHI

Reprint



## SUMMARY REPORT

## Thorium Molten-Salt Nuclear Energy Synergetics

Kazuo FURUKAWA\*<sup>1</sup>, Alfred LECOCQ\*<sup>2</sup>, Yoshio KATO\*<sup>3</sup>  
and Kohshi MITACHI\*<sup>4</sup>

\*<sup>1</sup> *Institute of Research & Development, Tokai University*

\*<sup>2</sup> *European Working Association for Molten-Salt Reactor Development [EURIWA]*

\*<sup>3</sup> *Fuels & Materials Research Div., Japan Atomic Energy Research Institute*

\*<sup>4</sup> *Department of Engineering, Toyohashi University of Technology*

Received February 26, 1990

In the next century, the "fission breeder" concept will not be practical to solve the global energy problems, including environmental and North-South problems. As a new measure, a simple rational Th molten salt breeding fuel cycle system, named "Thorium Molten-Salt Nuclear Energy Synergetics [THORIMS-NES]", which composed of simple power stations and fissile producers, is proposed. This is effective to establish the essential improvement in issues of resources, safety, power-size flexibility, anti-nuclear proliferation and terrorism, radiowaste, economy, etc. securing the simple operation, maintenance, chemical processing, and rational breeding fuel cycle. As examples, 155 MWe fuel self-sustaining power station "FUJI-II", 7 MWe pilot-plant "miniFUJI-II", 1 GeV-300 mA proton Accelerator Molten-Salt Breeder "AMSB", and their combined fuel cycle system are explained.

**KEYWORDS:** *energy demand, thorium, molten salts, fluorides, fission reactors, nuclear power plants, fissile producers, accelerator breeder, breeding fuel cycle, safety, research programs*  
R & D

## I. INTRODUCTION

The next (21st) century will be a transient period from fossil fuel era to solar era through nuclear energy. The present fossil fuel technologies induce, not only severe global environmental problems, but also regional difficulties connected with the effective and economical energy supply, which is necessary to overcome poverty and desertification, i.e. North-South problem.

However, the future nuclear energy technology as a measure of global problems in the medium and long terms such as 2020~2070 will not be established merely by some extensions or improvements of present technologies, due not only to recent several troubles of nuclear facilities, but also to the huge increase in amount of nuclear energy capacity

such as 100 times more than the present, which means a need of 100 times safer technology<sup>(1)</sup>.

This might require a technological revolution or a new philosophy on the following issues keeping deep connections among each other: (a) nuclear resources, (b) breeding fuel-cycle, (c) safety, (d) radio-wastes and their incineration, (e) nuclear proliferation and terrorism and (f) public and institutional acceptances related not only with the above, but also with the technological simplicity, flexibility and economy in the global applications.

A "nuclear energy system" should be a

\*<sup>1</sup> Kitakaname, Hiratsuka-shi 259-12.

\*<sup>2</sup> 11 Av. Dr. Vaillant, 91940 Gometz le Chatel, FRANCE.

\*<sup>3</sup> Tokai, Ibaraki-ken 319-11.

\*<sup>4</sup> Tenpakucho, Toyohashi-shi 440.



"nuclear chemical engineering facility", and essentially a "chemical plant". Following on this sense, more rational nuclear energy system should be developed for the global energy measure of the next century, fully re-examining the scientific and engineering efforts devoted in this century.

## II. ENERGY PROBLEMS IN NEXT CENTURY

### 1. Global Energy Demand<sup>(\*)</sup>

The growth rate of energy consumption in the world was about 2.3% per year in the past one hundred years. It means about 10 times increase after one hundred years. If this growth rate is also applied in the next one hundred years, the total energy demand surrounding the end of the next century will amount to about 115 TWth (th=thermal), which is about  $9 \times 10^{-2}$  % of the total solar energy input to the globe. The latter value is almost the limiting value of 0.1%, which is estimated

by some specialists considering the influence on the world climate. Thinking of the local abnormal weather, about 100 TWth seems to be a sound maximum heat emission to the atmosphere.

At the end of the next century, there is a consensus that the world population may be saturated at the value between 10 and 15 billion. This means about 10 kWth or 7 kWth per capita on an average corresponding to the 2 times (10 billion) or 3 times (15 billion) increase in the world population, respectively. This level is still less than that of the present USA, which is about 10 kWth per capita.

Therefore, at least, this energy demand should be satisfied in the next century of the world. This is the target of this report. An anticipating global energy demand in the next century is summarized in connection with the prediction of the population in Table 1<sup>(\*)</sup>, which includes an average energy consumption per capita, too.

Table 1 World energy demands in next century

|        | population | energy*<br>[TWth]               | (nuclear)* <sup>3</sup><br>[GWe] | energy per capita<br>[kWth/cap] |
|--------|------------|---------------------------------|----------------------------------|---------------------------------|
| 1988   | 5.1 B      | 9.                              | (200)                            | 1.8                             |
| 2000   | 6. B       | 11.8                            | (300)                            | 2.0                             |
| 2035   | 8. B       | 26.                             | (2,700)                          | 3.3                             |
| 2050   | 10. B      | 37.                             | (6,000)                          | 3.7                             |
| 2065   | 12. B      | 52.                             | (13,000)                         | 4.3                             |
| [ 2100 | 10~15 B    | 115.                            | (30,000)                         | 12~7.6 ]                        |
|        |            | (=0.09% of solar)* <sup>2</sup> |                                  |                                 |

\*) assuming the average growth rate of 2.3 % per year.

\*2) assuming less than 0.1 % of total solar input energy to earth, which would be a limit allowable in climate and environmental influence.

\*3) assuming from the prediction by Marchetti et al., IIASA [2].

If a sound industrial trend in energy supply is held in the next century, it will conform to the logistic prediction made by Marchetti *et al.* as shown in Fig. 1<sup>(3)</sup>, where the amount of primary energy is plotted as fraction "F" of the total energy market. The dotted curve of nuclear (fission) energy is added by the authors. The total electric capacity of the nuclear fission energy will become about 300 GWe in 2000, about 2,700 GWe in 2035, and about 13,000 GWe in 2065 as shown in Table 1.

### 2. Nuclear Proliferation and Terrorism

For the improvement of this issue the Pu

fuel cycle strategy should be criticized, and Th cycle would be recommended due to the high  $\gamma$ -activity of polluted fissile <sup>233</sup>U, which is effective for the safeguard and detection<sup>(4)</sup>.

### 3. Environmental Problem

This significant nuclear energy growth rate presented here seems to be necessary not only for securing the healthy, cultural and economical life, but also for reserving the sound environmental conditions in the world by the diminution of pollution including the "Greenhouse Effect"<sup>(5)</sup>, although the solar energy utilization could become more impor-



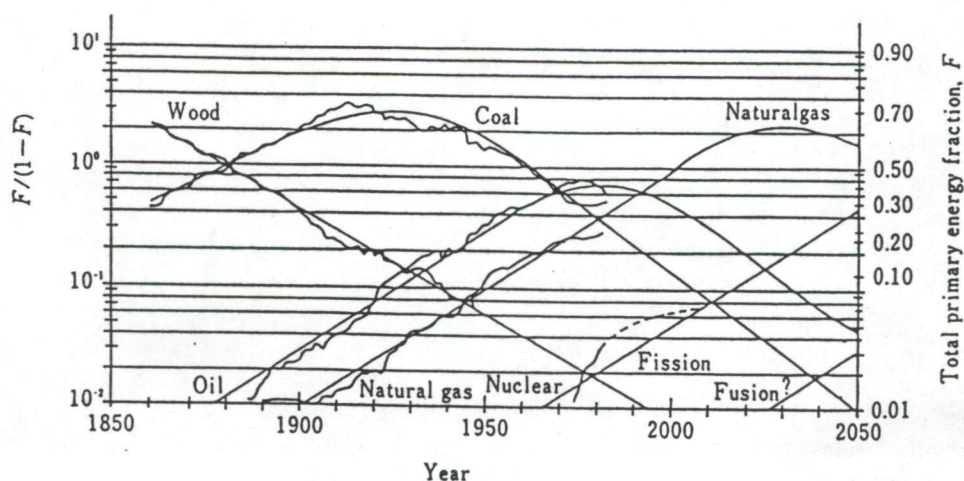


Fig. 1 Historical trend in energy substitution

tant toward the end of the next century because of the limitation on heat emission (cf. the item (\*2) in Table 1).

#### 4. Radio-waste

In this issue pure fusion technologies will have some advantages. However, it should be recognized as a long term program, because the energy gain even in the DT-fusion reaction is about one tenth of fission reaction which need not any essential energy input. In fission energy program, the following points should be considered for the radio-waste minimization:

- (i) Minimization of nuclear chemical productions such as fission and spallation products, and trans-uranium elements: A higher thermal efficiency in electric generation will contribute to minimize F.P. production. Thorium fuel cycle will have a big advantage to minimize or eliminate trans-uranium elements.
- (ii) Minimization of spent fuel materials: All irradiated fuel material should be fully used as far as possible and not be easily sent to graveyards. They should be fully burned out establishing a complete breeding fuel cycle (cf. Chaps. III & VIII).
- (iii) Minimization of fuel reprocessing steps and of reactor maintenance works.

#### 5. Doubt on "Fission Breeder" Concepts

It seems that the establishment of fission breeders such as LMFBR is a world's con-

sensus as one of the better solutions of energy and environmental problems. However, this concept might yield not only economical difficulty<sup>(4)</sup> but also several practical misfits related to public requirements<sup>(2)</sup>. Numerical examination is shown in APPENDIX.

(a) The first problem is a doubt whether the reactor could achieve the necessary growth rate as shown in Table 1, due to its low breeding power. This has been examined applying the following scenario acceptable as a sound example: all reactors until the year 2019 are thermal LWR of 1 GWe producing 0.25 t/yr of Pu, and all renewed and added reactors after 2020 are 1 GWe LMFBR, which need 5 t of Pu for initial inventory. This concludes the necessity of a very short doubling time such as 6~8 years in fissile breeding, and fully prepared reprocessing plants. These seem to be impossible.

(b) Power stations should be simple facilities, flexible in power size, responding the natural demand of world utilities. It would not be acceptable that all stations become sophisticated large high-performance LMFBR.

(c) The integrated Pu inventory necessary for FBR in minimum would be 11,000 and 28,250 t at 2036 and 2049, respectively. Handling and transportation of such a huge amount Pu would be fatally trouble-



some. (In practice, the shortage of Pu will appear at 2037 even using FBR of 20 years in doubling time.)

Molten-Salt Breeder Reactors (MSBR) such as designed by Oak Ridge National Lab. (ORNL), USA<sup>(7)</sup> also will not be acceptable by the items of (a) & (b) due to the long doubling time of about 20 years.

#### 6. Establishment of More Practical

##### Breeding Fuel-cycle

The fission energy technology holds an unique position due to its nature of "energy rich" and "neutron poor". The latter will require helps from the other nuclear technologies such as nuclear spallation, D-T fusion, etc., to get enough fissile materials to establish real "breeding fuel cycle" (cf. Chap. VIII).

#### 7. Basic and Engineering Safety

The significant improvement such as 100 times better than the probability of the present level of  $10^{-4}$  severe accident per reactor-year operation will be required to avoid total refusal by public<sup>(1)</sup>. The following points are

essential: simplicity in operation and maintenance, flexibility in power size, approach to civilian life area, and essential improvement in economy.

This might be established only by the essentially new safe reactor concept composed of chemical inert fluid-fuel, which has no radiation-damage, negligible excess nuclear-reactivity (nearly no control-rods), and low power density in value without harming its economy. [High Temperature Gas-cooled Reactor or Pebble-Bed Reactor which are more acceptable in safety issue than the other solid fuel reactors would not be suitable for establishing a breeding fuel cycle, too.]

### III. NEW PHILOSOPHY: THORIMS-NES

#### THORIUM MOLTEN-SALT NUCLEAR ENERGY SYNERGETICS

Now, to solve the several energy problems shown in Chap. II and Fig. 2, a new philosophy should be proposed to the public. The

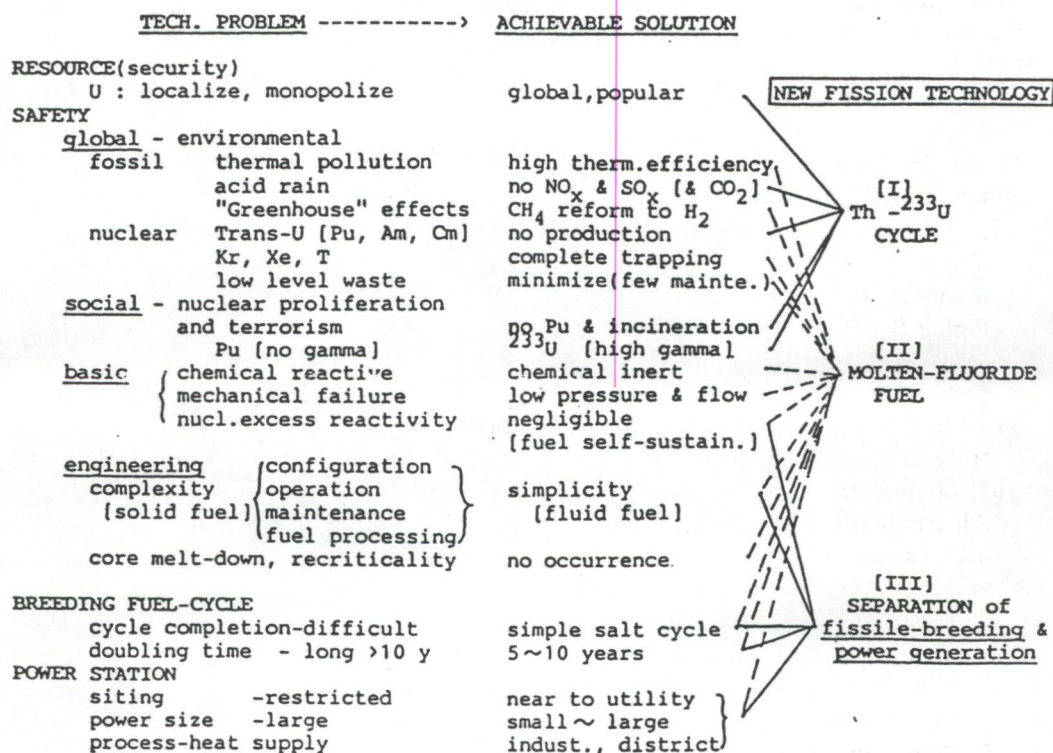


Fig. 2 Global energy problems and achievable solutions by  
New FISSION TECHNOLOGY [THORIMS-NES]



new proposal depends on the following three principles:

[I] Thorium utilization

Natural Th has only one isotope:  $^{232}\text{Th}$ , which can be converted to the fissile  $^{233}\text{U}$  in the similar manner as  $^{239}\text{Pu}$  converted from  $^{238}\text{U}$ . Thorium is more abundant and non-localized resource than U.

[II] Application of molten-fluoride fuel technology

The molten salt  $^7\text{LiF-BeF}_2$  (Flibe—named by ORNL) is the significantly low thermal-neutron capture cross section material (*cf.* Table 2) and the best solvent of fissile and fertile materials. This functions as one of the best liquids useful for nuclear fuel, blanket or target keeping coolant function in parallel.

Table 2 Natural elements and practically separable isotopes having tiny thermal neutron absorption cross-sections

|     | (natural abundance)          | cross-section<br>m barn (natural element) |                              |
|-----|------------------------------|-------------------------------------------|------------------------------|
| 1.  | $^8\text{O}$                 | 0.19                                      |                              |
| 2.  | $^2_1\text{H}$ [D] (0.0148%) | 0.519                                     | ( $^1_1\text{H}$ 332.6)      |
| 3.  | $^{12}_6\text{C}$            | 3.53                                      |                              |
| 4.  | $^{11}_5\text{B}$ (80.0%)    | 5.5                                       | ( $^{10}_5\text{B}$ 767,000) |
| 5.  | $^4_2\text{He}$              | 6.9                                       |                              |
| 6.  | $^9_4\text{Be}$              | 7.6                                       |                              |
| 7.  | $^{19}_9\text{F}$            | 9.6                                       |                              |
| 8.  | $^{209}_{83}\text{Bi}$       | 33.8                                      |                              |
| 9.  | $^{222}_{86}\text{Rn}$       | 39.                                       |                              |
| 10. | $^7_3\text{Li}$ (92.5%)      | 45.4                                      | ( $^6_3\text{Li}$ 70,500)    |
| 15. | $^{40}_{20}\text{Zr}$ 185.   | 17.                                       | $^1_1\text{H}$ 332.6         |
| 16. | $^{231}_{91}\text{Pa}$ 231.  | 67.                                       | $^{17}_{17}\text{Cl}$ 33500. |

[III] Separation of fissile producing breeders (process plants—MSB) and power producing reactors (utility facilities—MSR)

It will be essential for the global establishment of breeding fuel cycle flexibly applicable in any area.

This philosophy was named as “Thorium Molten-Salt Nuclear Energy Synergetics” [THORIMS-NES]<sup>(2),(8),(9)</sup>. Its main benefits will be briefly understood from the summary in Fig. 2.

## IV. SIGNIFICANT ASPECTS OF MOLTEM-SALT REACTOR TECHNOLOGY

### 1. Molten Fluoride Fuel Concept<sup>(7),(8)</sup>

Some brief historical presentation of significant studies on MSR concept are given in Fig. 3. MSR is classified to fast, epithermal and thermal reactors according to the kinds of neutron spectrum utilized. Fast or epithermal reactors not having any solid moderators might have more attractive due to the simple structure and high performance. However, it seems that no one has succeeded to present any practical designs yet. Fluoride salt fueled thermal MSR would be the most promising reactor concept.

The “Flibe ( $\text{LiF-BeF}_2$ ) base molten-salt fuel” concept has already been established its sound technological basis by the brilliant long effort of ORNL, throughout 1947~1976. It depends on the successful operation of MSRE (Molten-Salt Reactor Experiment, 7.5 MWth) in 1965~1969, and on their intensive R & D works on MSBR (1963~1976)<sup>(7)</sup>. The excellent final summary on ORNL works could be found in ORNL/TM-7207<sup>(10)</sup>. The short explanation will be given below.

However, the practical deployment of MSBR is not easy because of the following difficulties: (a) necessity of core-graphite exchange in every 4 years, (b) development of continuous chemical process *in situ*, and (c) necessity of improving doubling-time from the present estimation of 20 years, and (d) flexibility in power size (*cf.* Sec. II-5).

Now, the principle [III] should be accepted.

### 2. Flibe-base Molten-Salts

The molten  $^7\text{LiF-BeF}_2$ - $^{232}\text{ThF}_4$ - $^{233}\text{UF}_4$  system will be one of the better and idealistic nuclear materials as a carrier of Nuclear Energy Synergism due to the following characteristics:

- (1) A triple-functional medium working as
  - A. nuclear reaction medium—fuel, blanket and target
  - B. heat transfer medium—coolant
  - C. chemical processing medium.
- (2) No radiation damage as an idealistic



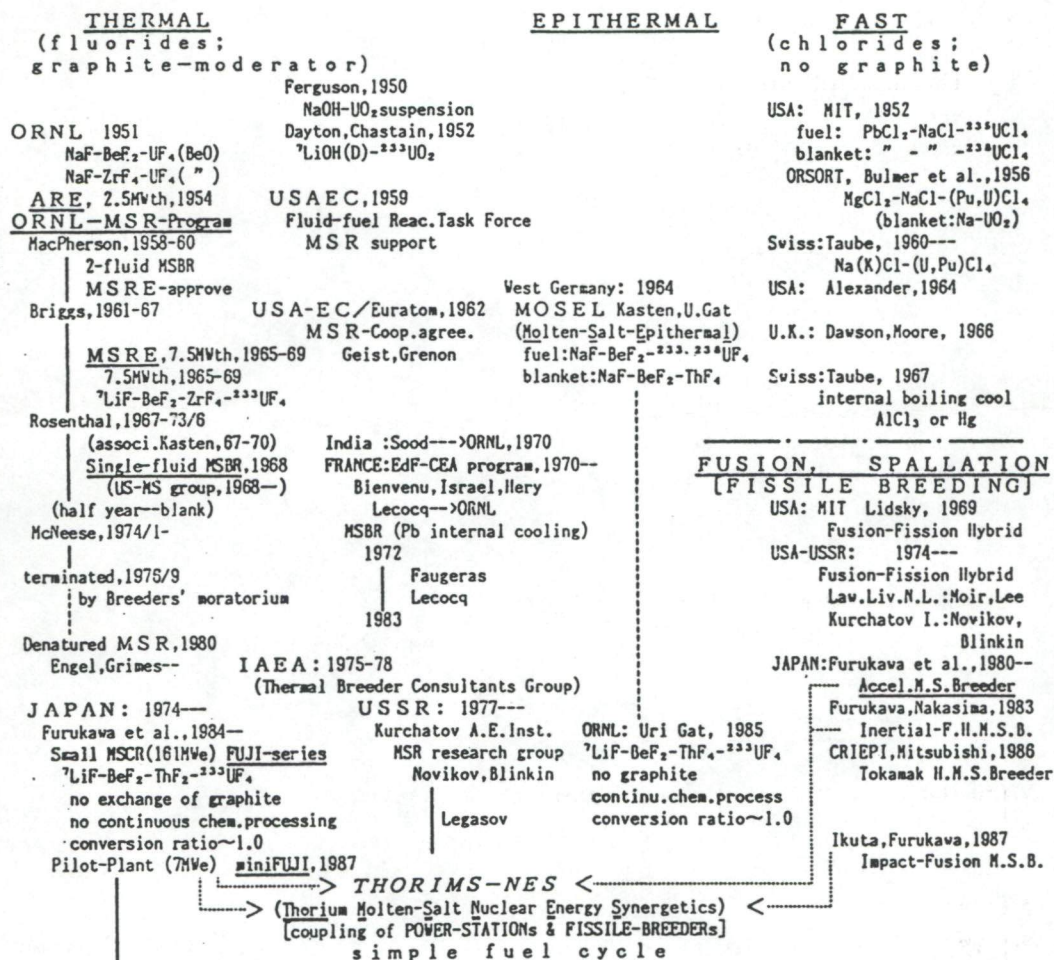


Fig. 3 Historical presentation of Molten-Salt Reactor concepts

"ionic liquid".

(3) High safety and economy assurance promised by chemically inert, low vapor pressure, moderate viscosity and thermal conductivity, and high heat capacity in fairly high working temperature (770~1,070 K).

Sodium technology has three severe disadvantages such as (i) high chemical reactivity, (ii) high thermal shock, and (iii) oxidized vapor condensation in gas spaces, different from molten salt technology.

Molten-Salt technology is much easier than water (high pressure, corrosive and reactive with Zircaloy) and Na technologies.

### 3. Graphite

Graphite is the best material for neutron moderator and reflector in MSR (cf. Table 2),

and is really compatible with molten fluorides in bare state. This is a great benefit in designing MSR. The satisfactory materials have been developed by the efforts of USA and France<sup>(11)</sup>.

### 4. Containment Materials

Fortunately, an easy manufacturable, weldable and high temperature resistant (till ca. 1,100 K) alloy compatible with molten fluorides has been developed basically according on the proposal of Dr. H. Inouye, ORNL. This alloy, Hastelloy N (Ni-(15~18)Mo-(6~8)Cr in %), has been modified by adding about 1% Nb for the protection of Te attack on surface. This was experimentally supported by Kurchatov Institute<sup>(12)</sup>.

This alloy needs not to be introduced in



with the advantages of MSR technology on the chemical inertness, low thermal shock, and no oxidized vapor condensation.

The MSRs including above mentioned small MSR might keep an excellent performance as effective partners of Fissile-producing MSBs in order to establish the practical THORIMS-NES all over the world including the developing countries and isolated areas.

#### 4. R & D for AMSB

In parallel, MSBs, especially AMSB will be developed by the rational procedure increasing the proton current in step-wise during 20 years, aiming the wide application from about 2020.

The first experimental research works on the spallation products and heat generation have to be recommended including the proton irradiation analysis of solidified salt targets in big size such as 50~80 cm in diameter and 150~250 cm in length. After these examinations our preliminary design features could be very much improved due to their big flexibility. As the technological basis of AMSB is clear except the proton injection-port, it will be able to develop within 20 years by the stepwise improvement of test facilities (*cf.* Chap. X). The economy of AMSB depends on the recovery of electricity.

Already 1 GeV-1 mA cw (continuous wave) class proton LINAC technology and basic molten fluoride reactor technology have been developed. The new items necessary for engineering developments of a small integral experimental facility AMSBE (Accelerator Molten-Salt Breeder Experiment) will be quite few, because we can start using pure molten Flibe (LiF-BeF<sub>2</sub>) of low melting point and low vapor pressure and using a low intensity 1 GeV pulsed proton beam initially. As a next stage nuclear material contents and beam intensity can be stepwise increased in the same facility, in the rational and economical mood. The general idea of R & D schedule including MSR is shown in Fig. 8.

The R & D of the spallation breeder AMSB would be surprisingly low in cost (\$4~8 B) and short in time (15~25 years) in comparison

with the other similar breeding system developmental projects, promising the wide global application in 2020~2070<sup>(22)(23)(18)(19)</sup>.

## XI. CONCLUSION

We have tackled one of the most promising approaches for establishing the simple and practical Thorium resource utilization program, which might be effective to solve the principal energy problems, concerning resource, safety, nuclear proliferation and terrorism, greenhouse effect, power size and fuel cycle economy, for the next century.

The first step will be the development of Small Molten-Salt Reactors (MSR). Its basic technology has been established by ORNL already, and, therefore, its R & D cost would be surprisingly low. The next is the development of Molten-Salt Fissile Breeders (MSB). Our proposed MSR is an effective partner of MSB for establishing the simplest and economical Thorium molten-salt breeding fuel cycle system named THORIMS-NES all over the world, including the developing countries and isolated areas, for solving poverty, *i.e.* North-South problem. This would be one of the most practical replies to the Lilienthal's appeal of "A NEW START" in Nuclear Energy by encouraging "a revival of positive and affirmative fighting spirit" of scientist and engineers<sup>(32)</sup>.

## ACKNOWLEDGMENTS

The author wish to express sincere thanks to many friends of Japan and the foreign countries for their kind cooperation and encouragement. Especially, Drs. J.R. Engel, U. Gat, F. Atchison, the late Prof. K. Tsukada, Drs. Y. Nakahara, N. Nakamura, K. Minami gave us their friendly helps or cooperation, and the late Dr. E. Nishibori, the late EmProf. S. Kaya, the late Dr. K. Kamei, EmProfs. E. Takeda, T. Mukaibo, T. Ishino, K. Husimi, N. Watanabe, Drs. A.M. Weinberg, H.G. MacPherson, C. Bienvenu, Prof. M. Chemla, Drs. M. Israel, R. Romano, J. J. Geist, R. Moir, H. Takahashi, V.M. Novikov, M. Ginatta, N. Irie, the late Dr. H. Murao gave their great interest and encouragement on our work. One



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WASHINGTON, DC 20510-1203

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May 27, 1992

D. Allan Bromley  
Assistant to President, Science and Tech. Policy  
Office of Science and Tech. Policy  
Executive Office Building  
Washington D.C. 20506

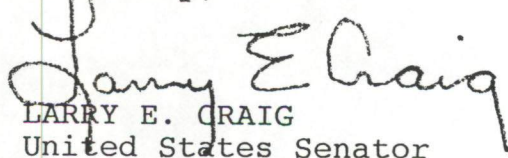
Dear Mr. Bromley:

Mr. J. Paul Pleasant, President of Energy Frontiers International, and Mr. Pete Wells, a constituent of mine, recently contacted me about the possibility of having Professor Kazuo Furukawa, Institute of Research and Development, Tokai University, meet with you. Professor Furukawa is interested in discussing Thorem-ness, his molten-salt reactor concept which utilizes thorium.

It is thought that the use of thorium in molten-salt reactors is an effective process and avoids plutonium as an end product. Professor Furukawa's believes that, to be successful in this endeavor, his concept will require close cooperation with the Oak Ridge National Laboratory. It is this concept and development of a cooperative that he would like to discuss with you.

Professor Furukawa will be in Washington, D.C. on June 10 and 11, 1992. I would greatly appreciate it if you could grant Professor Furukawa an opportunity to discuss his ideas with you. He may be reached via Mr. Paul Pleasant at (818) 890-4144.

Sincerely,

  
LARRY E. CRAIG  
United States Senator

LEC:tb



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TYPE: ACTION

DOCUMENT NUMBER: 9201603

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DIRECTORATE STATUS

\*\*\*\*\*

FROM: HUSSEIN, Mahir S.: UNIVERSIDADE DE SAO PAULO

TO: DR. D.A. BROMLEY

MAY 5 1992

DATE OF  
CORRESPONDENCE: 04/15/92

SUBJECT: HE IS WRITING TO ASK DR. BROMLEY'S OPINION OF SOME  
RECENT ARTICLES CONTAINING IDEAS DEVELOPED BY THEIR  
GROUP CONCERNING PARTICLE ACCELERATION USING  
POWERFUL LASERS.

\*\*\*\*\*

DIRECTORATE

STAFF

ASSIGNED: PHYSICAL SCIENCES

ASSIGNED: Lee Schroeder

ACTION

REQUIRED: REVIEW FOR DAB & Draft response

STAFF

ACTION: See bagged info + letter  
drafted by LSS -- letter sent  
under LSS signature.

\*\*\*\*\*

SENDER'S DUE DATE:

OSTP DUE DATE: 05/14/92

STAFF DUE DATE

DATE COMPLETED:

DATE COMPLETED/DEPT:

\*\*\*\*\*

COPIES TO: D. Allan Bromley  
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OSTP RECEIVED: 05/05/92  
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DEPT RECEIVED:

CENTRAL FILES:





June 1, 1992

TO: Karl Erb  
FROM: Lee Schroeder  
RE: Background + Recommendation Doc. #: 9201603  
(Particle Acceleration via Lasers)

The letter to DAB from Dr. Mahir S. Hussein (Universidade de Sao Paulo) contains 2 preprints (The Super Collider Revisited and Theory of Free Wave Acceleration) + a copy of a published article (Phys.Rev.Lett. 68,1136 (1992)) on the acceleration of charged particles using a laser and transverse static E-field.

Specific to the preprint on the SSC, the preprint suggests using their technique + strong superconducting magnets (10T) for transport/focussing to construct an accelerator 20X smaller than SSC. Relevant to this is the following:

- o they are talking about a linear collider, not circular machine
- o the spot size is several mm's, rather than microns needed for luminosity
- o my own opinion + discussions with Andy Sessler (LBL-advanced accelerator techniques) indicate that decade or more R&D needed to make such a device work at the luminosities required by the SSC (ie.,  $10E33$ ).

Recommended response: Letter, under my signature, thanking authors for papers; brief statement of time-scale to convert concepts to real device and wish them well in their continuing research.

Lee - Do you have an  
intuitive feeling for how  
this inverse Brems  
acceleration works? \$

Karl

Not really. One can intuitively  
see that the E-field component  
of the laser will cause an acceleration  
over  $1/2$  its period  $\rightarrow$  followed  
by decelerating over next. I think  
that you have to go into the coupled  
particle-field eqns. to get answer  $\rightarrow$   
not intuitive, unless you have  
worked with eqns. long  
enough.  
Lee

yes  
Thanks  
KSE 6/7/92

so E field is  
direct.  
of accelerating  
however.





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OSTP  
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Prof. D. Allan Bromley  
Science Advisor  
The White House  
Washington D.C.  
USA

April 15 1992

Dear Professor Bromley

I am pleased to send you some very recent articles containing ideas developed by our group here and also with the collaboration of Prof. A. Kerman concerning particle acceleration using powerful lasers. We predict quite smaller accelerators for very high energy physics.

Hope to hear of your opinion soon, I remain

Yours sincerely

Mahir S. Hussein

# THE SUPER COLLIDER REVISITED\*

M.S. Hussein and M.P. Pato

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Instituto de Física, Universidade de São Paulo  
C.P. 20516, 01498 São Paulo, S.P., Brazil

## Abstract

We suggest a revised version of the Superconducting Super Collider (SSC) that employs the planned SSC first stage machine as an injector of 0.5 TeV protons into a powerful laser accelerator. The recently developed Non-linear Amplification of Inverse Bremsstrahlung Acceleration (NAIBA) concept dictates the scenario of the next stage of acceleration. Post "Star Wars" lasers, available at several laboratories, can be used for the purpose. The 40 TeV CM energy, a target of the SSC, can be obtained with a new machine which can be 20 times smaller than the planned SSC.

---

\* Supported in part by the CNPq

April/1992



The SSC as presently planned purports to accelerate protons to 20 TeV in C.M. collider apparatus. The eventual aim of this gigantic project is the verification of the existence of the ever so elusive Higgs boson predicted to have a mass of  $> 50$  GeV. The dimension of this planned machine is, as is already known, colossal, with an estimated cost of several billions of dollars. Clearly the physics dictates the cost. However, one still wonders about possible cheaper alternatives. In this communication we propose a new accelerator that could reduce the dimension by more than an order of magnitude.

In a recent paper<sup>1)</sup>, we proposed the non-linear amplification of inverse bremsstrahlung electron acceleration (NAIBEA) as a way of accelerating electrons to a very high energy with the aid of powerful lasers which are available at several laboratories, in conjunction with an optimally determined applied electric field. Similar effects are obtained with an applied magnetic field<sup>2)</sup>. In the work of Hussein and Pato<sup>1)</sup>, the initial electron energy was taken to be about 35 MeV. To obtain similar effects with protons one would need an initial energy of about 70 GeV and a laser  $10^4$  more potent than the one used in Ref. 1.

Our proposal for a smaller Higgs machine is to inject protons with about 500 GeV energy (proton initial velocity  $v_0/c = \beta_0 = 0.999998$ ), which is the energy attained in the first stage of the SSC, in conjunction with a powerful laser (say of a power of  $6.6 \times 10^{20}$  W/cm<sup>2</sup> for a wavelength of  $\sim 5 \times 10^{-5}$  m). The laser wave would merely pump and subsequently remove a very large amount of energy into/from the protons. In fact, during a half cycle interaction with the laser, the protons are accelerated to about 1 TeV within a distance of  $\frac{\beta_0}{1-\beta_0} \lambda = 25$  meters. No net energy is gained in a full cycle encounter with the laser. In the process of pumping/removing energy into/from the protons, the proton energy oscillates. To obtain net acceleration, one would require to change the maxima in the proton energy into inflection points. This is obtainable with an appropriate applied electric,  $E_{app}$ , or magnetic,  $B_{app}$ , field. Significant acceleration can be obtained (up to the TeV regime) with an array of  $E_{app}$  or  $B_{app}$  with interchanging signs placed in

optimally determined positions<sup>1,2)</sup>. The dimensions involved are not as great as those in the planned SSC machine. We now turn to a detailed analysis of the proposal.

To reach a proton energy of 20 TeV we need, an array of applied magnetic field of an intensity of about 10 teslas. The sign changes of this field are made at macroscopic distances dictated by the requirement that, the particle is well contained in the transversal direction  $p_y(\varphi = n\pi) = 0$  where  $\varphi$  is the laser phase. These features of the physics become particularly transparent if we look at the equation of motions when the motion is ultrarelativistic in the z-direction,<sup>1)</sup>

$$\dot{p}_z = e \beta_y (E_y^{(0)} + B_{app}) \quad (1)$$

$$\dot{p}_y = -e \beta_z B_{app} \quad , \quad (2)$$

and the energy equation ( $\epsilon = \gamma$  in unit of the rest mass of the particle)

$$\dot{\gamma} = e \beta_y E_y^{(0)} c \quad . \quad (3)$$

In the above equations,  $E_y^{(0)} = B_x^{(0)}$  is the laser electric field intensity and  $\beta_i = \frac{v_i}{c}$ . The applied constant magnetic field in the x-direction is  $B_{app}$ .

Now the solution of the above equations can be expressed in the form

$$\epsilon = p_z - e B_{app} y + u_0 \quad (4)$$

$$p_y = p_y^{(0)} - e B_{app} z \quad (5)$$

$$p_z = \frac{1 + p_y^2 - (e B_{app} y + u_0)^2}{2(e B_{app} y + u_0)} \quad . \quad (6)$$



In Equation (4),  $u_0$  is a constant determined from the initial conditions;  $u_0 = \gamma_0 (1 - \beta_0 \cos \theta_0)$  where  $\theta_0$  is the injection angle.

It is obvious from Eq.(4) that to make  $\varepsilon$  increase,  $B_{app} y$  must be made positive ( $< u_0$ ). From obvious arguments  $y$  is oscillatory so as to keep the particle in the path of the laser pulse. This means that  $p_y$  is also oscillatory. Thus  $B_{app} z$  must oscillate. Since  $z$  is always increasing, one naturally reaches the conclusion that  $B_{app}$  should change sign at appropriate  $z$ 's, dictated by the machine characteristics.

Now the change in energy of the protons in the first stage of acceleration is given by<sup>1)</sup>

$$\Delta \varepsilon = \frac{e E_{y_0}^{(0)} \lambda}{\pi} \left[ \frac{m c^2 \gamma_0 \beta_0 \sin \theta_0 + \frac{e \lambda}{2\pi} E_{y_0}^{(0)}}{m^2 c^4 + \beta_0^2 \gamma_0^2 m^2 c^4 \sin^2 \theta_0} \right] \gamma_0 \beta_0 m c^2 (1 + \beta_0 \cos \theta_0) \quad (7)$$

where the laser electric field is represented by  $E_y^{(0)} = E_{y_0}^{(0)} \sin \varphi$ ,  $\varphi$  being the phase and  $\lambda$  the wave length, and  $\theta_0$  is the injection angle of the protons ( $\cos \theta_0 = \hat{y}_0 \cdot \hat{z}_0$ ). The overall change in energy,  $\Delta \varepsilon_f$ , of the proton after  $n$  inflection points (generated by  $n$  alternating sign magnetic fields (or electric fields)), is then, for  $\gamma_0 \gg 1$ ,

$$\Delta \varepsilon_f = n \Delta \varepsilon \approx n \left[ \frac{e E_y^{(0)} \lambda}{2\pi} \right] \left[ \frac{2 \sin \theta_0 (1 + \cos \theta_0)}{1 + \gamma_0^2 \sin^2 \theta_0} \right] \gamma_0^2 \quad (8)$$

or

$$(\Delta \gamma)_f \equiv n \cdot B \cdot \left[ \frac{2 \sin \theta_0 (1 + \cos \theta_0)}{1 + \gamma_0^2 \sin^2 \theta_0} \right] \cdot \gamma_0^2$$

where we have introduced the laser parameter  $B \equiv e E_y^{(0)} \lambda / 2\pi m c^2$ . If we take  $\gamma_0 = 500$ ,  $n = 20$ ,  $\theta_0 = 0.1^\circ$ , and  $B = 0.5$ , we reach the value of  $\Delta \varepsilon_f \simeq 20$  TeV.

The important question we address ourselves to now is how long the accelerator

tube will be. This is determined primarily by the intensity of the applied field  $B_{app}$ , and the injection angle  $\theta_0$  among other things such as the Doppler effect mentioned earlier.

To quantify the above discussion, we have used the NAIBA model to calculate the length of the proton accelerator taking for  $\gamma_0 = 500$ ,  $B_{app} = 5.14 \times 10^{-7} E_{y_0}^{(0)}$ ,  $P = 6.6 \times 10^{20} \text{ W/cm}^2$ ,  $\lambda = 5 \times 10^{-3} \text{ cm}$  and  $\theta_0 = 0.02$ . A laser pulse of a Gaussian shape with a width of  $\Delta = 3\pi$  is employed. The results are shown in Figure 1. The applied magnetic field was made to change sign 11 times along the accelerator tube. The length of the accelerator tube,  $\Delta z$ , needed to reach 20 TeV energy is about 3.0 km. This value is consistent with the slightly improved version of the estimate made by HPK<sup>2)</sup>, namely

$$\Delta z \simeq 2\gamma_0^2 (1 + \nu_0^2) \pi \lambda / (1 + \bar{\beta}_y^2 \gamma_0^2) \quad (9)$$

where  $\nu_0^2$  is the intensity of the laser pulse's vector potential<sup>2)</sup>, and  $\bar{\beta}_y$  is an average value of the y-component of the particle velocity.

It is very important to realize that the overall characteristics of our machine is strongly dependent on the values of the available variables. An extensive analysis of optimization must be made in order to reach final conclusions concerning the size of the accelerator (as small as possible), the final energy of the protons (as high as possible), the laser and applied field intensities (as low as possible) and the injection angle,  $\theta_0$ .

The new SSC which we are proposing here consists of two injectors of 0.5 TeV protons some 6.0 km apart. The protons are injected into two NAIBA linear accelerators of 3.0 km in length that face each other. The resulting collider energy in the center of mass system will be the same as the proposed 100 km circular collider. Clearly many questions remain to be answered. The most important to our mind, is the luminosity of the beam which should be about  $10^{33} \text{ cm}^{-2}\text{s}$ . Since the luminosity is inversely proportional to the intersection area of the two beams, this requires a very small beam cross-section area. In turn this implies a very small laser transversal extension. Our calculations indicate that



the proton dispersion in the  $y$ -direction is in the range of few mm's. This must be made smaller, possibly by using a combined applied electric and magnetic fields.

In conclusion, we have proposed in this paper a new linear super collider that is 20 times smaller than the planned SSC. The basic components of our proton accelerator are two 0.5 TeV proton injectors, two very powerful lasers ( $P = 6.6 \times 10^{20} \frac{\text{W}}{\text{cm}^2}$ ,  $\lambda = 5 \times 10^{-3} \text{ cm}$ ) and an array of ( $\sim 22$ ) several powerful magnets ( $B_{\text{app}} \sim 10 \text{ teslas}$ ) with alternating signs. The values of these parameters can be easily changed to better the optimization of the machine. The question of radiation damping, an important one not considered here, will be discussed in Ref. 3).

#### Acknowledgments

We thank Carlos Escobar and Arthur Kerman for useful and informative discussion.

## REFERENCES

- 1) M.S. Hussein and M.P. Pato, *Phys. Rev. Lett.* **68**, 1136 (1992); M.S. Hussein and M.P. Pato, in preparation.
- 2) M.S. Hussein, M.P. Pato and A.K. Kerman, submitted for publication.
- 3) M.S. Hussein, M.P. Pato and A.K. Kerman, to be submitted.

## FIGURE CAPTIONS

Fig. 1: The relativistic factor,  $\gamma$  vs.  $z$ . A Gaussian laser pulse with a width of  $\Delta = 3\pi$  is used in the calculation (see text for details).



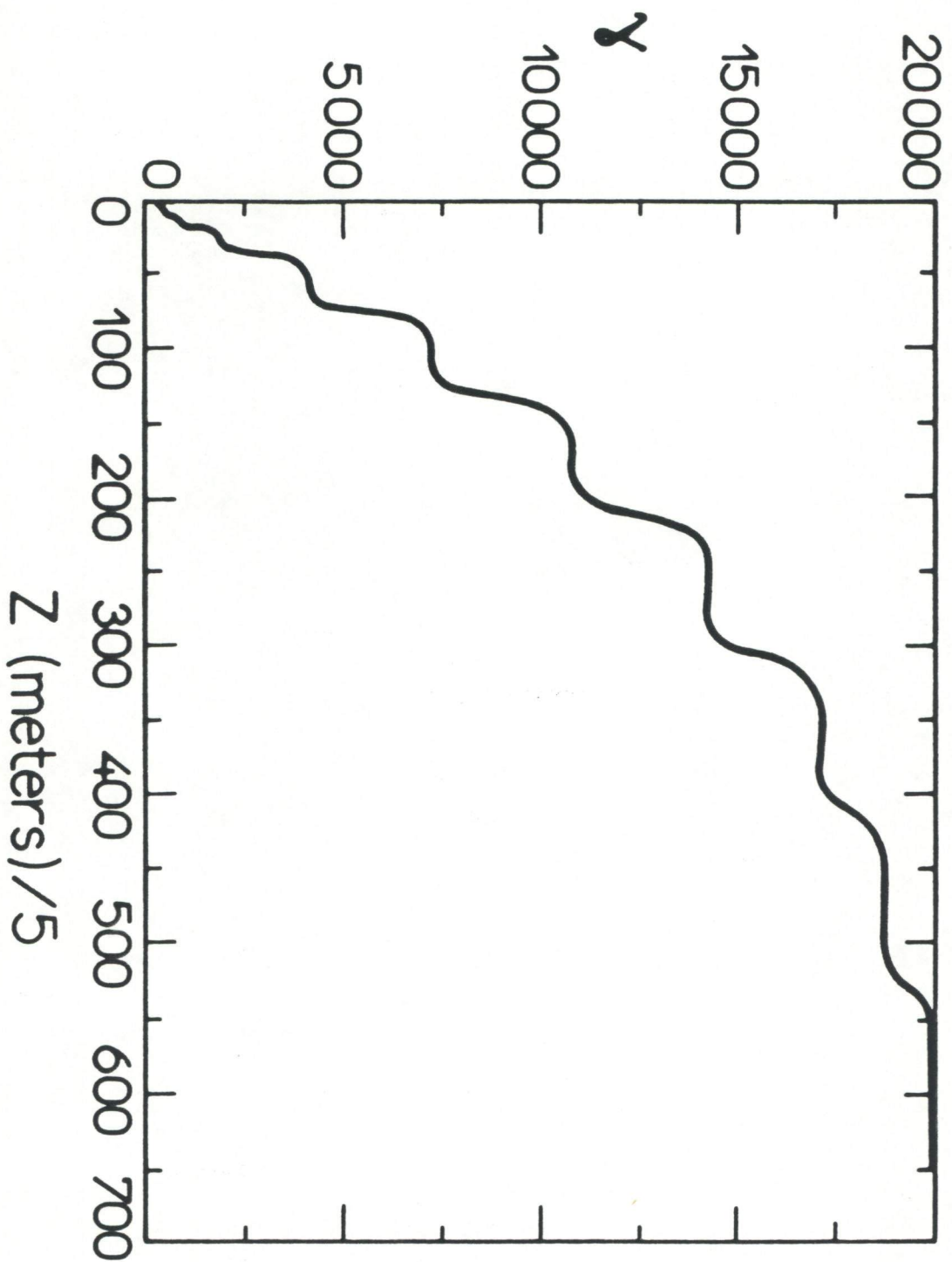


Fig. 1

# THEORY OF FREE WAVE ACCELERATION

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## Abstract

Laser acceleration of electrons is considered. A general formulation of the problem is developed which would allow the recently proposed NAIBEA accelerator to function with any state of polarization and shape of the laser pulse, and any kind of applied field. Analytical estimates as well as numerical analysis for the case of an applied magnetic field are made. It is found that electrons, injected with few tens of MeV's, can be accelerated to GeV energies using a NAIBEA accelerator of a length of few meters.

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Laser acceleration of particles, has been the focus of significant attention in the last few years. Recently, two of us<sup>1)</sup> have proposed a method of linearly accelerating electrons with the aid of a powerful laser coupled to an optimally determined static electric field which is made to change sign at appropriate places along the accelerator. With initial electron energy of 35 MeV, a laser power of  $10^{15}$  W/cm<sup>2</sup> for a wavelength of  $10 \mu\text{m}$  and an applied field intensity of  $\sim 10^{-5}$  that of the laser intensity, we predicted a final electron energy of, say,  $\sim 400$  MeV if three inversions of the static field are made along an accelerator tube of a length of about 3 meters! The advantages of such a machine obviously calls for a more general discussion concerning how optimum the set up is and the dependence on the laser parameters as well as the nature of the applied field.

In the present paper we develop a very general formulation of the problem that allows both semi-analytical and numerical answers to the above questions. Before entering into details, we first give some general remarks concerning the new acceleration principle which we called non-linear amplification of inverse bremsstrahlung electron acceleration (NAIBEA) in ref. 1). First, the new machine is meant to be a very high energy booster; the initial particle energy should already be highly relativistic. The reason is very simple. What sets the macroscopic scale of the machine is basically the Doppler shift of the laser wavelength as seen in the particle rest frame. Calling the laser wavelength  $\lambda_0$  and, the velocity of the particle  $v_0$  then the shifted wavelength obtained with the appropriate Lorentz transformation is

$$\lambda = \lambda_0 \left[ \frac{1 + \beta_0}{1 - \beta_0} \right]^{1/2}, \quad \beta_0 = v_0/c. \quad (1a)$$

Whereas  $\lambda_0$  is microscopic ( $\mu\text{m}$ 's),  $\lambda$  becomes macroscopic (cm's) if  $\beta_0$  is close to unity. The distance  $\Delta z$  travelled by the electron in the laboratory during a one cycle encounter

with the laser is then

$$\Delta z = v_0(\lambda/c)\gamma = \lambda_0 \frac{\beta_0}{1 - \beta_0} . \quad (1b)$$

Clearly  $\Delta z$  is one of the quantities that would decide the size of the accelerator.

Secondly, the rate of change of the particle energy is determined by  $\vec{v} \cdot \vec{E}$  and thus to keep the particle gaining energy from the laser,  $\vec{v} \cdot \vec{E}$  should be made always positive. This calls for another degree of freedom to couple to the system. A possible simple form for this extra degree of freedom, was found in Ref. 1) to be an array of applied static electric field with interchanging signs placed at appropriate positions along the accelerator. Clearly a more general form for this degree of freedom can be found that would make the machine more efficient. A combination of electric and magnetic fields, not necessarily static could be one of the choices. To better determine the nature of the applied field, one needs an equation, which we now turn our attention to its derivation.

To simplify the presentation, we consider the units of mass in  $mc^2$ , the vector potential  $A$  in  $mc/e$ , the distance  $x$  in  $1/k$ , where  $k$  is the wave number and time,  $t$  in  $1/\omega$ ;  $\omega$  being the frequency. We take the direction of wave propagation and particle, acceleration to be along  $z$ . The Hamiltonian of the system, particle + laser + applied field is (note that we are working in the temporal gauge)

$$H = \sqrt{1 + P_z^2 + (P_x - A_x)^2 + (P_y - A_y)^2} \equiv \gamma \quad (2)$$

in our units.

In Eq.(2)  $\vec{A} = \vec{A}^{(0)}(t-z) + \vec{A}_{app}(t,z)$ . Then  $\vec{E}_{app} = -\dot{\vec{A}}_{app}$  and  $\vec{B}_{app} = \vec{\nabla} \times \vec{A}_{app}$  are the external applied fields which add to those of the traveling laser pulse  $\vec{A}^{(0)}(t-z)$ .



Hamiltons equations follow from Eq.(1), i.e.

$$\begin{aligned}\dot{P}_z &= -\frac{\partial \gamma}{\partial z} ; \quad \dot{P}_x = 0 , \quad \dot{P}_y = 0 \\ \dot{\gamma} &= \frac{\partial \gamma}{\partial t} = \frac{\vec{P} - \vec{A}}{\gamma} \cdot \left[ \frac{\partial \vec{A}^{(0)}}{\partial t} + \frac{\partial \vec{A}_{app}}{\partial t} \right] .\end{aligned}\tag{3}$$

Futher reduction of  $\dot{P}_z$  gives

$$\dot{P}_z = \frac{\vec{P} - \vec{A}}{\gamma} \cdot \left[ \frac{\partial \vec{A}^{(0)}}{\partial t} + \frac{\partial \vec{A}_{app}}{\partial z} \right] .\tag{4}$$

Combining  $\dot{\gamma}$  and  $\dot{P}_z$  we obtain

$$\dot{\gamma} - \dot{P}_z = \frac{1}{\gamma} \left( (\vec{A} \times \vec{B}_{app})_z + \vec{A} \cdot \vec{E}_{app} \right)\tag{5}$$

which, when integrated yields

$$\gamma = P_z + u ; \quad u = u_0 + \int_{-\infty}^t \frac{((\vec{A} \times \vec{B}_{app})_z + \vec{A} \cdot \vec{E}_{app})}{\gamma} dt' ,\tag{6}$$

$$u_0 = \frac{1}{\gamma_0} (1 + \beta_0)^{-1} = \left[ \frac{1 - \beta_0}{1 + \beta_0} \right]^{1/2}$$

At this point, we remark, as was done in Ref. 1), that since  $\vec{A}^{(0)}$  will be the dominant field, it is more convenient to use the phase  $\varphi = t - z$  as an integration variable. Then, since  $\dot{\varphi} = 1 - \dot{z}$  and  $\dot{z} = \partial \gamma / \partial P_z = P_z / \gamma$  and from (6),  $1 - \dot{z} = u / \gamma$ , we have  $d\varphi / u = dt / \gamma$ . Further, since  $\dot{u} = (1 - \dot{z}) du / d\varphi = (u / \gamma) du / d\varphi$ , we obtain from Eq.(6)

the following

$$u^2(\varphi) = u_0^2 + 2 \int_{-\infty}^{\varphi} ((\vec{A} \times \vec{B}_{\text{app}})_z + \vec{A} \cdot \vec{E}_{\text{app}}) d\varphi' , \quad (7)$$

and from  $\gamma^2 = (P_z + u)^2 = 1 + P_z^2 + \vec{A}^2$  (Eq. 2) ,

$$\gamma(\varphi) = \frac{1 + \vec{A}^2 + u^2}{2u} ; \quad P_z = u \frac{dz}{d\varphi} = \frac{1 + \vec{A}^2 - u^2}{2u} \quad (8)$$

$$z(\varphi) = \int_{-\infty}^{\varphi} \left[ \frac{1 + \vec{A}^2 - u^2}{2u^2} \right] d\varphi' = \int_{-\infty}^{\varphi} \left[ \frac{\gamma(\varphi')}{u(\varphi')} - 1 \right] d\varphi' . \quad (9)$$

The  $x$  and  $y$  coordinates of the particle are determined from the equations  $\dot{P}_x = 0$  and  $\dot{P}_y = 0$  , which yield for the canonical momenta,  $P_x = 0$  and  $P_y = 0$  , and thus the physical momenta are given by

$$p_x = \gamma \dot{x} = -A_x \quad \text{and} \quad p_y = \gamma \dot{y} = -A_y \quad (10)$$

or

$$x(\varphi) = - \int_{-\infty}^{\varphi} \frac{A_x(\varphi') d\varphi'}{u(\varphi')} \quad (11)$$

$$y(\varphi) = - \int_{-\infty}^{\varphi} \frac{A_y(\varphi') d\varphi'}{u(\varphi')} . \quad (12)$$



The set of equations (7–11) constitutes the Free Wave Accelerator (FWA) equations. These equations are important generalizations of the NAIBEA equations of Ref. 1 in that: 1) the laser could be in any state of polarization, and have any pulse shape, and 2) the applied EM field  $\vec{E}_{\text{app}}$  and  $\vec{B}_{\text{app}}$  is quite general. Note that since  $\vec{A}$  is defined to within an arbitrary constant, we have here full freedom in giving the electron non zero initial value of  $p_x$  and/or  $p_y$  (Eq. 10). The trajectory parameter,  $Q$ , which was introduced in Ref. 1 is here generalized to be a vector in the  $x$ - $y$  plane and is defined by the equation

$$\frac{d\vec{Q}}{d\varphi} = -\vec{A} . \quad (13)$$

It is a simple matter to show that the second derivative of  $\vec{Q}$  can be written as

$$\frac{d^2\vec{Q}}{d\varphi^2} = \frac{-d\vec{A}^{(0)}(\varphi)}{d\varphi} + \frac{\gamma}{u} \vec{E}_{\text{app}} + \left[ \frac{\gamma}{u} - 1 \right] \vec{B}_{\text{app}} \quad (14)$$

and the rate change of  $\gamma$  with respect to  $\varphi$

$$\frac{d\gamma}{d\varphi} = (\vec{p} \cdot \vec{E})/u = -\frac{1}{u} \vec{A} \cdot \vec{E} = \frac{1}{u} \frac{d\vec{Q}}{d\varphi} \cdot \vec{E}(\varphi) . \quad (15)$$

For  $\gamma$  to increase with  $\varphi$ ,  $\frac{d\vec{Q}}{d\varphi} \cdot \vec{E}(\varphi)$  must always be positive (notice that  $u(\varphi) > 0$ )

$$\frac{d\vec{Q}}{d\varphi} \cdot \vec{E} > 0 . \quad (16)$$

The above is the condition that guarantees that when  $E_i(\varphi_j) = 0$ ,  $p_i(\varphi_j) = \frac{dQ_i}{d\varphi_j}$  is also zero, then  $\frac{d\gamma(\varphi_i)}{d\varphi} = 0$  and  $\frac{d^2\gamma(\varphi_i)}{d\varphi^2} = 0$ . Having such an inflection point in  $\gamma$  at  $\varphi_j$

(instead of a maximum) guarantees that  $\gamma$  keeps increasing for  $\varphi > \varphi_j$ . If  $B_{app}$  is taken to be zero as Ref. 1, then  $\vec{p} \cdot \vec{E} = \vec{p} \cdot \vec{E}^{(0)} + \vec{p} \cdot \vec{E}_{app}$ . If  $\vec{E}$  is taken in the y-direction, then we have  $p_y E_y^{(0)} + p_y E_{app} > 0$ . Since  $E_y^{(0)}$  is the dominant field, except when passing through zero, the above condition says that we use  $E_{app}$  to "fine tune" the sign of  $p_y$  so that it is always the same as that of  $E_y^{(0)}$ . The fundamental role of the applied field is to guarantee the validity of Eq.(16). This can happen even if  $E_{app}/E^{(0)}$  or  $B_{app}/B^{(0)}$  or both are much smaller than unity. The injection of electrons with a non-zero  $p_x(0)$  or  $p_y(0)$ , albeit very small, is very important to set the machine to work. This is so since in the x-y plane the motion of the electron must be oscillatory in accordance with Eq.(16).

We turn now to specific choices of the accelerator. We consider a linearly polarized pulse with  $\vec{A}$  taken to be along the y direction. We first consider a constant applied electric field,  $E_{app}$ , then

$$\vec{A} = \left[ A_y^{(0)}(\varphi) - E_{app} t - p_y(0) \right] \hat{j} . \quad (17)$$

With the  $\vec{A}$  above used in the FWA equations we recover the NAIBEA equation of Ref. 1. Inversions of  $E_{app}$  are made at appropriate values of  $z$  to assure the validity of Eq. (16), namely  $p_y(n\pi) = 0$ . This means that the applied field is inverted at  $\varphi_j$ 's such that  $\left. \frac{dp_y(\varphi)}{d\varphi} \right|_{\varphi_j = \frac{n\pi}{2}} = 0$ .

We now replace  $E_{app}$  by a constant magnetic field along x. Then

$$\vec{A} = \left[ A_y^{(0)}(\varphi) - B_{app} z - p_y(0) \right] \hat{j} . \quad (18)$$

The resulting NAIBEA equations are almost identical to those of Ref. 1 except for a



change in sign of the second term in Eq.(8) of that reference (with  $E_{app}$  replaced by  $B_{app}$ ). Further, Eq.(7) reduces to

$$u^2 = u_0^2 - 2 B_{app} Q . \quad (19)$$

The y-component of the momentum is given by (Eq. 10)

$$p_y(\varphi) = p_y(0) - A_y^{(0)}(\varphi) + B_{app} z . \quad (20)$$

The continuous acceleration of the particle results if  $B_{app}$  is chosen so that  $p_y(n\pi) = 0$ . This requires changing the sign of  $B_{app}$  at appropriate places ( $\varphi \simeq \frac{n}{2} \pi$ ).

We consider the following numerical example. The initial value of  $\gamma$ ,  $\gamma_0 = 70$ ,  $P = \frac{3}{2} \nu_0^2 10^{+15} \text{ W/cm}^2$  for  $\lambda_0 = 10^{-3} \text{ cm}$ . The parameter  $\nu_0 = 1$  refers to the maximum value of electric field of the pulse in our units. We also take nine cycles within the pulse. The shape of the pulse is taken to be a Gaussian,  $\bar{A}_0^2 = \exp(-\varphi^2/\Delta^2)$ , Fig. 1, with  $\Delta = 3\pi$ . The applied field intensity is taken to be 2.34 teslas which corresponds to  $\sim 5 \times 10^{-5}$  that of the laser. The electrons are injected at an angle of  $0.6^\circ$  with respect to the z-axis ( $p_y(0) \approx \frac{0.6}{180} \pi \gamma_0$ ). We consider, as an example nine changes in the sign of the modulated applied magnetic field. Since we have not self consistently chosen the position of the field reversal we have not actually optimized the decrease of  $u$  in Eq.(6). In figure 2 we show the change of  $\gamma$  vs.  $z$ . The gain in energy is a factor of 35 over a distance (accelerator length) of seven meters! The accelerator length could be made smaller if full optimization is accomplished. The corresponding trajectory of the particle, confined in the (z,y)-plane is shown in figure 3. The undulation in  $y(z)$  is a consequence of the changes in the sign of  $B_{app}$  and it guarantees that the particle remains in the path of the laser if one insists that

$$y = - \int_{-\infty}^{\varphi} \frac{A_y^{(0)}(\varphi')}{u(\varphi')} d\varphi' , \quad (21)$$

is contained within the laser transversal extension. As we see from figure 2, at the end of the acceleration the dispersion in  $y$  is  $\sim 2$  mm which could be within available laser transversal dimensions<sup>2)</sup>.

Before ending we comment briefly on the case of circularly polarized laser pulse,

$$\vec{A}^{(0)} = \bar{A}(\varphi) [\hat{i} \cos \varphi + \hat{j} \sin \varphi] , \quad (22)$$

$$\bar{A}(\varphi) = \nu_0 \exp(-\varphi^2/2\Delta^2) .$$

Thus, clearly  $\vec{A}^2$  is just  $\bar{A}^2(\varphi)$ , which does not oscillate. Then we get approximately for the accelerator length

$$\Delta z = \frac{1 - u_0^2}{2u_0^2} T + \frac{\nu_0^2}{2u_0^2} T \approx (2\gamma_0^2)(1 + \nu_0^2) T \quad (23)$$

where  $T$  is  $\Delta\varphi$  of the pulse defined as  $\int_{-\infty}^{\infty} A^2 d\varphi' = \nu_0^2 T \equiv 2\pi \nu_0^2 n$ , where  $n$  is the number of oscillations in the pulse. Thus  $\Delta z$  is determined by three large factors  $(\gamma_0^2, \nu_0^2, n)$  which can easily make it macroscopic even though it is in units of  $\frac{\lambda}{2\pi}$ . This generalizes the simple Doppler shift argument concerning the size of the accelerator.

In conclusion, we have developed here a general formalism for Free Wave Acceleration. A combined powerful laser pulse plus an optimally determined EM field, which could be time-dependent, was found to be able to accelerate electrons to very high



energies with relatively small accelerator dimensions. Radiation damping has not been included in our theory and it may modify some of our conclusions, even in setting a limit to the final energy of the particle<sup>3,4)</sup>. After the completion of this paper we learned of related work done in Refs. <sup>5)</sup> and <sup>6)</sup>.

## REFERENCES

- 1) M.S. Hussein and M.P. Pato, *Phys. Rev. Lett.* **68**, 1136 (1992) and references therein; M.S. Hussein and M.P. Pato, to be published.
- 2) P.W. Milonni and J.H. Eberly, "Lasers", (John Wiley & Sons, New York, 1988) pg. 484.
- 3) L.D. Landau and E.M. Lifshitz, "The Classical Theory of Fields", (Addison-Wesley, Reading, Massachusetts, 1962).
- 4) M.S. Hussein, M.P. Pato and A.K. Kerman, to be published.
- 5) P.K. Kaw and R.M. Kulsrud, *Physics of Fluids* **16**, 321 (1973).
- 6) A.A. Chernikov, G. Schmidt and A.I. Neishtadt, *Phys. Rev. Lett.* **68**, 1507 (1992).



## FIGURE CAPTIONS

- Figure 1. The laser pulse vs.  $\varphi$  used in our calculation the width  $\Delta = 3\pi$ .
- Figure 2. The energy of the particle in units of  $mc^2$  vs. the traveled distance  $z$ .
- Figure 3. The trajectory of the particle in the  $y$ - $z$  plane. Inset: scale of  $y$  in mm.

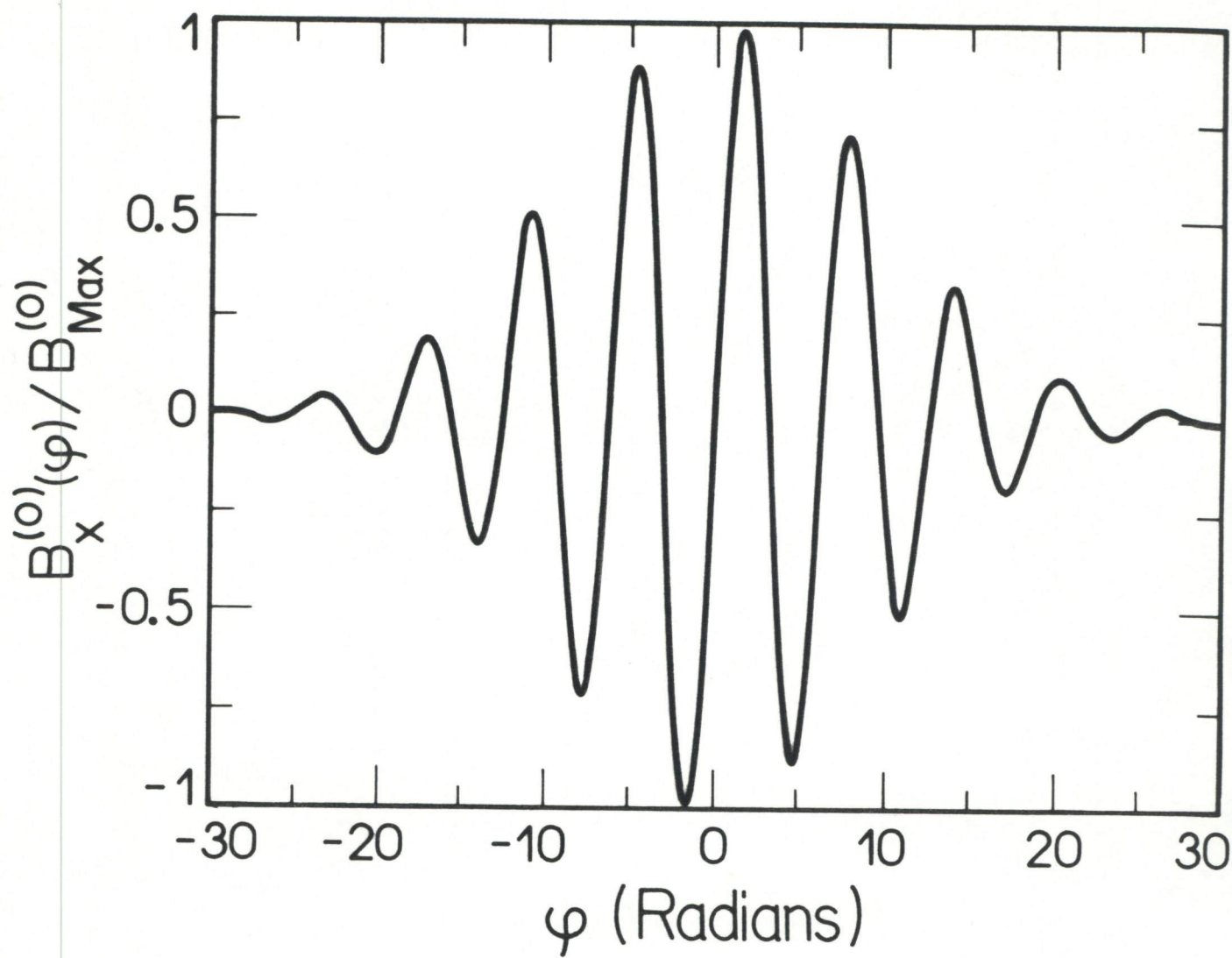


Fig. 1



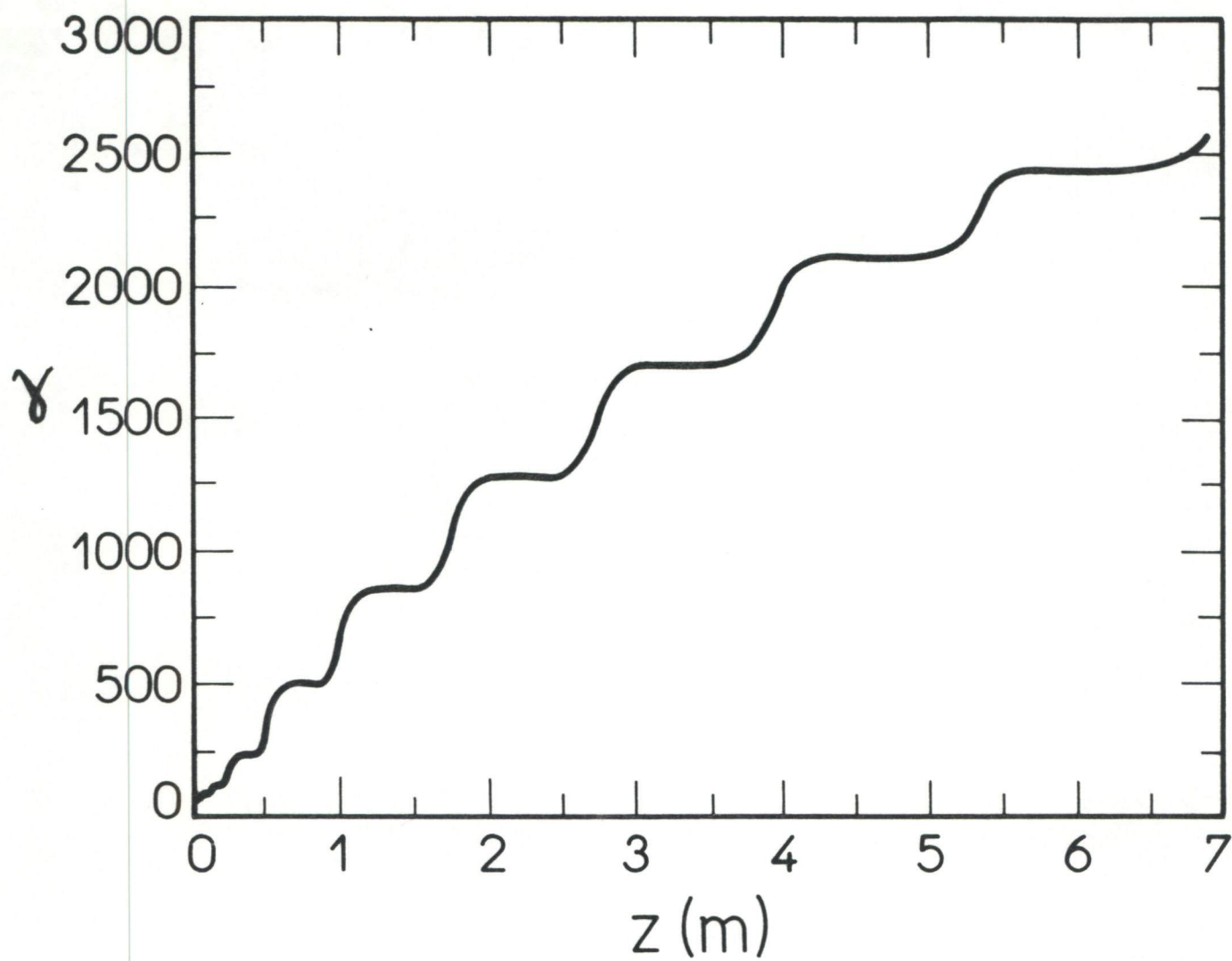


Fig. 2

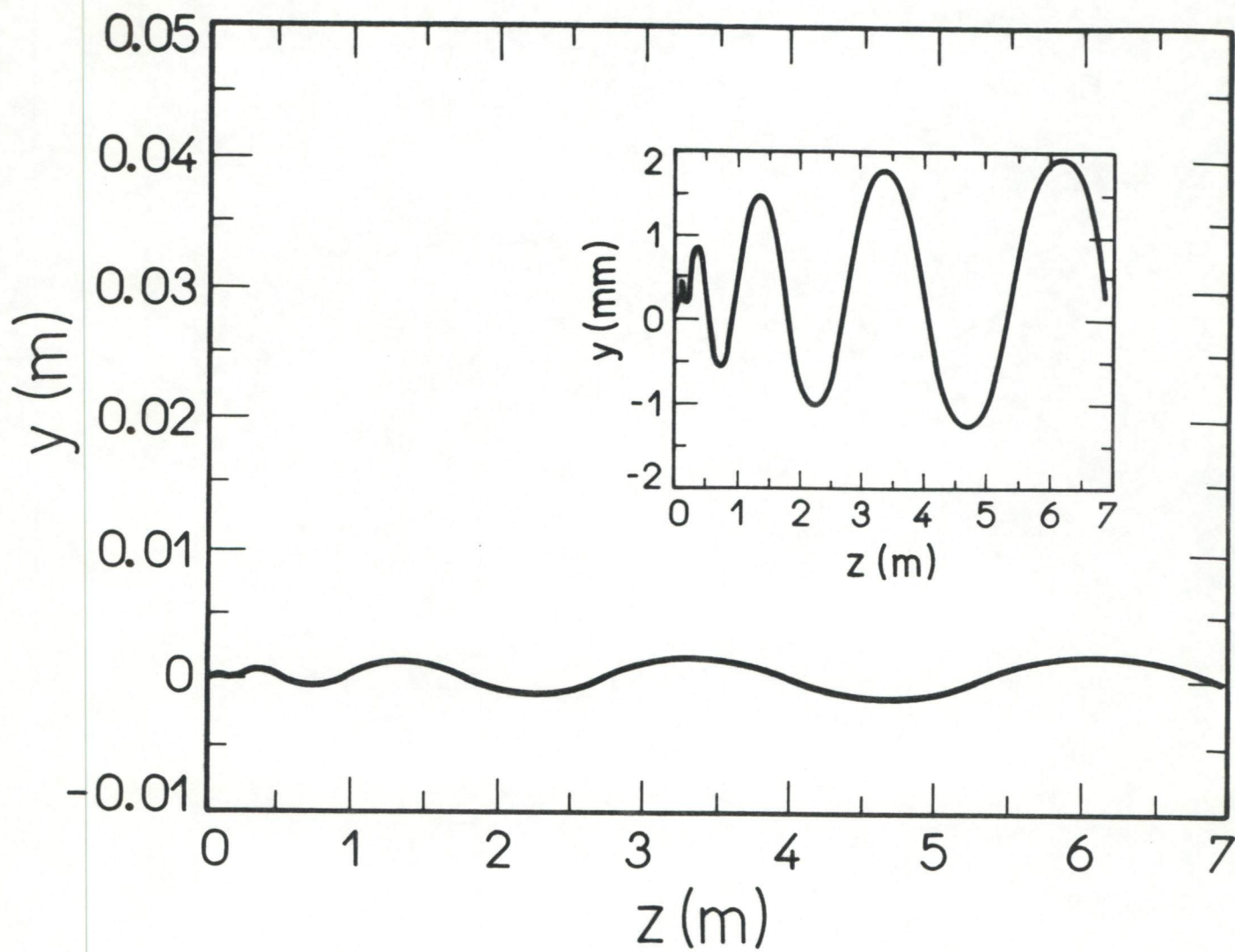


Fig. 3



# Nonlinear Amplification of Inverse-Bremsstrahlung Electron Acceleration

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(Received 20 December 1991)

The acceleration of electrons using a laser and a static electric field perpendicular to the former is considered. The coupled particle-field equations are reduced to a second-order nonlinear inhomogeneous equation which determines the trajectory of the particle. The particle energy equation is considered and found to exhibit fold catastrophes. At these catastrophes, which may occur whenever the wave phase is  $n\pi$  if the direction of the applied weak field is reversed at  $(2n-1)\pi/2$ , further net acceleration occurs. The trajectory equation is found amenable to analytical treatment.

PACS numbers: 41.75.Fr, 29.17.+w

Laser acceleration of particles without plasma has been proposed as a means of gaining energy without the difficulty of plasma control [1-3]. In this method one uses a strong laser field (typically the power is  $\sim 10^{15}$  W/cm<sup>2</sup> for a wavelength of 10  $\mu$ m) to set the particles in motion, and a weak perpendicular static electric or magnetic field (with a intensity of  $10^{-5}$  that of the laser field). The resulting slightly deformed electromagnetic (EM) field allows for the acceleration of the particles. Clearly the laser field alone only sets the kinetic energy of the particle oscillation without any net gain [4].

In a recent paper, Kawata *et al.* [5] discussed in detail the optimal conditions for electron acceleration with a laser plus small perpendicular static electric field,  $E_{app}$ . Through single-particle computation and particle simulation, they found that the electron is accelerated in both half wavelengths of the wave, and its relativistic factor  $\gamma$  increases by as much as a factor of 3.

In this Letter we analytically analyze the work of Ref. [5] and show that the coupled electron-EM-field system is governed by a set of equations containing one nonlinear and several linear ones. The nonlinear equation can be solved exactly and it governs the bulk of the physics; the linear equations are then solved from the knowledge of the solution to the nonlinear one. We predict, among other things, that the increase of  $\gamma$  can be made much larger than given in Ref. [5] by applying, at optimally determined positions, an array of  $E_{app}$ 's with interchanging signs.

The starting point of our analysis is the coupled particle-field equations (see Fig. 1)

$$\frac{dP_x}{dt} = -e\beta_y E_y, \quad (1)$$

$$\frac{dP_y}{dt} = -e(1 - \beta_x)E_y - eE_{app}, \quad (2)$$

where  $E_{app}$  is the applied field intensity,  $\beta_x = v_x/c$ ,  $\beta_y = v_y/c$ , and  $B_z = E_y = -E_{y0} \sin \varphi$  with  $\varphi = k(ct - x)$ .  $P_x$  and  $P_y$  are the  $x$  and  $y$  components of the linear momentum of the particle. The energy equation can be easily derived from Eqs. (1) and (2) by multiplying Eq. (1) by

$v_x$  and (2) by  $v_y$  and adding to obtain

$$\frac{d\epsilon}{dt} = -eE_y v_y, \quad \epsilon(t) = mc^2 \gamma(t) + eE_{app} y(t), \quad (3)$$

where  $\gamma$  is the time varying relativistic factor which relates  $P_x$  and  $P_y$  to  $v_x$  and  $v_y$  through  $P_x = m\gamma v_x$  and  $P_y = m\gamma v_y$ .

From (1), (2), and (3) one can obtain the solutions

$$P_x c = mc^2 \gamma + eE_{app} y + K_1, \quad (4)$$

$$P_y c = -(e/k)E_{y0} \cos \varphi - eE_{app} ct + K_2, \quad (5)$$

where  $K_1$  and  $K_2$  are constants determined from the initial conditions. We now show that the dynamical equations (1), (2), and (3) can be reduced to a one-dimensional problem through a change of the independent variable from the time to the phase  $\varphi$ . This is accomplished by introducing the new coordinate  $Q$ ,

$$Q = -(k/2c)(eE_{app} y^2 + 2K_1 y), \quad (6)$$

such that  $P_y = dQ/d\varphi$ . Using the fact that  $\varphi = k(ct - x)$

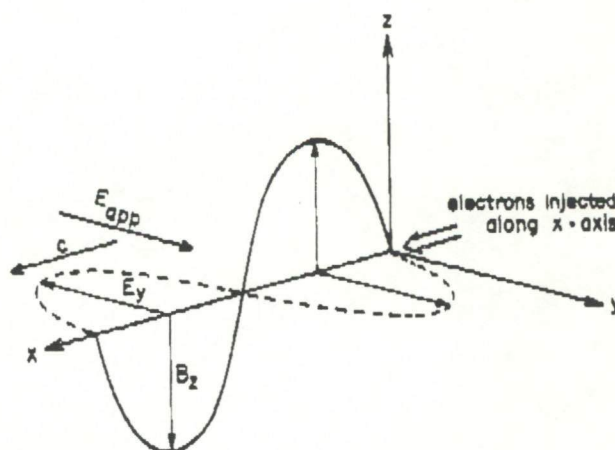


FIG. 1. The coupled electron-laser-static-field configuration.



$-v_x) = -(k/mc\gamma)(eE_{app}y + K_1)$  and from (4),

$$mc^2\gamma = \frac{1}{2} \frac{m^2c^4 + P_y^2c^2}{(K_1^2 - 2ceE_{app}Q/k)^{1/2}} + \frac{1}{2} \left[ K_1^2 - \frac{2ceE_{app}Q}{k} \right]^{1/2} \quad (7)$$

Taking the derivative with respect to the phase  $\varphi$  of Eqs. (4) and using (5) and (7) we finally obtain

$$Q'' = -\frac{c}{2k} eE_{app} \frac{m^2c^2 + Q'^2}{K_1^2 - (2c/k)eE_{app}Q} - \frac{eE_{app}}{2kc} + \frac{e}{kc} E_{y0} \sin\varphi \quad (8)$$

and

$$\varepsilon' = \frac{ceE_{y0}}{k} \frac{1}{(K_1^2 - 2ceE_{app}Q/k)^{1/2}} Q' \sin\varphi. \quad (9)$$

Equations (8) and (9) are the inverse-bremsstrahlung electron acceleration (IBEA) equations. Equation (8) is a second-order nonlinear inhomogeneous one that deter-

mines the trajectory of the particle since  $x$  and  $y$  are explicitly given in terms of  $Q$  as

$$x = \frac{1}{k} \left[ kc \frac{1}{eE_{app}} \left( -Q' - \frac{e}{kc} E_{y0} \cos\varphi + \frac{K_2}{c} \right) - \varphi \right], \quad (10)$$

$$y = -\frac{1}{eE_{app}} \left[ \left( K_1^2 - \frac{2ceE_{app}Q}{k} \right)^{1/2} + K_1 \right]. \quad (11)$$

The acceleration equation, Eq. (9), is easily solved once a first integration of (8) is done. The important feature to be emphasized here is that  $\varepsilon'$  is proportional to  $Q' \sin\varphi$ .

Before discussing the solution of Eq. (8), we analyze the expected behavior of the energy as a function of  $\varphi$  (or  $t$ ). Clearly whenever  $\varphi = n\pi$ ,  $\varepsilon'$  is zero ( $\varepsilon$  is maximum or minimum). If, say, at  $\varphi = \pi$ ,  $Q' = P_y$  is also zero, then  $\varepsilon$  is at an inflection point,  $\varepsilon'' = 0$ . This behavior is commonly referred to as a fold catastrophe, according to the classification of Thom [6]. This catastrophe also characterizes the phenomenon of a rainbow. This behavior is shown in Fig. 2, where a case similar to that of Ref. [5] is considered, namely, the amplitude of the EM wave is  $E_{y0} = 0.1E_0$ , where  $E_0 = mc^2/(e\lambda/32) = 1.636 \times 10^7/\lambda$  (V/cm),  $\lambda$  is the wavelength in cm, and  $E_{app}/E_{y0} = 4.28 \times 10^{-3}$ . The laser power is  $3.5 \times 10^{15}$  W/cm<sup>2</sup> for  $\lambda = 10 \mu\text{m}$ . The initial electron velocity is  $v_0 = 0.9999c$ . The electrons are injected at an angle of  $0.608^\circ$  with respect to the laser direction (along  $x$ ). The figure exhibits  $\varepsilon(\varphi)$  and  $Q(\varphi)$ . The inflection point alluded to above is clearly shown (indicated by the arrow). At later times  $\varepsilon$  reaches a maximum at  $\varphi = 2\pi$  and then just oscillates along with the wave. If the applied field is reversed at  $3\pi/2$ , the original maximum in  $\varepsilon$  at  $\varphi = 2\pi$  becomes an inflection point and the particle energy is then pushed up to another maximum at  $3\pi$  after which the oscillation sets in again. The net gain in energy after the first kick is about 300%, whereas after the second kick it is 600%. Thus one can double the gain by reversing the direction of the applied electric field at the appropriate time (or  $x$ ). In Fig. 3 we show  $\varepsilon(t)$  vs  $t$  which exhibits the staircase

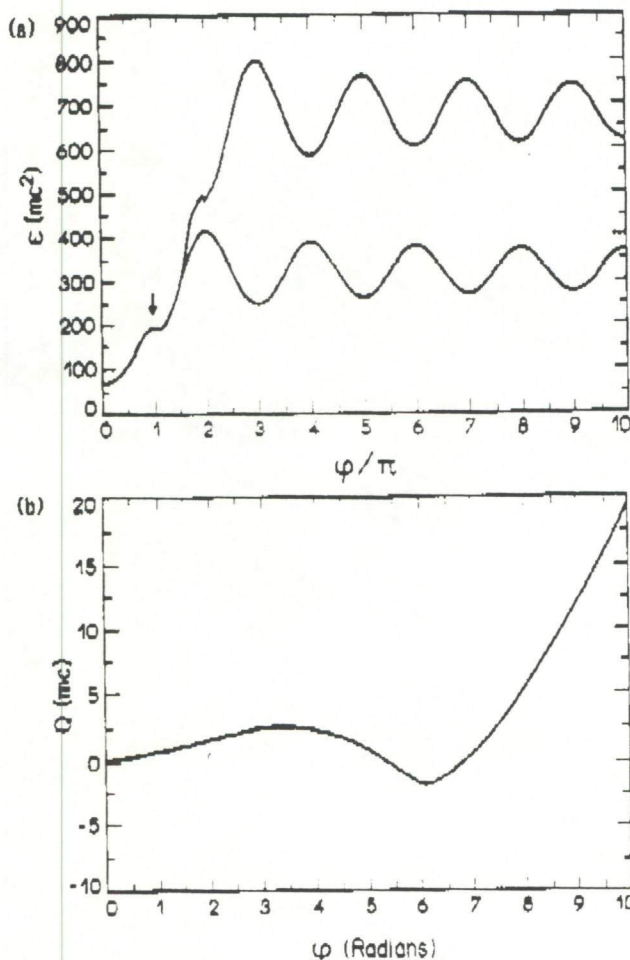


FIG. 2. (a) The energy  $\varepsilon$  in units of the electron rest mass  $mc^2$  vs the laser phase. The lower curve is the result of Ref. [5], whereas the upper one is our result (see text for details). (b) The trajectory variable in units of  $mc$  vs the laser phase.

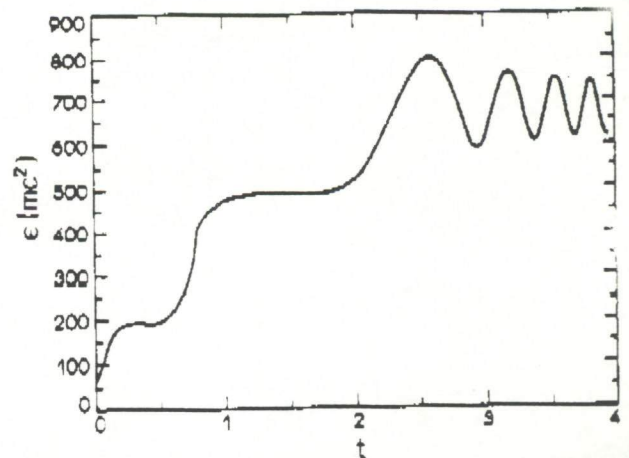


FIG. 3. The energy  $\varepsilon$  in units of  $mc^2$  vs the time in units of  $1.01 \times 10^6 \lambda/32c$  (see text and Ref. [5] for details).



structure of the acceleration quite clearly.

The mechanism responsible for this doubling of the gain in the particle energy is governed by nonlinear equations. We therefore call it the nonlinear amplification of inverse-bremsstrahlung electron acceleration (NAIBEA). Clearly the NAIBEA can be repeated several times by merely alternating the sign of the applied field at the appropriate phase of the wave. A simple estimate of the net gain in energy after the elapse of  $n\pi$  in  $\varphi$ , with accompanying changes in the sign of  $E_{\text{app}}$ , is  $\sim n(\Delta\epsilon)$ , where  $\Delta\epsilon$  is the gain after the first kick (in our case  $\Delta\epsilon$  is about 150 MeV). The way to accomplish this is by arranging an array of  $E_{\text{app}}$ 's with interchanging signs at appropriate positions along the  $x$  direction. These locations are obtained from Eq. (10). The position  $x_1$  at which the first inflection point in  $\epsilon$  occurs is

$$x_1 = \frac{E_{y0}}{\pi E_{\text{app}}} \lambda + \frac{cP_y(0)}{eE_{\text{app}}} - \frac{\lambda}{2} = 0.11 \text{ m}. \quad (12)$$

If the applied field is reversed at  $\varphi = 3\pi/2$ , which corresponds to the position  $x'_1$ ,

$$x'_1 = \frac{1}{k} \left[ \frac{kc}{eE_{\text{app}}} \left[ -Q'_{3\pi/2} + P_y(0) + \frac{e}{kc} E_{y0} \right] - \frac{3\pi}{2} \right] \approx 0.243 \text{ m}, \quad (13)$$

then the position of the second kick or inflection point is

$$x_2 = x_1 + \frac{2|Q'_{3\pi/2}|c}{eE_{\text{app}}} - \frac{\lambda}{2} = x_1 + 0.365 \text{ m} = 0.474 \text{ m}. \quad (14)$$

It is easy to show that the position of the  $n$ th reversing of the static field is given by

$$x'_n = \frac{K_2^{(n-1)} + |Q'_{(2n+1)\pi/2}|}{eE_{\text{app}}} - \frac{2n+1}{2k} \pi, \quad (15)$$

where  $K_2^{(n-1)}$  is given by

$$K_2^{(n-1)} = K_2^{(n-2)} + 2Q'_{(2n+1)\pi/2}, \quad (16)$$

and the corresponding following kick by

$$x_{n+1} = x_n + \frac{2Q'_{(2n+1)\pi/2}}{eE_{\text{app}}} - \frac{\lambda}{2}. \quad (17)$$

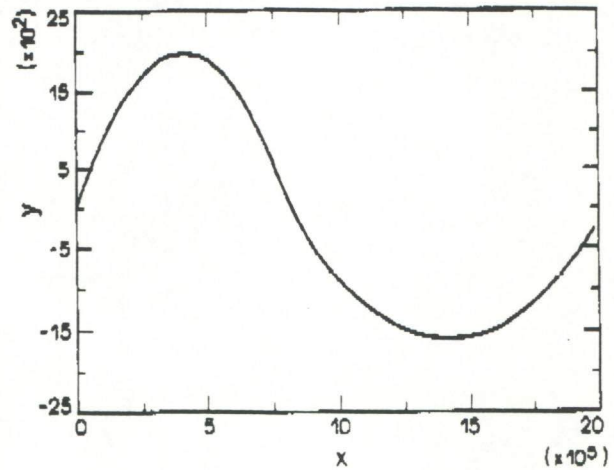


FIG. 4. The trajectory of the electron. Axes  $y$  and  $x$  are given in units of  $\lambda/32$ , where  $\lambda$  is the wavelength of the laser wave (see text for details).

The values of  $Q'$  can be calculated from the trajectory equation, Eq. (8), to which we turn our attention below. Before doing this we mention that the trajectory of the electrons accelerated with the NAIBEA mechanism is well behaved. Figure 4 shows a typical case. The dispersion (oscillation) along the  $y$  direction is quite small.

Numerical integration of Eq. (8) is quite simple. However, to gain more insight into what to expect we develop in what follows a procedure through which an analytical solution can be obtained albeit in an approximate way. To proceed we write the solution of  $q = Q/mc$ , as

$$q = q_0 + Bq_1 + B^2q_2 + \dots, \quad (18)$$

where  $B$  is the laser parameter,

$$B = eE_{y0}/kmc^2 = 0.5093. \quad (19)$$

In Eq. (18)  $q_0$  satisfies the nonlinear equation

$$q_0'' = \frac{1}{4} \frac{1+q_0'^2}{q_0 - k_0}, \quad (20)$$

whereas  $q_1$  and  $q_2$  are both given by linear equations

$$q_1'' + \frac{q_0'}{2(k_0 - q_0)} q_1' + \frac{1+q_0'^2}{4(k_0 - q_0)^2} q_1 = -\frac{1}{2} BG + B \sin \varphi, \quad (21)$$

$$q_2'' + \frac{q_0'}{2(k_0 - q_0)} q_2' + \frac{1+q_0'^2}{4(k_0 - q_0)^2} q_2 = \frac{1}{4} \frac{q_1'^2}{q_0 - k_0} - \frac{q_0' q_1 q_1'}{2(q_0 - k_0)^2} + \frac{(1+q_0'^2)q_1^2}{4(q_0 - k_0)^3}, \quad (22)$$

where

$$k_0 = \frac{kK_1^2}{2mc^2 e E_{\text{app}}}, \quad G = \frac{E_{\text{app}}}{E_{y0}}. \quad (23)$$

Equation (20) can be easily solved analytically, and from the solution,  $q_0$ , Eqs. (21) and (22) can be integrated. The details of the full solution will be presented elsewhere [7]. In Fig. 5 we present a comparison between the analytical method, based on Eq. (18) (dashed line), and the numerically generated one. We have here an agreement to better than

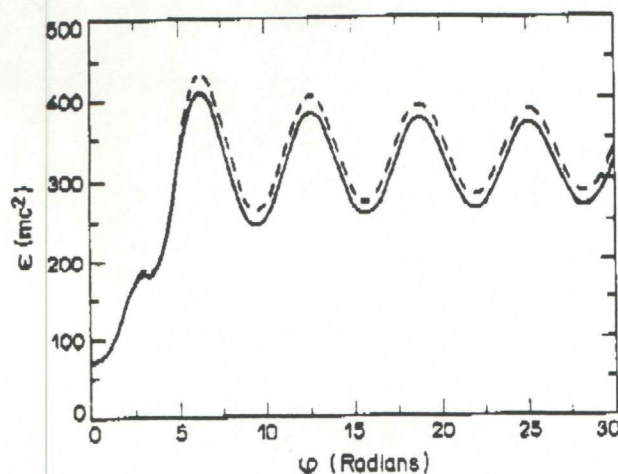


FIG. 5. Solid curve: Numerically generated solution of Eqs. (8) and (9) in the one-kick case of Ref. [5]. Dashed curve: The result obtained from the analytical method, Eqs. (18), (20), (21), and (22) (see text for details).

7% at the maxima and minima and better than 2% on the average. Therefore, for all practical purposes, the set of Eqs. (18), (20), (21), and (22) is an excellent substitute for the numerically generated solution.

In conclusion, we have further analyzed the IBEA model of Kawata *et al.* [5], and found it to be amenable to analytical treatment. We also discovered a new way of

increasing the gain in electron energy through the mechanism we coined NAIBEA. Our accelerator involves applying an array of  $E_{app}$ 's with interchanging signs at optimally determined positions. Further optimization can be obtained by adjusting (through magnets) the new "entrance" angle after every kick.

This work was supported in part by CNPq.

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- [1] V. V. Apollonov, A. I. Artem'ev, Yu. L. Kalachev, A. M. Pronkhorov, and M. V. Fedorov, *Pis'ma Zh. Eksp. Teor. Fiz.* **47**, 77 (1988) [*JETP Lett.* **47**, 91 (1988)].
  - [2] S. Kawata, A. Manabe, and S. Takeuchi, *Jpn. J. Appl. Phys.* **28**, L704 (1989).
  - [3] S. Kawata, H. Watanabe, and A. Manabe, *Jpn. J. Appl. Phys.* **29**, L179 (1990).
  - [4] To be more precise, in the absence of the static field, the electron can be accelerated only during a half period. One can more than double the value of  $\gamma$  in this period, in the case study of this paper.
  - [5] S. Kawata, T. Maruyama, H. Watanabe, and I. Takahashi, *Phys. Rev. Lett.* **66**, 2072 (1991).
  - [6] R. Thom, *Stabilité Structurelle et Morphogénese* (Benjamin, Reading, MA, 1972); in *Dynamical Systems — Warwick, 1974, Lecture Notes in Mathematics* Vol. 468 (Springer-Verlag, Berlin, 1974); see also M. V. Berry, *Adv. Phys.* **25**, 1 (1976).
  - [7] M. S. Hussein and M. P. Pato (to be published).



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WASHINGTON, D.C. 20506

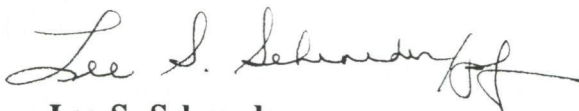
June 8, 1992

Dear Dr. Hussein:

Thank you for your recent letter and enclosed material on new particle acceleration techniques. Dr. Bromley has asked me to respond to it.

I have read your papers with considerable interest. As we have seen in high energy physics, the need to probe yet higher energies, has required ever larger machines which in turn have pushed the limits of accelerator technology outward, e.g., use of superconducting magnets. The SSC, with its present magnet design, is coming along nicely. Full size prototype dipoles will be operated in a string test later this summer at the SSC laboratory, and I am optimistic that their technical properties will allow completion of the accelerator complex by the end of the decade--assuming Congress appropriates the requisite funds. For the longer term, and future generations of particle accelerators, ideas such as yours, involving powerful lasers in conjunction static electric fields and high magnetic field magnets, need to be carefully considered. Of course, as pointed out in your preprint, you discuss a linear collider rather than a synchrotron and thus the question of achieving sufficient luminosity is a critical issue. From discussions that I have had on this subject, I would expect that considerable time and energy will be required, both on the theoretical and experimental side, to demonstrate the feasibility of the technical approach that you are proposing for particle acceleration. However, it is through such efforts as those of you and your colleagues that breakthroughs in accelerator technology occur and I wish you continued success in these endeavors.

Sincerely yours,



Lee S. Schroeder  
Assistant Director

Dr. Mahir S. Hussein  
Nuclear Theory and Elementary Particle  
Phenomenology Group  
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Caixa Postal 20516  
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TO: DR. D.A. BROMLEY

APR 20 1992

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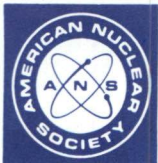
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The Honorable Allan D. Bromley  
Assistant to the President for  
Science and Technology Policy  
Old Executive Office Building  
17th Street & Penn Avenue, NW  
Washington, DC 20500

Dear Assistant Bromley:

The American Nuclear Society (ANS) supports the concept of continued development of the peaceful applications of nuclear science and technology throughout the world and assured safety, protection of the environment, and non-proliferation of nuclear materials. Nuclear professionals involved in weapons-related activities need to be made aware of and have available to them training, education and other opportunities which offer experience and, ultimately, employment in the peaceful uses of nuclear technology.

The Society is offering its services including professional placement activities to government, industry and academia to assist these professionals. Additionally, ANS urges its individual and organizational members to consider opportunities for joint international endeavors with foreign counterparts. These efforts will strengthen the international nuclear community and encourage the continued peaceful uses of nuclear science and technology.

Sincerely Yours,

A handwritten signature in dark ink, appearing to read 'Robert L. Long', written in a cursive style.

Robert L. Long  
ANS President

/mrh

EXECUTIVE OFFICE OF THE PRESIDENT  
OFFICE OF SCIENCE AND TECHNOLOGY POLICY  
WASHINGTON, D.C. 20506

May 12, 1992

Dear Mr. Long:

I am responding to your letter to Dr. Bromley concerning the expertise of the American Nuclear Society, and the Society's activities to strengthen the international nuclear community and to encourage the continued peaceful uses of nuclear science and technology. The efforts of the Society are very much appreciated and will, I believe, help lead to a future in which nuclear energy plays its logical role in the worldwide energy technology portfolio.

Sincerely,



Karl A. Erb  
Associate Director--Designate  
for Physical Sciences and Engineering

Mr. Robert L. Long  
President  
American Nuclear Society  
555 North Kensington Ave.  
La Grange Park, IL 60525

*I would welcome the  
opportunity to discuss the  
Society's initiatives with  
you.*



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FROM: AUBRY, Arthur S.: AUBRY PHOTOGRAPHY

TO: DR. D.A. BROMLEY

APR 1992

DATE OF  
CORRESPONDENCE: 03/25/92

SUBJECT: HE IS WRITING REGARDING THE DOE'S DECISION TO PUT  
THE FAST FLUX TEST FACILITY ON STAND BY. HE URGES  
DR. BROMLEY TO DO EVERYTHING IN HIS POWER TO ENABLE  
THE CONTINUED OPERATION OF THE FACILITY.

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REQUIRED: AS NECESSARY ACTION:

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DOCTOR D. A. BROMLEY

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MAIL ROOM

AS AN ENVIRONMENTALLY CONCERNED INDIVIDUAL AND AS AN ARTIST, I FIND THE DEPARTMENT OF ENERGY'S DECISION TO PLACE THE FAST FLUX TEST FACILITY (ON THE HANFORD NUCLEAR RESERVATION IN WASHINGTON STATE) ON 'STAND BY' COMPLETELY INCONGRUOUS.

AS THE ONLY FUNCTIONAL PIECE OF AMERICAN EQUIPMENT CAPABLE OF FINDING SOLUTIONS TO NUCLEAR-RELATED PROBLEMS, IT JUST DOES NOT MAKE SENSE - ECONOMICALLY OR ECOLOGICALLY - TO TURN IT OFF (OR EVEN MEXICALLY, AS THE FAST FLUX TEST FACILITY PROVIDES A LARGE PERCENTAGE OF THE MEDICAL ISOTOPES NOW IN USE).

PLEASE DO WHAT IS IN YOUR POWER TO ENABLE THE CONTINUED OPERATION OF THE FAST FLUX TEST FACILITY AT THE HANFORD SITE.

Cordially,

-ANDREW S. AUBURN



MAY 22 1985

DOCTOR D. A. BROWNE

AS AN ENVIRONMENTAL CONCERNED, I AM  
AND AS AN ARTIST, I FIND THE DEPARTMENT  
OF ENERGY'S DECISION TO PLACE THE FAST FURNACE  
TEST FACILITY (ON THE HANFORD NUCLEAR RESERVE)  
NATION IN A STATE OF UNSTABLE  
COMPLETED INCORPORATION.

AS THE ONLY FUNCTIONAL LIEGE OF AMERICAN  
EQUILIBRIUM CAPABLE OF FINDING SOLUTIONS  
TO NUCLEAR-RELATED PROBLEMS, IT JUST  
DOES NOT MAKE SENSE - ECONOMICALLY OR  
ECOLOGICALLY - TO TURN IT OFF (OR EVEN  
REPAIR IT). AS THE FAST FURNACE TEST FACILITY  
PROVIDES A LARGE PERCENTAGE OF THE  
MEDICAL ISOTOPEES NOW IN USE.

PLEASE DO NOT LET IT IN YOUR HANDS TO ENRICH  
THE CONTINUED OPERATION OF THE FAST FURNACE  
TEST FACILITY AT THE HANFORD SITE.  
CONSIDER,

DOCTOR D. A. BROWNE



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REQUIRED: AS NECESSARY ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE:  
OSTP DUE DATE: 04/16/92 STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT:

\*\*\*\*\*  
COPIES TO: D. Allan Bromley  
PHYSICAL SCIENCES  
LIFE SCIENCES

\*\*\*\*\*  
WHITE HOUSE TRACKING #: CONTACT PERSON:  
PHONE: EXT:  
REMARKS: MARY - per Dr. Maynard please reassign to Dr. Erb (4/6/92)

OSTP RECEIVED: 03/31/92 DEPT RECEIVED:  
FILE: P-ENVIRONMENT

CENTRAL FILES:



"Document Control"

TYPE: ACTION DOCUMENT NUMBER: 9201070  
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS  
\*\*\*\*\*

FROM: AUBRY, Arthur S.: AUBRY PHOTOGRAPHY

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 03/25/92

SUBJECT: HE IS WRITING REGARDING THE DOE'S DECISION TO PUT  
THE FAST FLUX TEST FACILITY ON STAND BY. HE URGES  
DR. BROMLEY TO DO EVERYTHING IN HIS POWER TO ENABLE  
THE CONTINUED OPERATION OF THE FACILITY.

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: ENVIRONMENT ASSIGNED:

ACTION STAFF  
REQUIRED: AS NECESSARY ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE:  
OSTP DUE DATE: 04/16/92 STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT:

\*\*\*\*\*  
COPIES TO: D. Allan Bromley  
PHYSICAL SCIENCES  
LIFE SCIENCES

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WHITE HOUSE TRACKING #: CONTACT PERSON:  
REMARKS: PHONE: EXT:

OSTP RECEIVED: 03/31/92 DEPT RECEIVED:  
FILE: P-ENVIRONMENT  
CENTRAL FILES:

EXECUTIVE OFFICE OF THE PRESIDENT  
OFFICE OF SCIENCE AND TECHNOLOGY POLICY  
WASHINGTON, D.C. 20506

April 20, 1992

Dear Mr. Aubry:

Thank you for your letter to the Office of Science and Technology Policy concerning the Fast Flux Test Facility (FFTF) at Hanford.

I can assure you that the decision to phase out federal support of the FFTF was taken only after lengthy deliberation. Unfortunately, the cost of operating the FFTF cannot be justified in view of competing, higher priority needs in this time of strictly limited funding. The Office of Science and Technology Policy, as well as the Office of Management and Budget, therefore must concur in the decision by the Department of Energy to close the facility.

Sincerely,

Karl A. Erb  
Associate Director--Designate  
for Physical Sciences and Engineering

Mr. Arthur S. Aubry  
Aubry Photography

*need address*

*see: LS*



Dear Mr. Aubrey

Thank you for your letter to the

Office of - - - concerning the Fast Flux  
Test Facility (FFTF) at Hanford.

I can assure you that the decision to  
phase out federal support of the FFTF was  
taken only after lengthy deliberation. ~~The~~  
~~Department of Energy, the Office of Management~~  
~~and Budget and the Office of Science and~~  
~~Technology Policy all agree that the~~

Unfortunately, the cost of operating the  
FFTF can not be justified ~~scientifically~~ in view of  
competing, higher priority needs in this  
time of strictly limited funding. The Office  
of Science & Tech Pol, as well as the  
Office of Management and Budget, ~~therefore~~  
~~concur~~ ~~must~~ ~~in~~ the decision by the Department of  
Energy to close the facility.

bcc  
Lee Schroeder

KAR



"Document Control"

TYPE: ACTION DOCUMENT NUMBER: 9201035  
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS  
\*\*\*\*\*

FROM: DIAMOND, George: GEORGE DIAMOND & COMPANY, INC.

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 03/25/92

MAR 31 1992

SUBJECT: HE REQUESTS ASSISTANCE IN SECURING FUNDING FOR HIS  
ADVANCED MATERIALS.

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: PHYSICAL SCIENCES ASSIGNED: Dave Gamm 4/4/92

Phase Draft response  
(see note attached)

ACTION STAFF  
REQUIRED: DIRECT REPLY ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE:  
OSTP DUE DATE: 04/06/92 STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT: 4/24/92

\*\*\*\*\*  
COPIES TO: D. Allan Bromley

\*\*\*\*\*  
WHITE HOUSE TRACKING #: CONTACT PERSON:  
REMARKS: Dr. Gamm requested. PHONE: EXT:

OSTP RECEIVED: 03/30/92 DEPT RECEIVED:  
FILE: P-PHYSICAL SCIENCES  
CENTRAL FILES:





1035A

RECEIVED

92 MAR 30 P 5:11

George **DIAMOND** & Co., Inc.

CONNECTOR DIVISION  
METAL DIVISION  
MAIL ROOM

MARCH 25, 1992

MR. D. ALLAN BROMLEY  
ASSISTANT TO THE PRESIDENT  
FOR SCIENCE AND TECHNOLOGY  
THE WHITE HOUSE OFFICE  
1600 PENNSYLVANIA AVE N.W.  
WASHINGTON, D.C. 20500

DEAR MR. BROMLEY:

WE ARE ASSOCIATED WITH ROBERT W. WARD, WHO IS THE  
DEVELOPER OF A PROCESS TO PRODUCE COMPOSITE METAL  
POWDER.

BOB WARD RETIRED LAST SEPTEMBER FROM GENERAL MOTORS  
WHERE HE WAS GRANTED THE PRESTIGIOUS "BOSS" KETTERING  
AWARD FOR DEVELOPING COMPOSITE IRON THAT IS NOW IN  
PRODUCTION IN GM FACILITIES. THIS TECHNOLOGY ENABLES  
MANUFACTURERS TO REDUCE COSTS WHILE ALLOWING THEM TO  
PRODUCE SHAPES NOT POSSIBLE HERETOFORE.

ADVANCED MATERIALS WILL CHANGE THE BASIC ECONOMICS OF  
DOZENS OF INDUSTRIES. MORE THEN ALMOST ANY OTHER FACTOR,  
THEY WILL AFFECT THE COMPETITIVENESS AND PROFITS OF  
COMPANIES AROUND THE WORLD.

NEW MATERIALS WILL REWRITE BASIC PRODUCT SPECIFICATIONS,  
WHILE ADVANCED MATERIAL PROCESSES WILL SLASH MANUFACTUR-  
ING COSTS AND TIMES.

AT THE PRESENT TIME WE ARE WORKING WITH A POWDER METAL  
MANUFACTURER TO PRODUCE A SECOND AND THIRD GENERATION OF  
THIS TECHNOLOGY, AND WITH A FEW MOTOR MANUFACTURERS AND  
BALLAST MANUFACTURERS.

PAGE 1 OF 2 PAGES.

108 WILMOT ROAD ♦ DEERFIELD, ILLINOIS 60015 ♦ 708-940-8100

MARCH 25, 1992

PAGE 2 OF 2 PAGES.

HOWEVER, WE NEED HELP IN GETTING THIS TECHNOLOGY TO MORE MANUFACTURERS WHERE IT WILL HAVE THE GREATEST IMPACT AND OBTAIN THE BEST RESULTS. WE ALSO NEED HELP TO SET UP A LABORATORY TO FURTHER THIS WORK.

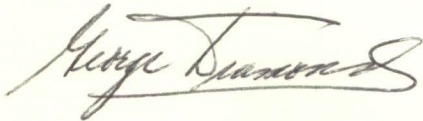
INITIAL COST FOR SETTING UP THE LABORATORY AND A PROGRAM TO PROPERLY DISSEMINATE THIS INFORMATION WILL BE APPROXIMATELY TEN MILLION DOLLARS. A SMALL PRICE TO PAY FOR GIVING AMERICAN INDUSTRY A TREMENDOUS BOOST AND HELP BRING BACK OUR MANUFACTURING BASE.

OUR COUNTRY CAN ILL AFFORD TO IGNORE THIS ADVANCED TECHNOLOGY BREAKTHROUGH. IT IS IMPERATIVE THAT WE ACT ON THIS IMMEDIATELY.

PLEASE CALL OR WRITE THE UNDERSIGNED FOR FURTHER INFORMATION.

SINCERELY,

GEORGE DIAMOND & CO., INC.

A handwritten signature in cursive script, appearing to read "George Diamond".

GEORGE DIAMOND, PRESIDENT.

GD/DL

CC: ROBERT W. WARD.



EXECUTIVE OFFICE OF THE PRESIDENT  
OFFICE OF SCIENCE AND TECHNOLOGY POLICY  
WASHINGTON, D.C. 20506

April 29, 1992

Dear Mr. Diamond:

Thank you for your letter of March 25 to Dr. Bromley describing your company's advance in materials. I agree with you that advances in materials can change the course of many industries: In fact, this is an important reason for our recommendation that materials research be highlighted as a Presidential Initiative in the FY 1993 budget.

The Office of Science and Technology Policy develops policy concerning science and technology for the Administration, but does not provide funding for these activities. I would suggest that you contact the funding agencies directly. If basic research funds are needed for your effort, you could contact the National Science Foundation. For more application-oriented R&D, you might try the Department of Defense or the Department of Energy. You should also contact Dr. Schneider at the National Institute of Standards and Technology to obtain a copy of the report entitled "Advanced Materials and Processing: The Federal Program in Materials Science and Technology" which will provide some more insight into other Federal agencies which might be interested in the metals technology you mentioned. I wish you success in your endeavor.

Sincerely,



David C. Cranmer  
Fellow

Mr. George Diamond  
George Diamond and Company, Inc.  
108 Wilmot Road  
Deerfield, IL 60015

"Document Control"

TYPE: INFORMATION

DOCUMENT NUMBER: 9200905

ORIGINATOR: 02

STATUS C

DIRECTORATE STATUS

\*\*\*\*\*

FROM: THOMAS, JOHN MEURIG: THE ROYAL INSTITUTION OF GREAT BRITAIN

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 03/12/92

SUBJECT: ATTENDED DR. BROMLEY'S TALK AT THE ROYAL SOCIETY;  
ALSO A BOOK ON MICHAEL FARADAY WILL SOON BE  
ARRIVING. FRANK PRESS AND THE REVIEWER IN SCIENTIFIC  
AMERICAN ENJOYED THE BOOK.

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: ASSIGNED:

ACTION STAFF  
REQUIRED: ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE:

OSTP DUE DATE: STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT:

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COPIES TO: D. Allan Bromley  
PHYSICAL SCIENCES  
INTERNATIONAL/POLICY

\*\*\*\*\*

WHITE HOUSE TRACKING #: CONTACT PERSON:  
REMARKS: PHONE: EXT:

OSTP RECEIVED: 03/18/92  
FILE: P-PHYSICAL SCIENCES

DEPT RECEIVED:

CENTRAL FILES:







THE ROYAL INSTITUTION

21 ALBEMARLE STREET

LONDON

W1X 4BS

TELEPHONE: 071-409 2992

FAX: 071-629 3569

Dear Dr Bromley

I have sent the book  
under separate cover to save  
postage.

I hope this does not  
cause you too much  
inconvenience

Yours sincerely

A handwritten signature in dark ink, appearing to read 'Tanya Donnan'.

Tanya Donnan  
PA to Sir John

WITH THE COMPLIMENTS OF  
SIR JOHN MEURIG THOMAS, F.R.S.,  
FULLERIAN PROFESSOR OF CHEMISTRY



THE ROYAL INSTITUTION OF GREAT BRITAIN

21 ALBEMARLE STREET, LONDON, W1X 4BS

TELEPHONE: 071-409 2992

FAX: 071-629 3569

FROM SIR JOHN MEURIG THOMAS F.R.S.  
FULLERIAN PROFESSOR OF CHEMISTRY

905  
2  
RECEIVED  
92 MAR 18 P 5: 09

OSTP  
MAIL ROOM

12 March 1992

Dr Allan Bromley  
Science Advisor to the President  
Office of Science and Technological Policy  
New Executive Office Building  
Washington DC  
20506  
USA

Dear Dr Bromley

I have just returned to my office after listening to your excellent talk at the Royal Society today and to the marvellous replies that you gave in answer to the questions that were posed.

During our conversation with Michael Atiyah I mentioned in relation to your point about the increased use of electricity in the US that I was the present occupant of the post created for Michael Faraday here at the Royal Institution. I am enclosing a copy of my book on Michael Faraday which you might find useful as bedtime reading. The President of your National Academy, Frank Press, uttered kind words about it and so did the reviewer in Scientific American. I hope you enjoy it.

With best wishes

Yours sincerely

John Meurig Thomas



THE WHITE HOUSE  
WASHINGTON

April 15, 1992

Dear Sir John:

Many thanks for your kind letter following my talk to the Royal Society and many thanks, indeed, for the copy of your excellent book on Michael Faraday. I have read it with great pleasure and profit and believe that it is the sort of book that all physics students should have as required reading. Far too few of them have any feeling for the wonderful activities of those upon whose shoulders all of us stand.

Your position at the Royal Institution is one of which you can be justly proud. Going back many years I must tell you that on a visit to London I had occasion to visit your institution with my son, who was then 12 or 13 years old, and we had occasion to attend one of your public lectures. We were both absolutely delighted by the lecture and I remember noting at the time that had I an opening in the Physics Department at Yale University, of which I was then the chairman, I would have offered it immediately to the lecturer. You have a long and wonderful tradition of making science accessible to the general public and I admire the skill and devotion that are evident in each of the lectures that I subsequently had the pleasure of attending during a number of visits to London.

But I should complete this anecdote by telling you that my son, in part, inspired by his exposure to the activities of your institution, went on to study physics at Harvard, later receiving his doctorate in theoretical physics at Stanford. I am sure that a great many young people worldwide have had similar experiences.

Again, my warmest thanks for your hospitality and for your book.

Sincerely yours,

A handwritten signature in dark ink, appearing to read "D. Allan Bromley". The signature is fluid and cursive, with the first name "D. Allan" and the last name "Bromley" clearly distinguishable.

D. Allan Bromley  
The Assistant to the President  
for  
Science and Technology

**Sir John Meurig Thomas F.R.S.**  
**Director**  
**The Royal Institution of Great Britain**  
**21 Albermarle Street**  
**London, W1X 4BX**  
**England**



"Document Control"

TYPE: INFORMATION

DOCUMENT NUMBER: 9200942

ORIGINATOR: 02

STATUS C

DIRECTORATE STATUS

\*\*\*\*\*

FROM: TOLL, JOHN: UNIVERSITIES RESEARCH ASSOCIATION, INC.

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 03/05/92

SUBJECT: ENCLOSURE OF THE 1991 ANNUAL REPORT OF UNIVERSITIES  
RESEARCH ASSOCIATION, INC.

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: ASSIGNED:

ACTION STAFF  
REQUIRED: ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE:

OSTP DUE DATE: STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT:

\*\*\*\*\*

COPIES TO: D. Allan Bromley  
PHYSICAL SCIENCES  
INTERNATIONAL/POLICY  
INDUSTRIAL

\*\*\*\*\*

WHITE HOUSE TRACKING #: CONTACT PERSON:  
REMARKS: PHONE: EXT:

OSTP RECEIVED: 03/05/92 DEPT RECEIVED:  
FILE: P-PHYSICAL SCIENCES-SSCL

CENTRAL FILES:

942 I

**UNIVERSITIES RESEARCH ASSOCIATION, INC.**

1111 19th Street, N.W. Suite 400 Washington, D.C. 20036  
Telephone: (202) 293-1382 Fax: (202) 293-5012

March 5, 1992

Dr. D. Allan Bromley  
Assistant to the President for  
Science and Technology Policy  
Office of Science and Technology Policy  
OEOB Room 360  
17th & Pennsylvania Avenue, N.W.  
Washington, D.C. 20506

Dear ~~Dr.~~ <sup>Allan</sup> Bromley:

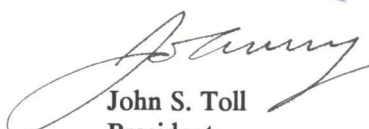
Enclosed is the 1991 Annual Report of Universities Research Association, Inc. (URA), contractor to the Department of Energy for the management and operation of the Fermi National Accelerator Laboratory (Fermilab) and the Superconducting Super Collider Laboratory (SSCL). As a consortium of seventy-nine major universities, URA reflects the national character of both laboratories, which serve as core facilities for the majority of present and future high energy physicists doing experiments in the United States.

There have been several significant developments for Fermilab and the SSCL since the enclosed report was published. Fermilab was described in January by the Department of Energy as "the current jewel in the crown of high energy physics, and the key facility for exploring forefront particle physics in the 1990s." Also in January, a critical milestone was passed in the SSC's development: the machine's sophisticated superconducting dipole magnets -- developed in laboratories and then produced by industry -- were successfully tested, proving that these vital components can be mass-produced. This is a major step in keeping the SSC on schedule and on budget toward completion in 1999, when it will magnify twentyfold our ability to study basic interactions.

Universities and industries throughout the nation are participating in this coordinated research effort, which is pushing the limits of technology and attracting outstanding scientists and engineers from around the world. Details of each laboratory's progress, including contributions to technology transfer, education, and related fields, are summarized in the Annual Report. The search for the fundamental building blocks of nature has already contributed immeasurably to our understanding of the universe, with an array of new discoveries. The next phases of the search will inevitably assist in development of products and processes that can only be imagined at this point. You are cordially invited to visit Fermilab in Illinois, currently the home of the world's highest energy accelerator and collider, and the SSC Laboratory in Texas, now establishing its permanent facilities on the site near Waxahachie and preparing to excavate the 54-mile oval tunnel.

Please let me know if you have any questions or if you would like additional material on URA, Fermilab, or the SSC.

Sincerely,

  
John S. Toll  
President

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MAR 12 1992  
MAIL ROOM

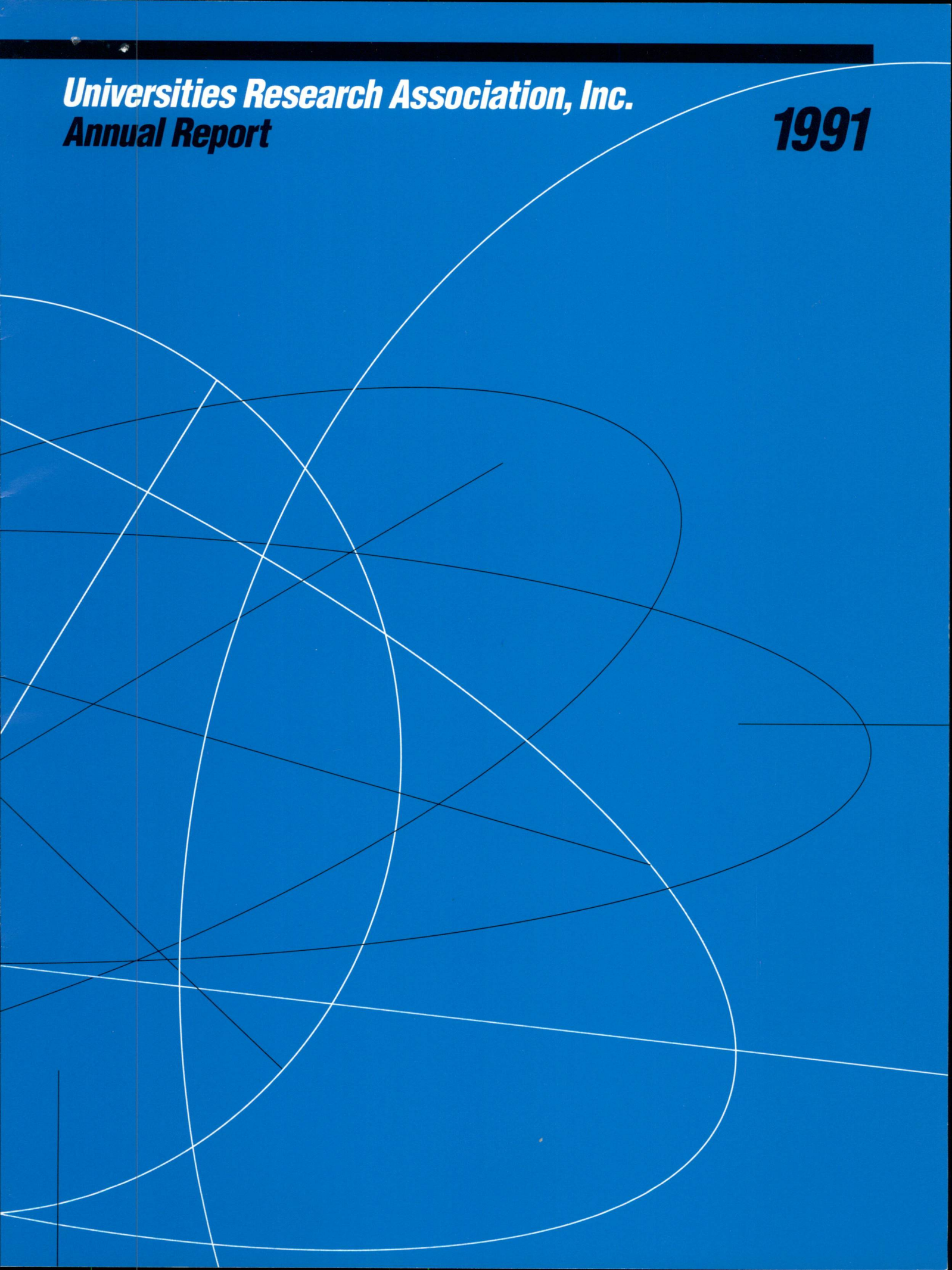
Enclosure

*I thank you for your magnificent leadership  
on behalf of science! Call whenever we can help.*



***Universities Research Association, Inc.***  
***Annual Report***

**1991**







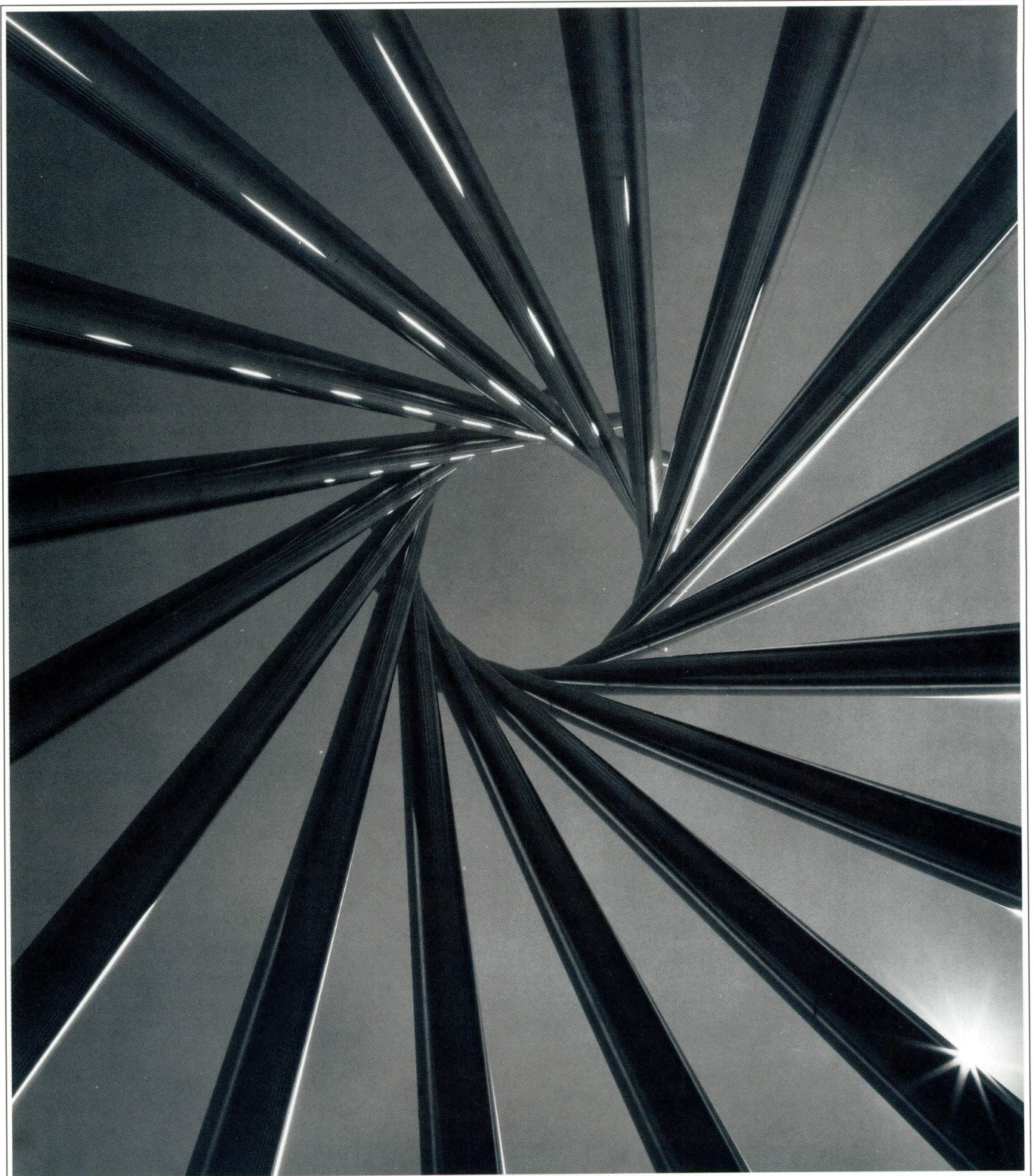


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*URA, a private, non-profit consortium of research universities, serves as a contractor to the Federal Government for the development and operation of major scientific facilities. This volume—updated annually with new financial data, personnel, and developments at URA laboratories—provides the historical context for the consortium's structure and mission.*

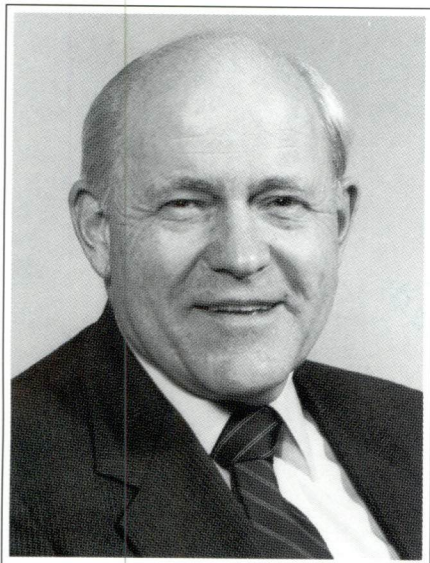




"Tractricious," a sculpture designed by Fermilab founding director Robert R. Wilson and built with scraps from construction of the Tevatron.



# Message from the President



John S. Toll, URA President

**P**rogress in science and technology depends on the cooperative efforts of laboratories throughout the world, as discoveries are pieced together in a mosaic to extend our understanding of nature and to permit applications for human betterment. An especially challenging field is high energy physics, which uses particle accelerators as essential tools.

Universities Research Association operates two major national accelerator laboratories, the Fermi National Accelerator Laboratory (Fermilab) and the Superconducting Super Collider Laboratory (SSCL). Let me explain why their work is so important and why they are rated as the highest priority programs among U.S. laboratories in this field.

Accelerators, although they may seem remote to many people, play increasingly significant roles in our lives. Few citizens realize, for example, that the key component of a television set is a low energy accelerator, or that accelerators are used in treating cancer patients and in manufacturing microchips.

The Tevatron, now the world's highest energy accelerator and collider, has given Fermilab the greatest potential for particle discoveries during this decade. The advances made during the 1990's, as well as the scientists trained, will provide the foundation for the SSC Laboratory early in the next century. At that time, the SSC will increase twentyfold the magnification with which scientists study the fundamental interactions of nature.

The year 1991 was notable for URA. The SSCL demonstrated successful operation of the full-scale superconducting magnets and constructed its first facilities on the site. Good progress was made in planning two major detectors for the first SSC experiments. Fermilab had an especially successful fixed-target run and prepared for upcoming collider runs with two superior general-purpose detectors. Both laboratories involved outstanding physicists from around the world. Congress and the President *doubled* the annual appropriations for the SSCL and allocated \$15 million to begin construction of the *Main Injector*, a major upgrade at Fermilab.

To maintain this high level of performance and thus to maximize the potential for scientific discovery, careful judgments have to be made so that available research funds are expended optimally. Fortunately, the U.S. program in high energy physics is guided by a national committee of experts, the High Energy Physics Advisory Panel (HEPAP), which has made hard choices after careful reviews. With tight limits on the Federal budget, it is now more important than ever that the HEPAP process be used to determine Federal priorities.

In November, 1991, a letter from HEPAP reported: "Of the ongoing laboratory programs, we give the highest priority to Fermilab. We reached that decision because it is the highest energy collider and fixed target accelerator in the world and is optimally poised to explore many of the key issues in high energy physics today."

But Fermilab's promise is dependent upon adequate operating budgets for the Laboratory and related university programs and upon the *Main Injector*, which will increase the scientific productivity of the Tevatron *fivefold*. For example, the Main Injector is necessary to assure that Fermilab experiments can answer during this decade whether the elusive top quark exists in the mass range and with the properties predicted by current theory. In 1990, HEPAP established the Main Injector as the *top priority* for the pre-SSC era; the panel reiterated this ranking in the summer of 1991.

Similarly, HEPAP's guidance on the SSC has been especially significant. The panel has repeatedly reaffirmed that the number one priority in the U.S. high energy physics program is the SSC, where physicists expect important insights on the nature of mass and on the fundamental processes that determined the distribution of matter in the early expanding universe.

Universities Research Association's contract for management of Fermilab is being renewed for another five years just as 1991 comes to a close, and our contract for the SSC Laboratory extends at least through 1997. We are proud to be responsible for the two U.S. national laboratories that are most important in mankind's study of energy and matter at the most fundamental level.





Flags in front of Wilson Hall symbolize the participation and collaboration of scientific groups from all over the world doing research at Fermilab.



**Members of Universities Research Association, Inc., contractor  
to the U.S. Department of Energy for the Fermi National Accelerator  
Laboratory and the Superconducting Super Collider Laboratory**

**Alabama**

University of Alabama—Tuscaloosa

**Arizona**

Arizona State University  
University of Arizona

**California**

California Institute of Technology  
University of California—Berkeley  
University of California—Irvine  
University of California—Los Angeles  
University of California—Riverside  
University of California—San Diego  
San Francisco State University\*  
Stanford University

**Colorado**

University of Colorado—Boulder

**Connecticut**

Yale University

**Florida**

Florida State University

**Hawaii**

University of Hawaii—Manoa

**Illinois**

University of Chicago  
University of Illinois  
—Urbana  
Northern Illinois University\*  
Northwestern University

**Indiana**

Indiana University  
University of Notre Dame  
Purdue University

**Iowa**

University of Iowa  
Iowa State University

**Louisiana**

Louisiana State University  
Tulane University

**Maryland**

Johns Hopkins University  
University of Maryland

**Massachusetts**

Boston University  
Harvard University  
University of Massachusetts  
Massachusetts Institute  
of Technology  
Northeastern University  
Tufts University

**Michigan**

University of Michigan  
Michigan State University

**Minnesota**

University of Minnesota

**Missouri**

Washington University

**New Jersey**

Princeton University  
Rutgers University

**New York**

Columbia University  
Cornell University  
University of Rochester  
Rockefeller University  
State University of New York  
—Buffalo  
State University of New York  
—Stony Brook  
Syracuse University

**North Carolina**

Duke University  
University of North Carolina

**Ohio**

Case Western Reserve University  
Ohio State University

**Oklahoma**

University of Oklahoma

**Oregon**

University of Oregon

**Pennsylvania**

Carnegie Mellon University  
University of Pennsylvania  
Pennsylvania State University  
University of Pittsburgh

**Rhode Island**

Brown University

**South Carolina**

University of South Carolina

**Tennessee**

University of Tennessee—Knoxville  
Vanderbilt University

**Texas**

University of Houston  
University of North Texas  
Prairie View A&M University\*  
Rice University  
Texas A&M University  
Texas Tech University  
University of Texas—Arlington  
University of Texas—Austin  
University of Texas—Dallas

**Utah**

University of Utah

**Virginia**

Virginia Polytechnic Institute  
University of Virginia  
College of William and Mary

**Washington**

University of Washington

**Wisconsin**

University of Wisconsin—Madison

**Canada**

McGill University  
University of Toronto



\*Denotes an associate member institution

# Corporate Overview: 1965–1991

**U**niversities Research Association (URA), Inc., a non-profit corporation founded in 1965, consists of 78 major research-oriented universities in the United States and Canada. Institutions with full membership provide doctoral programs in science and are active in particle physics. Associate members have an interest or program in particle physics and hope to achieve full membership in the future.

The need to create URA was identified in 1962, when a committee chaired by Norman F. Ramsey of Harvard University, under the joint sponsorship of the President's Science Advisory Committee and the General Advisory Committee of the Atomic Energy Commission (AEC), issued a report recommending construction of an accelerator capable of energies far greater than any achievable at individual university or laboratory facilities. The president of the National Academy of Sciences called together the presidents of U.S. universities engaged in particle physics to consider management options for a such a national facility; as a result, 25 attendees agreed to form a consortium for that purpose, an initiative that led to URA's incorporation in 1965.

Since January 1967, URA has been contractor to the Department of Energy (DOE) and its predecessor agencies for the design, construction, management, and operation of the first nationally managed accelerator facility for high energy physics, now known as the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois. The

Tevatron at Fermilab, the world's first superconducting particle accelerator, is the world's highest energy instrument for physics research. Current highlights of Fermilab's mission include the search for the top quark, national leadership in science and math education, cutting-edge development of supercomputers, and a multi-year upgrade to make the most productive use of the national investment in the Tevatron.

URA entered a contract with DOE in 1989 for the design, construction, management, and operation of the Superconducting Super Collider Laboratory (SSCL). The SSC will be the largest and most energetic particle accelerator in the world when it is scheduled to begin operations at the end of the decade. Initial SSC activities were conducted by a URA subsidiary, the Central Design Group at Lawrence Berkeley Laboratory.

SSC Laboratory personnel moved to Dallas-area offices after the Texas site was chosen in 1988 and began to establish the Waxahachie campus in 1991. As part of that development, the Magnet Development Laboratory was completed this year as SSCL's first on-site building. Preliminary 1991 tests of the re-designed superconducting dipole magnets have been successful at Brookhaven National Laboratory's and Fermilab's SSC magnet facilities, construction of SSC collider systems is under way, and SSC-related research is producing provocative results at universities around the nation.



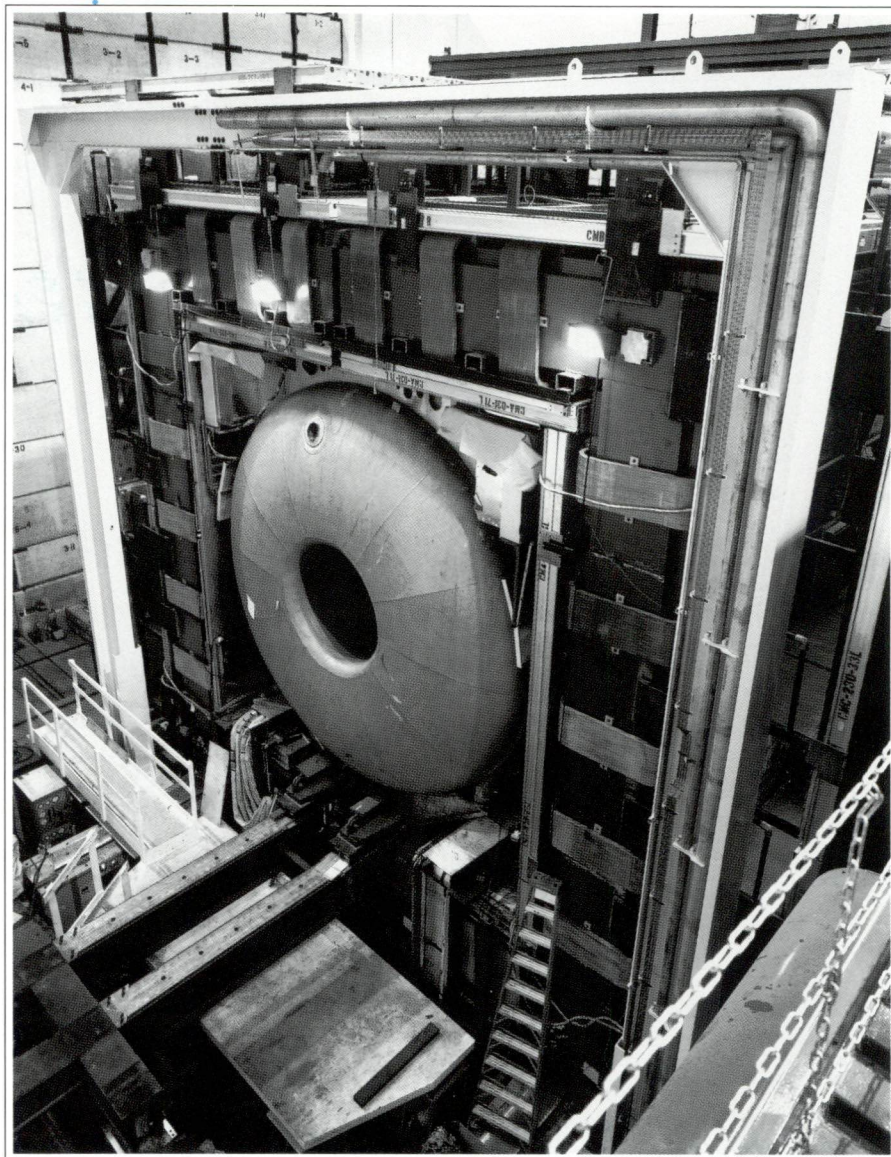
# History and Mission: Particle Physics

Research in elementary particle physics, also known as high energy physics, involves the study of subatomic particles and the forces acting between them. Beams of particles are accelerated to high energies and collide either with stationary targets or with opposing particle beams. Computer-controlled detectors record the patterns of the particles produced in such collisions, providing experimental data for further examination. From this information, physicists learn more about the behavior of matter and energy at extremely small scales.

Accelerators represent a radical improvement upon the early days of particle physics, when the principal source of energetic particles was cosmic rays, which occur randomly in nature. With the advent of accelerator technology, high energy particles could be produced in a controlled fashion right at the Earth's surface. The newer colliding-beam techniques developed over the past three decades have allowed physicists to generate collision energies so high they can now replicate conditions that occurred previously during the Big Bang origins of the universe.

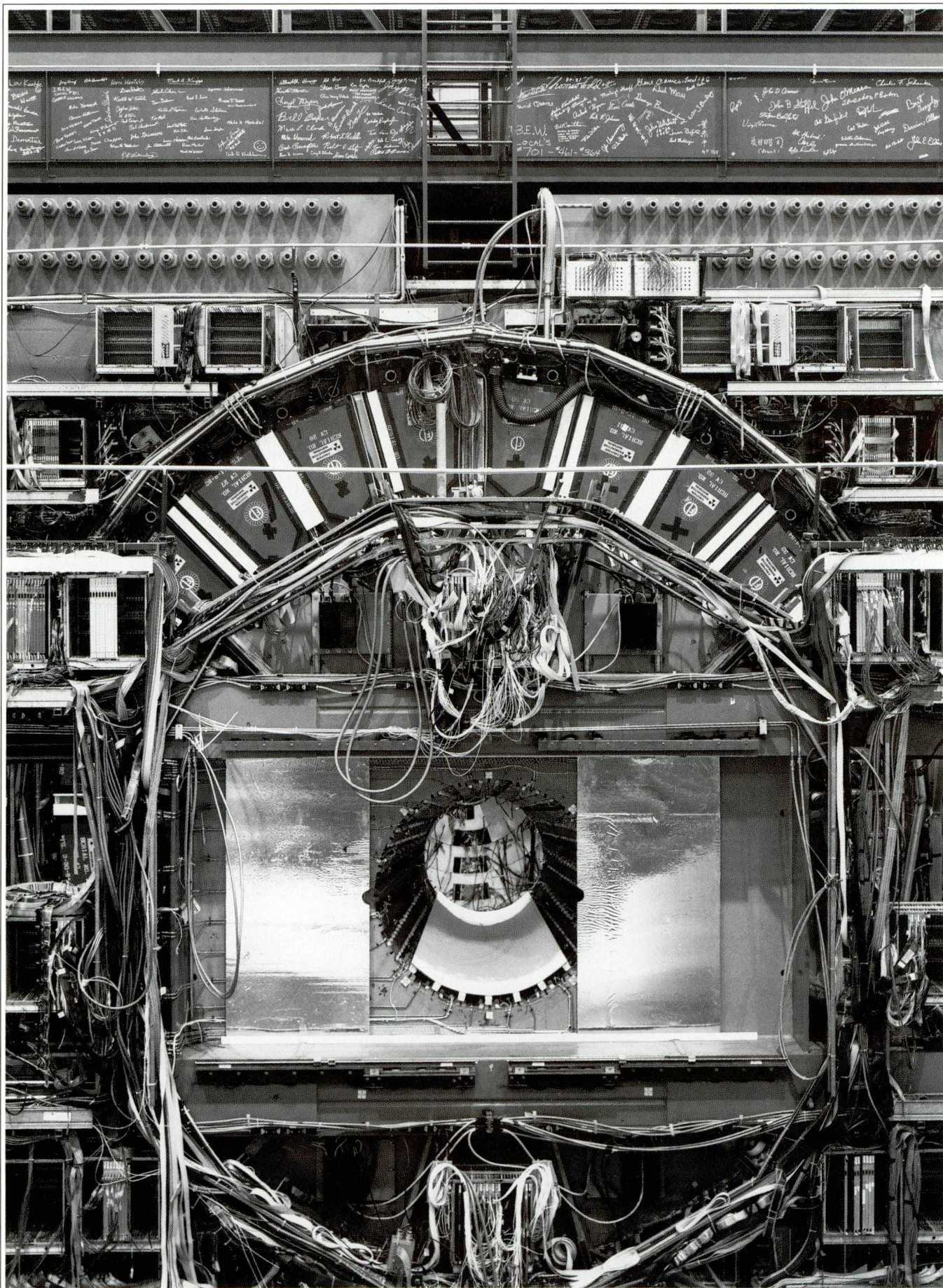
Within the larger scientific community, particle physics shares information with nuclear, atomic, molecular and optical physics, while key insights from condensed matter physics and mathematical theory have had important impacts on the field. And, as experience at Fermilab has shown, particle physics has rapidly growing links with astrophysics and cosmology. An understanding of matter and energy at the most fundamental levels attainable will continue to be an important foundation of the physical sciences, contributing to further advances on many fronts.

Currently, the Fermilab and SSCL programs represent the core of URA's mission. The corporation can also submit proposals to the Federal Government for the management and operation of other facilities within or outside the field of particle physics, if that were to become desirable.



The central calorimeter for the D-Zero detector at Fermilab weighs 300 tons. Following the successful cosmic ray commissioning run, physicists look forward to the first D-Zero run in 1992.

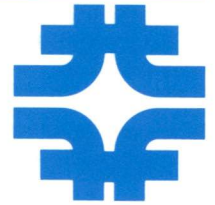




The Collider Detector at Fermilab (CDF) has undergone significant improvements in the past two years, in preparation for the 1992 Tevatron collider run. Data provided by CDF from previous collider runs are being analyzed as part of the search for the top quark.

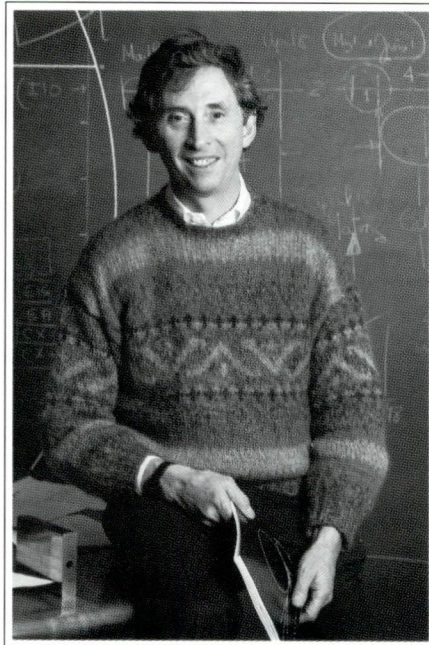


# Fermilab



**T**he AEC received 125 site proposals for the first national accelerator laboratory in the United States. The winning proposal from Illinois was selected in 1966, for a location about 30 miles west of Chicago. The headquarters are in Wilson Hall, designed by the Laboratory's first director, Robert Rathbun Wilson. Groundbreaking was in 1968, and in 1974 the Laboratory was dedicated to the memory of physicist Enrico Fermi.

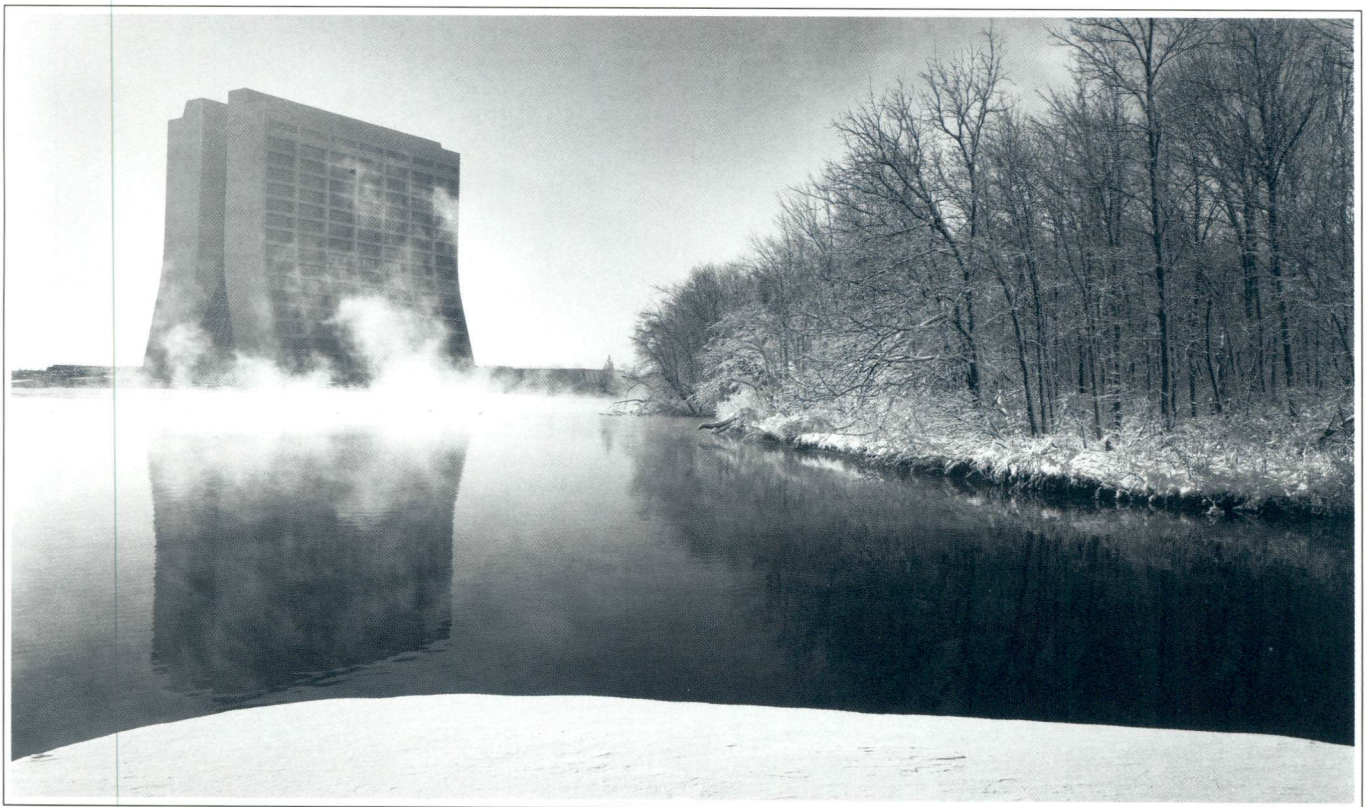
Fermilab now has about 2,300 full-time employees, including over 400 scientists and engineers. Approximately 3,500 visiting experimenters have conducted research at Fermilab and about 150 institutions—roughly half from the United States and half from abroad—are represented in the research program.



## *Laboratory Director*

Dr. John Peoples, Jr., became Fermilab's third director on July 1, 1989. Dr. Peoples had participated in experiments at Fermilab in the early 1970's as a professor of physics at Cornell. After transferring to the Laboratory, he headed the Proton Laboratory and the Research Division, and was project manager of the Antiproton Source, which made it possible to collide protons and antiprotons. After serving with the SSC Central Design Group in Berkeley as head of the Magnet Division, Dr. Peoples returned to Fermilab as deputy director.

Fermilab's founding director, Robert R. Wilson, served from 1968 to 1978. Leon M. Lederman directed the Laboratory from 1979 to 1989.



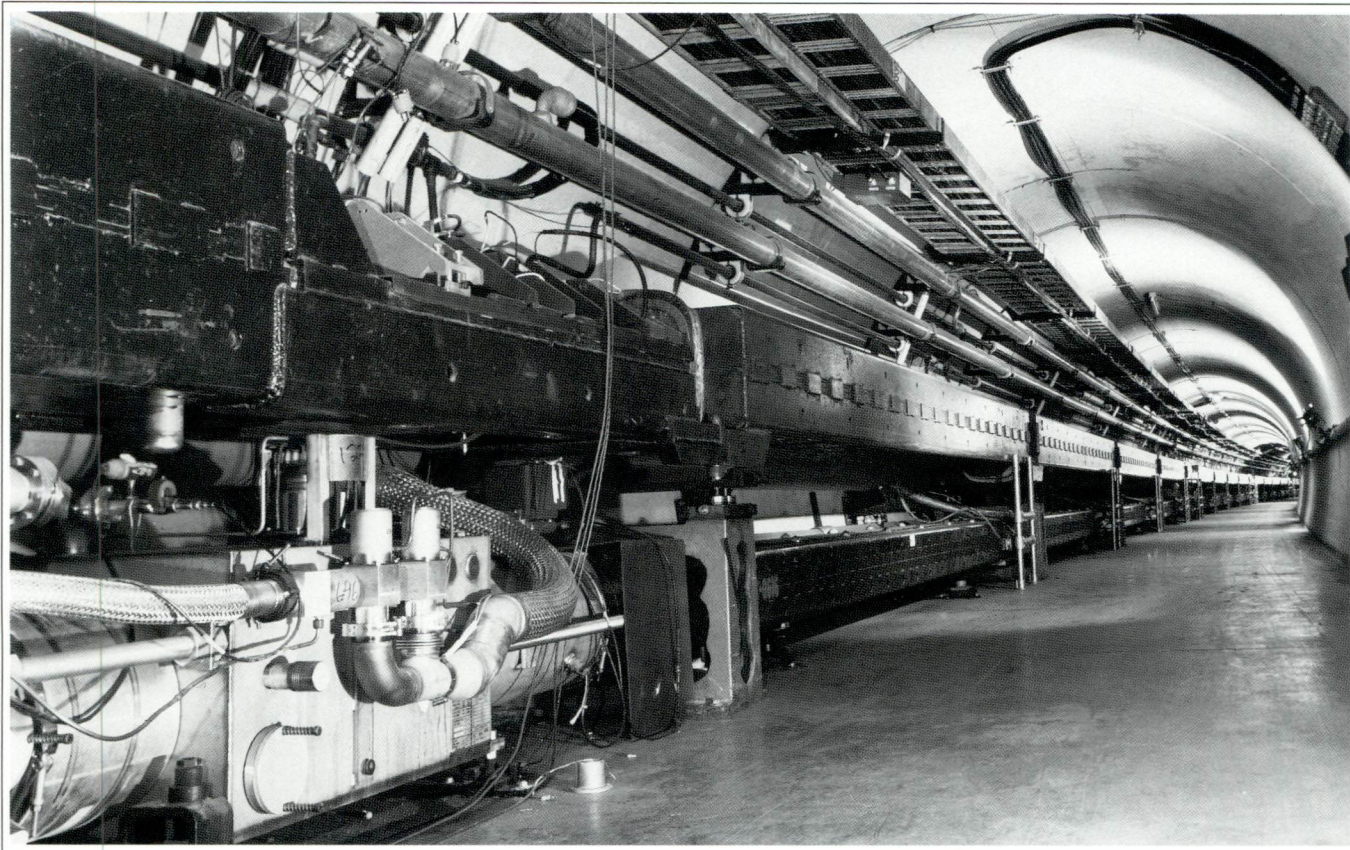
Robert Rathbun Wilson Hall. The 16-story building houses research laboratories and the administrative headquarters of the Laboratory.





As part of the cooling system for the accelerator, some of Fermilab's lakes and ponds do not freeze even during the coldest days. The watering spots are a major attraction for geese and ducks.





The tunnel of the Main Accelerator at Fermilab. The upper ring of conventional magnets comprise the fourth stage of particle acceleration. The particle beam can then be injected into the Tevatron (lower ring), which is composed of superconducting magnets.

## ***Laboratory Design and Performance***

Fermilab's basic system of accelerators includes a four-mile main ring in which magnets curve the paths of particle beams. Since the first facilities were built, several upgrades have magnified the Laboratory's powers of observation. The prime example is the world's first superconducting accelerator, originally known as the Energy Saver (because superconducting magnets reduced the need for electric power input) and now called the Tevatron, with a beam of about one trillion electron volts (TeV). It operated initially in 1983, and in 1989 the National Medal of Technology was awarded to the leaders of its design and construction team.

Major upgrades enabled the Tevatron to become a collider, which can accelerate antiprotons as well as protons at trillion-

electron-volt energies. The first proton-antiproton collisions were achieved in 1985, and the Laboratory now operates both in collider and fixed-target modes.

The first detector for collider-generated events in the Tevatron is the Collider Detector at Fermilab (CDF), founded as a U.S.-Italy-Japan collaboration. The experimental group that designed, built, and now uses it includes more than 350 individuals from 30 institutions. Currently, over one-fourth of the participants are graduate students, and approximately 25 theses are being completed each year by students working on the CDF experiment. A second major collider detector, D0 ("D-Zero"), completed all tests in 1991 and will collect data in the 1992 collider run. The collaboration includes 273 physicists, of which 50 are graduate students, from 30 institutions in the United States, France, (Soviet Union), India, Brazil, and Colombia.

To keep pace with the requirements of forefront particle physics research through the 1990's and beyond, Fermilab initiated Fermilab III, a series of upgrades designed to realize the full potential of the Tevatron. The first of three elements in Fermilab III was completed in 1991: installation of new magnets and beam separators to amplify data-gathering. The second phase, an upgrade of the Linear Accelerator, made significant progress toward scheduled operation in 1992. The final phase, a new Main Injector, was approved by DOE, and initial funding was provided by Congress for Fiscal 1992. It will dramatically intensify Fermilab's search for the top quark and will also provide vital scientific and technological grounding for the SSC.





The ACPMAPS supercomputer was designed and constructed by Fermilab physicists and engineers. Fabricated from hundreds of independent, inter-

connected computer modules, ACPMAPS is used to perform elaborate simulations of theories of the force which binds quarks together.

Fermilab is a pioneer in this type of parallel computer architecture.

## ***Computing and Cosmology***

The computing capacity necessary to analyze data of the complexity and volume of the Tevatron's output, and the requirements of theoretical physics research, have made Fermilab a natural site for development of the world's foremost computing hardware, software, and applications. Fermilab has been a pioneer in massively parallel computing, pushing the extreme limits of technology in order to test theories of quark behavior: in 1991, Fermilab and International Business Machines (IBM), as part of a research collaboration, dedicated a new computing facility consisting of a "farm" of 68 IBM workstations with the capacity of more than 1700 traditional minicomputers.

The Fermilab astrophysics group is also continuing its work, funded by a grant from the National Aeronautics and Space Administration. Linking particle physics with astrophysics and cosmology, Fermilab scientists are working with astronomers from the University of Chicago, the Institute for Advanced Study, and Princeton University on the Digital Sky Survey which will map the location of a million galaxies.

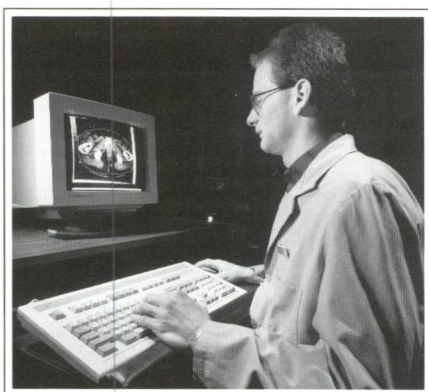
## ***Industrial Affiliates and Technology Transfer***

The Fermilab Industrial Affiliates group, active since 1980, stimulates transfer to private industry of the technical innovations resulting from the Fermilab basic research program. Symposia, tours,

and exhibits are held at the Laboratory to encourage the exchange of information between Laboratory staff and the Affiliates.

A new era in tech-transfer arrived with the advent of Cooperative Research and Development Agreements authorized by Congress and incorporated into URA's Fermilab contract in 1990. Previously, under authority of the Bayh-Dole Act and the Stevenson-Wydler Amendment, URA had already entered into several licensing agreements with companies to foster commercialization of Fermilab inventions. Exchanges and areas for transfer include developments in superconductivity, cryogenics, data processing, computer hardware and software, computer controls, fast electronics, ion beams and sources, high power radio-frequency designs, cryogenic vacuum technology, and particle detectors.





At the Neutron Therapy Facility, a new magnetic contouring device is used to calculate the radiation distribution for treatment.

## ***Cancer Therapy***

Fermilab scientists helped pioneer the technology of using particle beams for treatment of cancer. In June 1975, the National Cancer Institute awarded a grant for a Cancer Therapy Facility at Fermilab to explore the effectiveness of fast neutrons versus that of x-rays in the management of certain types of cancer. During its multi-phase transition to the private sector, the treatment facility was operated under contract with the Midwest Institute for Neutron Therapy

and is now under contract with Rush-Presbyterian St. Luke's Medical Center of Chicago.

Fermilab also built a 250-million-electron-volt proton accelerator for the hospital of Loma Linda University Medical Center in California. The accelerator, shipped to Loma Linda in 1989, will supply proton beams to five treatment rooms that can handle 1,000 patients per year. The first patients were treated in October 1990.



## Conservation Programs

Fermilab was designed with various forms of conservation in mind, from energy conservation to prairie restoration. For example, to preserve the natural water supply, a recycling water system cools the booster accelerator ring and pumps the heated water into an outdoor waterway through a full circuit, providing habitats for fish, geese, ducks, and swans through the winter. The Nature Conservancy, assisted by several hundred volunteers from the area, has supported restoration of a prairie landscape on the 600 acres inside the Fermilab main accelerator ring. Buffalo, deer, and waterfowl are plentiful, and nature walks are organized for local school children. In 1989, the Laboratory was designated as a National Environmental Research Park by the Department of Energy.



The Fermilab Education Office coordinates programs to facilitate effective science teaching, provides informal science experiences for young students, and offers assistance in locating resources for the science classroom.

## Undergraduate and Precollege Education Programs

Fermilab sponsors and participates in a variety of educational activities, including college-level internships and co-op programs. Among them, for example, are summer internships targeted to minority students and physics majors that include research assignments with scientists or engineers. The Laboratory also works with undergraduate institutions to assign students to internships during the school year. Fermilab participates in the National Consortium for Graduate Degrees for Minorities in Engineering and (with URA) in a graduate fellowship program in physics for minority students.

The Laboratory sponsors 35 programs for precollege teachers and students under the auspices of the new Fermilab Education Office. Funding is partially from DOE, with external financial support provided through Friends of Fermilab with funding from the National Science Foundation, DOE, the State of Illinois, and private donors. Key programs for high school students include Saturday Morning Physics, science and engineering for high-potential minority

students, and the DOE High School Honors Research Program in Particle Physics. Key teacher enhancement programs include the several DOE-sponsored initiatives for science and mathematics teachers. A publication, *Topics in Modern Physics*, has produced instructional materials, suitable for introductory high school and college physics classes. Over 20,000 students and 8,000 teachers participate annually in the precollege programs.

## The Fermilab Community

Fermilab also sponsors cultural activities to which the public is invited. Laboratory employees volunteer in support of an arts series featuring dance, theater, and musical ensembles; physics colloquia and lectures on science and human values presenting guest speakers; international, documentary, and feature films; and an art gallery displaying work ranging from technologically produced and ethnic art to painting, photographs, and sculpture.

For further information: (708) 840-3351.



The Department of Energy's Teacher Research Associates Program recognizes superior science teaching and exposes teachers to state-of-the-art scientific research equipment and procedures. Here, a teacher from Alaska studies a position-sensing photo detector while at Fermilab.



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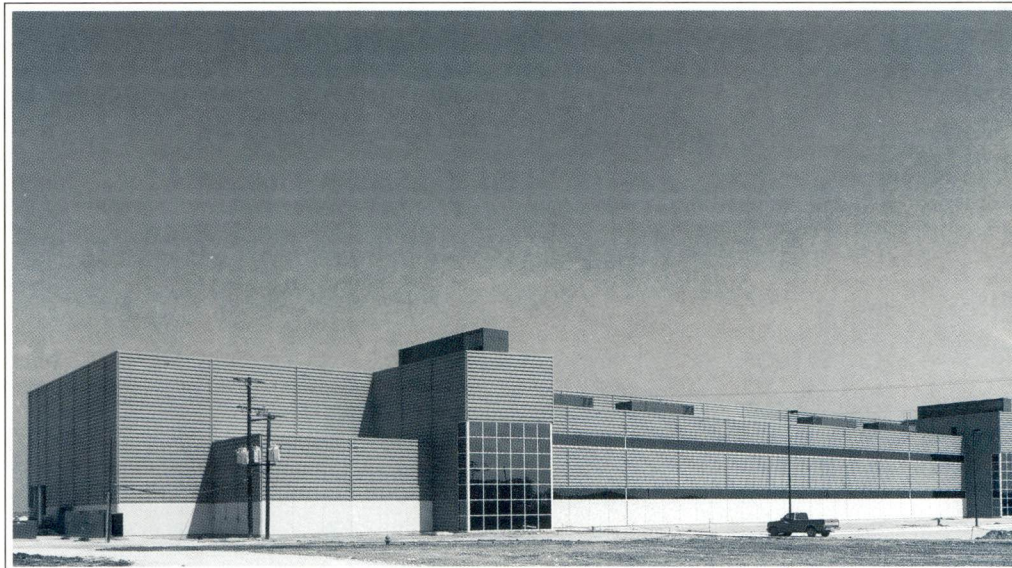
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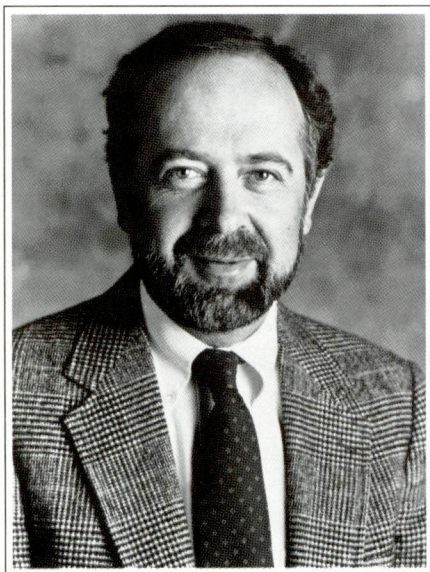


# Superconducting Super Collider Laboratory

**T**he Superconducting Super Collider (SSC) will be the world's largest and most powerful particle accelerator when it begins operations at the end of this decade. Guided and focussed by almost 10,000 superconducting magnets in a 54-mile oval tunnel deep underground, two proton beams will travel in opposite directions at nearly the speed of light, reaching energies of up to 20 trillion electron volts (20 TeV) each. The results of head-on collisions between these beams will be recorded for analysis by particle detectors whose design, construction and operation will push the limits of modern technology on many frontiers.



The Magnet Development Laboratory, the first building to be constructed on the SSCL site, was completed in 1991.



## Laboratory Director

The founding director of the SSC Laboratory (SSCL) is Dr. Roy F. Schwitters, former professor of physics at Harvard University. Dr. Schwitters had served as co-director and head of construction and operations for the Collider Detector at Fermilab and as a member of URA's SSC Board of Overseers. Prior to 1980, he was associate professor of physics at the Stanford Linear Accelerator Center, where he earned recognition for his developmental work on detectors that are now widely used in the field.

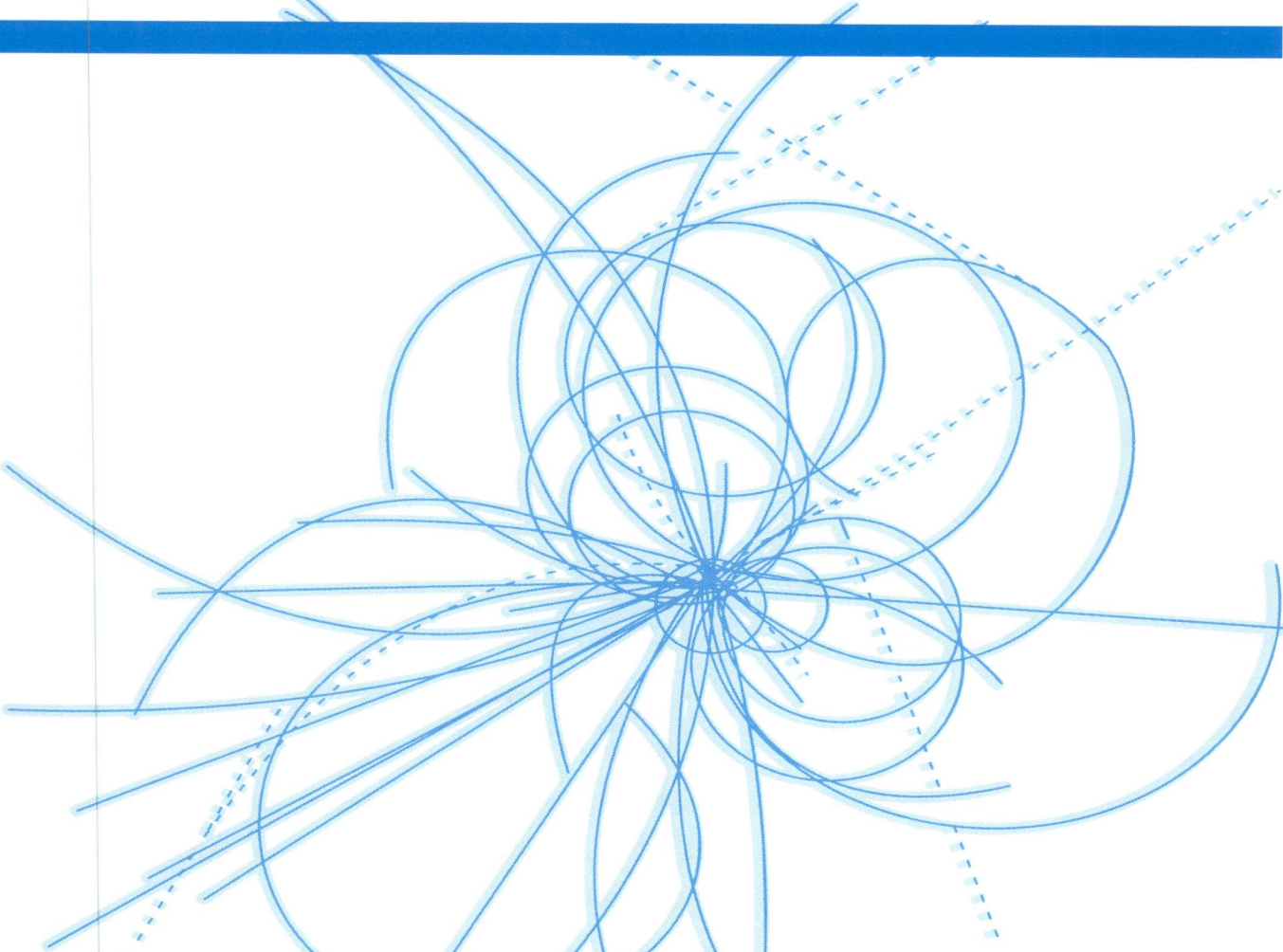
## Origins of the Project

The roots of the SSC can be found in discussions of a "Very Big Accelerator" that began during the 1970's among members of the world high energy physics community. The views of U.S. scientists began to crystallize during a 1982 workshop in Snowmass, Colorado, sponsored by the American Physical Society. There a consensus was reached that a multi-TeV particle collider using superconducting magnets to guide two opposing proton beams, each with energies between 10 and 20

TeV, was needed to address the most important research issues confronting the field. The technology of these magnets—plus that of the cryogenic and other systems needed to support them—had recently been demonstrated by the success of the Fermilab Tevatron, which delivered beams with energies close to 1 TeV. Physicists concluded that a new collider generating energies up to 20 times higher was a technologically feasible project.

After conducting reference design studies, the U.S. Department of Energy contracted in 1984 with URA to direct the R&D program for the proposed SSC. The implementation of this agreement was organized according to a Memorandum of Understanding endorsed by Associated Universities, Inc., Cornell University, Stanford University, Texas Universities Consortium, URA, the University of California, and the University of Chicago. URA established the SSC Board of Overseers, an advisory panel for the program. The Overseers then established the SSC Central Design Group, with Dr. Maury Tigner of Cornell University as director. The group produced a general conceptual design in 1987.





The site of the SSCL—Ellis County, Texas—was ratified in early 1989 by the administration after DOE selected it from 43 proposals and seven finalists. Laboratory offices were opened near the site in 1989, and a site-specific conceptual design was completed in 1990.

### ***1991 Milestones: Summary***

In 1991 the SSC Laboratory began making the transition from a project that had existed mainly on paper to an institution in which real technical accomplishments were being made. Several major contracts were awarded to industry partners for laboratory facilities and for prototypes of the more than 10,000 superconducting magnets required for the collider. Total staff exceeded 1700, with an increasing fraction devoted to scientific, engineering and technical tasks. Reflecting this growth, the annual budget for the SSCL rose from \$416 million in Fiscal Year 1991 (which includes \$267 million from the DOE and \$149 million from the state of Texas) to \$614 million for Fiscal Year 1992 (\$484 million from DOE and \$130 million from Texas in Fiscal Year 1992).

### ***Site Planning and Development***

In January, a contract was awarded to the team of Parsons, Brinkerhoff, Quade and Douglas, Inc. of New York and Morrison Knudsen, Inc. of Idaho, in association with CRSS, Inc. of Texas, to serve as architect, engineer, and contract manager for conventional facilities. This team will oversee the design and construction of office, laboratory and accelerator facilities, plus some 70 miles of tunnels. Preliminary plans for the two SSCL campuses and construction activities have been drawn. The final "foot-print" of the accelerator complex was established during the year. By mid-October, title or rights to about 11,000 acres had been acquired out of a total of 16,460.

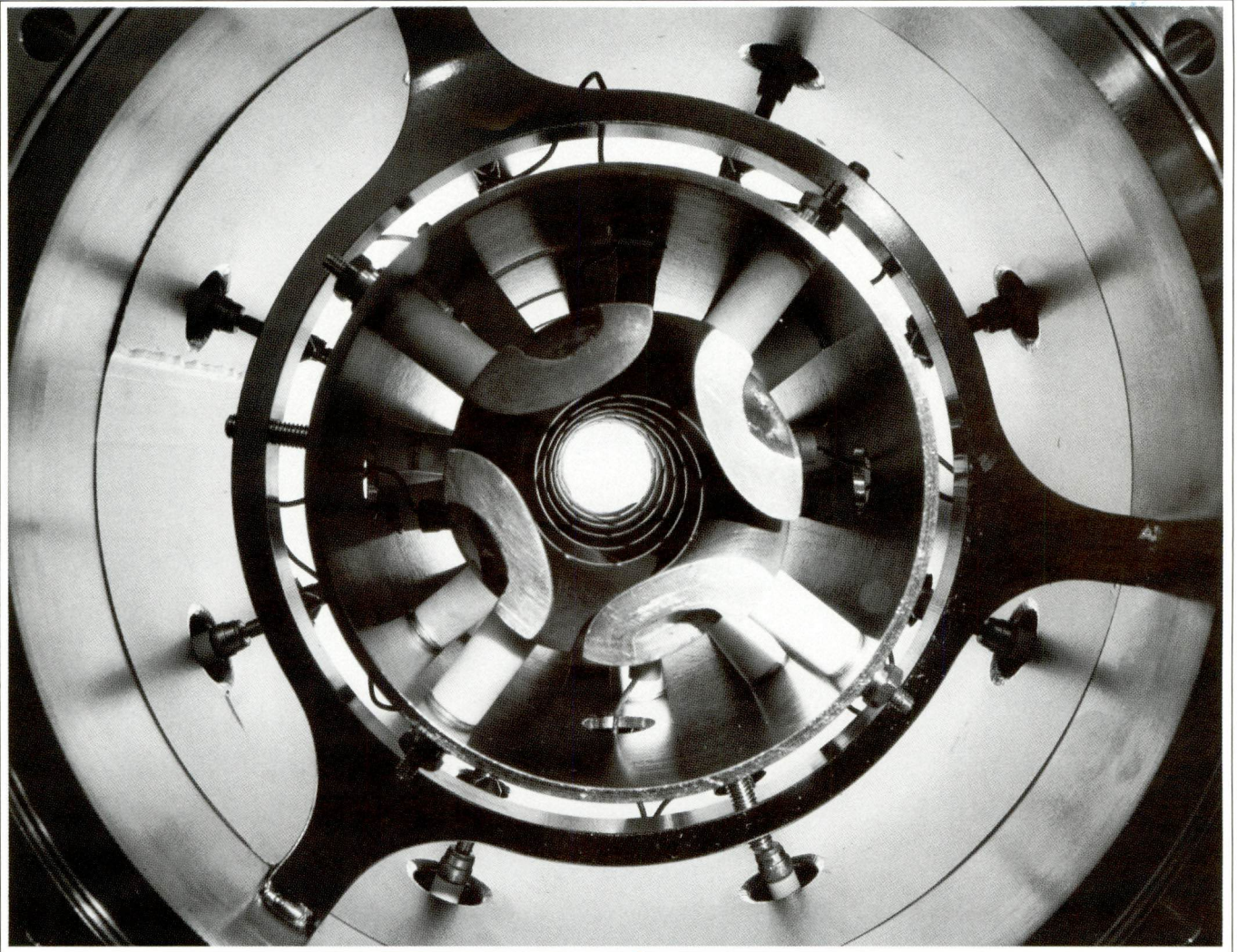
The first building constructed on the SSCL site, the Magnet Development Laboratory (MDL), is essentially complete. Laboratory staff are installing equipment for the prototyping and fabrication of SSC magnets. The Accelerator System String Test (ASST) building has also been completed and is now being outfitted for tests scheduled to begin in late 1992. Under construction are adjacent buildings that will house helium refrigeration

and storage equipment supplied by Processing Systems International.

Construction of the Magnet Test Laboratory (MTL) and the first magnet delivery shaft began in the fall. The MTL will be used to test both R&D magnets and a portion of the industry-produced superconducting magnets as they are delivered for installation. The delivery shaft will first provide access for a tunnel-boring machine that will begin work in 1992; the shaft will later be used to lower magnets into the tunnel. This pattern will be repeated during the next few years as four more such shafts are excavated for tunnel access and magnet delivery.

By late October, the staff of the SSCL numbered 1,720, including visitors from other labs and universities, temporary or contract employees, and consultants. The rapid staff growth has been accommodated by the purchase of a vacant warehouse in Waxahachie now outfitted with offices, laboratories, and machine shops; it is being prepared for use as the SSCL's central services facility. About 600 accelerator-systems employees began moving to this facility in late 1991, awaiting permanent facilities on the SSCL campus.





Cross-section of a helical electrostatic quadrupole magnet, which will help focus the SSC's proton beams.

## Magnet Development and Testing

Great progress was made in 1991 on the development of superconducting magnets for the SSC. After approval by the DOE, two contracts valued at a total of \$267 million were awarded in July to General Dynamics and Westinghouse to complete the design and begin manufacturing the 15-meter dipole magnets that are central to the operation of the SSC. The first stage of this work began shortly thereafter, with employees of the two companies working side by side with Fermilab and Brookhaven staff to fabricate prototype dipoles with the new 50-mm aperture. In November the first of these magnets were tested at the two labs with very encouraging results. In both cases, the magnet currents exceeded 7200 amperes—more than 10 percent above the designated operating level of 6500 amperes. This feat represents a major milestone for the SSC.

In 1991 the SSCL contracted with the Babcock & Wilcox Company to complete the design and begin initial production

of the superconducting quadrupole magnets to be used in the Collider. This firm will work with SSCL and Lawrence Berkeley Laboratory to transfer the magnet production technology to its production facilities in Virginia. Superconducting correction magnets needed to make small adjustments to the orbits of the proton beams will be developed under contracts with Babcock and Wilcox, Everson Electric Company, and Martin Marietta Strategic Systems.

Seven vendors—including IGC Advanced Superconductors, Teledyne SC, and Oxford Superconducting Technology in the United States—have been selected to proceed with development of superconducting niobium-titanium wire and cable for winding the SSC magnets. Plans are to review their production readiness by 1993 and approve those companies that qualify to serve as suppliers for the manufacturers of the SSC magnets.

In September, a string of five dipole magnets, which had been fabricated



SSCL engineers and technicians wind the coil for a prototype corrector magnet.

at Brookhaven with the old 40-mm aperture, were successfully tested at Fermilab—another important step in the magnet development program. Preparations are now well under way at the SSCL for a string test in late 1992 (the ASST mentioned above) which includes the 50-mm prototype dipoles being built by General Dynamics and Westinghouse, a prototype quadrupole, and associated support equipment.





Prototype dipole magnets on a test stand at Fermilab. Successful tests of the redesigned 50-mm SSC

collider dipoles were conducted in 1991 at Fermilab and Brookhaven National Laboratory.

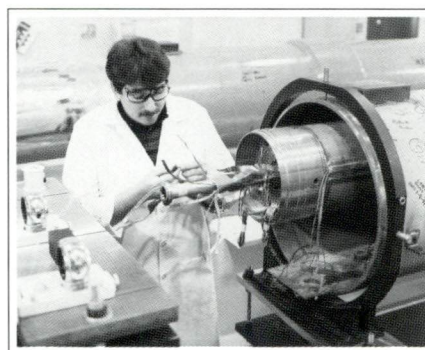
## Scientific Program

During 1991 the SSCL made important progress in defining its initial scientific program. The Laboratory has already received 21 proposals or letters of intent from a total of more than a thousand physicists describing new particle detectors or potentially interesting experiments. Guided by the Scientific Policy Committee and the Program Advisory Committee, the Laboratory Directorate has determined the major outlines of the SSC program.

Surrounding two SSC interaction regions there will be large (more than 10,000-ton), general-purpose detectors with complementary capabilities, ideally ready to take data when the SSC beams begin to collide in late 1999. In addition, there will be several smaller experiments at other interaction regions. Because of the long gestation times involved in designing and building the two large detectors, planning for them is already well under way.

In January, the Laboratory approved the Solenoidal Detector Collaboration (SDC)—a group of more than 700 scientists and engineers from over 100 institutions around the world—to proceed with a complete technical design proposal for one of the two large detectors. In June, members of the two collaborations whose letters of intent were not approved by the SSCL met with other physicists to begin developing a joint proposal for the other large detector—called GEM (for Gammas, Electrons, and Muons). This collaboration is already over 600 strong and each month accepts additional physicists.

Although no formal commitments have yet been made, the SSCL has received letters of intent describing smaller experiments that could be mounted and has also reserved funds for these experiments. SSCL engineers are currently designing appropriate facilities.



In preparation for testing, a technician inspects the instrumentation of a full-size structural model of a collider dipole magnet.



## ***Education Programs***

In addition to being a laboratory for frontier research in high energy physics, the SSCL will also serve as a major resource for science education at all levels. To lead this effort Dr. Thomas Gadsden was appointed head of the new Education Office in April. Two of its current activities include the "Adopt-a-Magnet" program for elementary school students and an internship program for high school students and college undergraduates.

The Education Office also coordinates the SSC Fellowships, awarded annually to promising young scientists throughout the United States since 1990. Supported by funds provided by the Texas National Research Laboratory Commission, 24 SSC Fellows will spend the next academic year working at their home institutions on research related to the scientific goals of the SSC.



The 1991 summer intern program at SSCL introduced dozens of high school and college students to the SSC's scientific and technological potential.

## ***Industrial Organizations and Technology Transfer***

The third annual International Industrial Symposium on the Super Collider was held in Atlanta in March. The IISSC promotes discussion among scientific, government, and industrial partners in the SSC program, emphasizing goals, technical challenges, and industrial opportunities.

The annual SSC fall conference was held from October 13 to 17 in Corpus Christi. Entitled "The Project, The Progress, The Physics," the meeting explored most aspects of the SSC, including the machines, the superconducting magnets, the evolving physics research program, conventional construction, computing, and education programs. A major part of the conference was devoted to reports on detector subsystems R&D.

For further information on the SSC:  
(214) 708-9000.



The building for the Accelerator System String Test (ASST) during an early stage of its construction, which was completed in 1991.



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Japan

**James McEwan Paterson**  
Stanford Linear Accelerator Center  
California

**John Peoples**  
Fermilab  
Illinois

**Grahame H. Rees**  
Stanford Linear Accelerator Center  
California

**Alvin V. Tollestrup**  
Fermilab  
Illinois

## **Users Organization for the SSC**

**David G. Cassel (Chairman)**  
Cornell University  
New York

**Robert K. Adair**  
Yale University  
Connecticut

**Maris A. Abolins**  
Michigan State University  
Michigan

**Robert N. Cahn**  
Lawrence Berkeley Laboratory  
California

**Roger J. Cashmore**  
Oxford University  
United Kingdom

**Alex W. Chao**  
SSC Laboratory  
Texas

**Thomas J. Devlin**  
Rutgers University  
New Jersey

**Paul D. Grannis**  
SUNY—Stony Brook  
New York

**Daniel Green**  
Fermilab  
Illinois

**Gordon L. Kane**  
University of Michigan  
Michigan

**Anne Kernan**  
University of California—Riverside  
California

**Lawrence E. Price**  
Argonne National Laboratory  
Illinois



# Organization Structure

## **Fiscal Year 1992 Funding Profile** (\$ Millions)

|                          |                 |
|--------------------------|-----------------|
| <b>Total DOE Funding</b> | <b>\$ 584.6</b> |
|--------------------------|-----------------|

|                 |                 |
|-----------------|-----------------|
| <b>Fermilab</b> | <b>\$ 216.6</b> |
|-----------------|-----------------|

|                                       |          |
|---------------------------------------|----------|
| Operations                            | \$ 160.9 |
| Capital Equipment<br>and Construction | 55.7     |

|                       |                 |
|-----------------------|-----------------|
| <b>SSC Laboratory</b> | <b>\$ 368.0</b> |
|-----------------------|-----------------|

|                                       |          |
|---------------------------------------|----------|
| Operations                            | \$ 120.1 |
| Capital Equipment<br>and Construction | 247.9    |

## **Membership and Boards**

URA conducts its affairs under the authority of its member universities, through a Council of Presidents. The council appoints the Board of Trustees, which in turn appoints a Board of Overseers for each major research activity.

Directors and staffs of URA-operated facilities are monitored by a separate Board of Overseers for each activity. Each board is responsible for oversight of the general management and operation of assigned programs. The directors of each major research facility are selected by the Board of Trustees with the approval of DOE. The combined total number of URA employees at the corporate headquarters and at affiliated activities now exceeds 3,000. Daily operations are coordinated directly between facility management and the appropriate DOE operations office or DOE headquarters.

In order to give its boards a truly national character, URA originally established geographic regions within the United States. The Council of Presidents elects one trustee from each of the seven regions; each regional trustee is president or the equivalent chief executive officer of a member institution in the region. In addition to regional members, there are up to eight at-large trustees and eleven at-large members of each board of overseers.

URA board members over the years have included chief executive officers of major industrial corporations, corporate vice presidents, and university presidents and vice presidents. Boards have also included winners of major science prizes, including Nobel laureates, as well as directors of major research laboratories. In 1988, the first URA overseer at large from Europe was appointed to the SSC Board, and in 1991, the first overseer at large from Japan joined that Board.

Each member university has agreed to contribute up to \$100,000 to URA on the call of the URA trustees. Since the

formation of the corporation in 1965, assessments have totaled \$30,000 per charter member. The availability of these funds has been a great source of assistance to the corporation. For example, initial construction of buildings at Fermilab, later repurchased by the AEC, helped to save approximately one year in accelerator construction time. URA funds have been used almost exclusively for expenditures that, for one reason or another, could not be made with funds derived from the Federal Government.

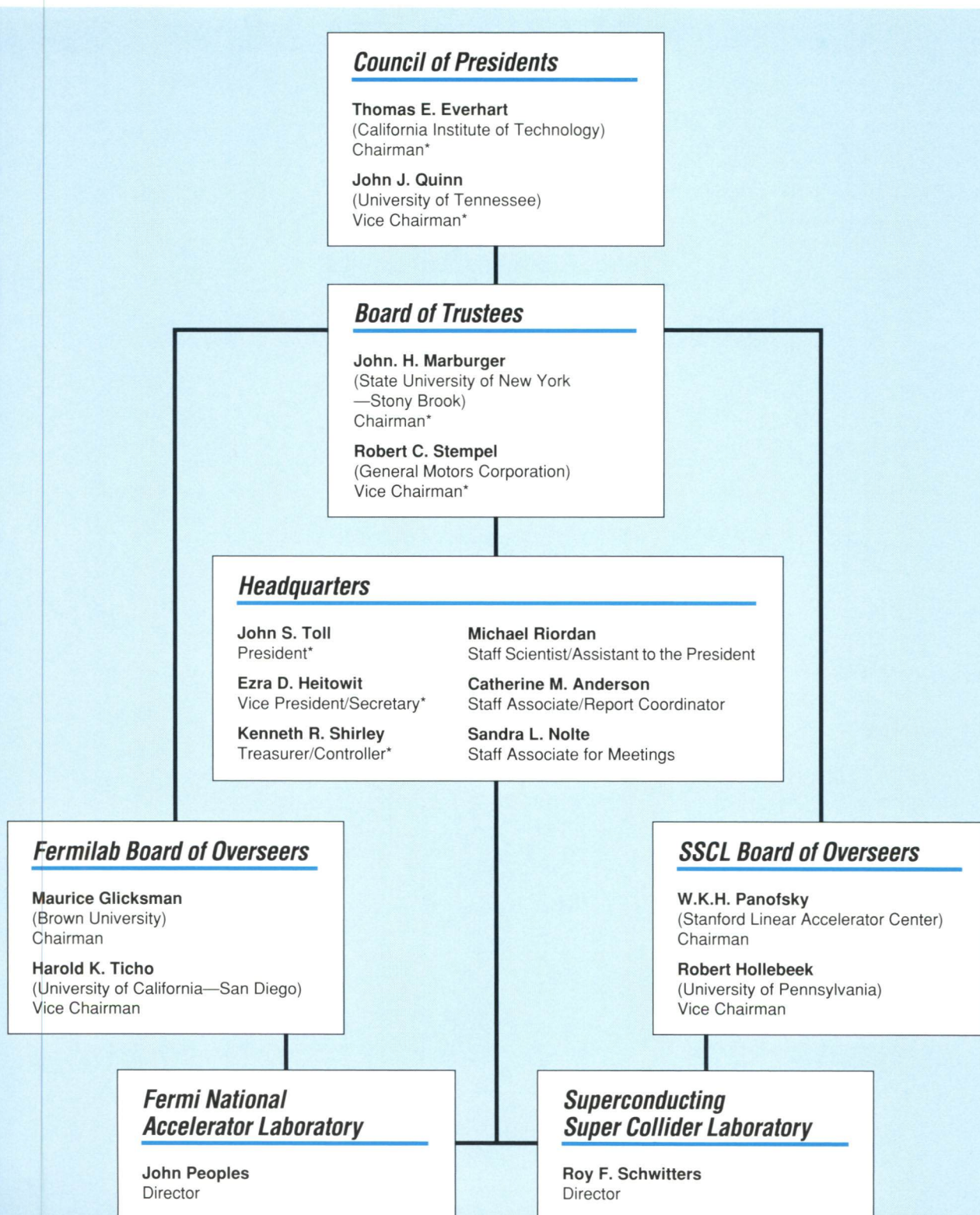
## **Headquarters Office**

Corporate officers include leaders of the URA governing bodies (Council of Presidents and Board of Trustees) and administrative officers at headquarters in Washington, D.C. Headquarters officers are the president, the vice president/secretary and the treasurer/controller. The Washington staff includes a staff scientist, a staff associate for communications, a staff associate for meetings, and two administrative staff members.

As chief executive officer, the president is responsible for overall policy development and general management of URA and its research facilities. The laboratory directors report directly to the president. The vice president is responsible for planning and coordination, with the assistance of the staff associate for meetings, in support of the Council of Presidents, the Board of Trustees, and the two Boards of Overseers; for management guidance of Fermilab and SSCL activities; and for administration of the DOE contracts. The treasurer manages corporate accounts, coordinates audits, and prepares financial statements. The staff scientist assists the president in providing liaison to the scientific community and responding to technical inquiries from the public. The staff associate for communications reports on legislative actions affecting URA and develops corporate communications.



# Organization Chart



\*Officers of the Corporation



# 1991 URA Boards

## Board of Trustees

### Regional Trustees

| Region                                              | Term Expires |
|-----------------------------------------------------|--------------|
| 1 William Gerberding<br>University of Washington    | 1994         |
| 2 Hanna Holborn Gray<br>University of Chicago       | 1993         |
| 3 William Davis<br>Louisiana State<br>University    | 1992         |
| 4 Agnar Pytte<br>Case Western Reserve<br>University | 1994         |
| 5 Joe B. Wyatt<br>Vanderbilt University             | 1993         |
| 6 Harold T. Shapiro<br>Princeton University         | 1992         |
| 7 *John H. Marburger<br>SUNY—Stony Brook            | 1994         |

### Trustees at Large

|                                                                                 |      |
|---------------------------------------------------------------------------------|------|
| William R. Frazer<br>University of California<br>System                         | 1994 |
| Emanuel J. Fthenakis<br>Fairchild Industries<br>—retired                        | 1992 |
| Robert Galvin<br>Motorola, Inc.                                                 | 1993 |
| Leon M. Lederman<br>University of Chicago and<br>Director Emeritus,<br>Fermilab | 1992 |
| Morton Meyerson<br>2M Companies                                                 | 1993 |
| George P. Mitchell<br>Mitchell Energy &<br>Development Corp.                    | 1994 |
| **Robert C. Stempel<br>General Motors<br>Corporation                            | 1993 |
| H. Guyford Stever<br>National Academy<br>of Engineering<br>—retired             | 1992 |

## Fermilab Board of Overseers

### Regional Overseers

| Region                                                       | Term Expires |
|--------------------------------------------------------------|--------------|
| 1 Roberto Peccei<br>University of California<br>—Los Angeles | 1994         |
| 2 Leland E. Holloway<br>University of Illinois<br>—Urbana    | 1992         |
| 3 George R. Kalbfleisch<br>University of Oklahoma            | 1992         |
| 4 David K. Scott<br>Michigan State University                | 1993         |
| 5 Charles E. Putman<br>Duke University                       | 1992         |
| 6 Paul F. Slatery<br>University of Rochester                 | 1992         |
| 7 Robert K. Adair<br>Yale University                         | 1993         |

### Overseers at Large

|                                                                                   |      |
|-----------------------------------------------------------------------------------|------|
| William V. Braun<br>Motorola, Inc.                                                | 1993 |
| David H. Cohen<br>Northwestern University                                         | 1994 |
| E. William Colglazier<br>University of Tennessee                                  | 1994 |
| *Maurice Glicksman<br>Brown University                                            | 1993 |
| Gail Hanson<br>Indiana University                                                 | 1994 |
| Kenneth Heller<br>University of Minnesota                                         | 1992 |
| David Schramm<br>University of Chicago                                            | 1994 |
| **Harold K. Ticho<br>University of California<br>—San Diego                       | 1994 |
| Robert R. Wilson<br>Cornell University<br>—retired<br>Director Emeritus, Fermilab | 1992 |

## SSC Board of Overseers

### Regional Overseers

| Region                                                         | Term Expires |
|----------------------------------------------------------------|--------------|
| 1 Peter A. Carruthers<br>University of Arizona                 | 1993         |
| 2 Don Reeder<br>University of Wisconsin<br>—Madison            | 1994         |
| 3 Neal F. Lane<br>Rice University                              | 1993         |
| 4 Homer A. Neal<br>University of Michigan                      | 1994         |
| 5 Robert Gluckstern<br>University of Maryland<br>—College Park | 1994         |
| 6 **Robert Hollebeek<br>University of Pennsylvania             | 1992         |
| 7 Frank Sciulli<br>Columbia University                         | 1992         |

### Overseers at Large

|                                                                  |      |
|------------------------------------------------------------------|------|
| Roy Billinge<br>CERN                                             | 1994 |
| Martin Blume<br>Brookhaven National<br>Laboratory                | 1993 |
| B.O. Evans<br>Technology Strategies<br>and Alliances             | 1994 |
| Harold Forsen<br>Bechtel Corporation                             | 1994 |
| Robert A. Frosch<br>General Motors Corporation                   | 1993 |
| Boyce D. McDaniel<br>Cornell University                          | 1992 |
| Albert Narath<br>Sandia National Laboratories                    | 1992 |
| *Wolfgang K.H. Panofsky<br>Stanford Linear<br>Accelerator Center | 1993 |
| Tetsuji Nishikawa<br>Science University of Tokyo                 | 1993 |
| Martin Walt<br>Lockheed Missiles<br>and Space Company            | 1992 |
| Bjorn Wiik<br>DESY                                               | 1992 |

\*Chairman \*\*Vice Chairman



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