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REPORT OF THE AD HOC COMMITTEE ON THE POTENTIAL
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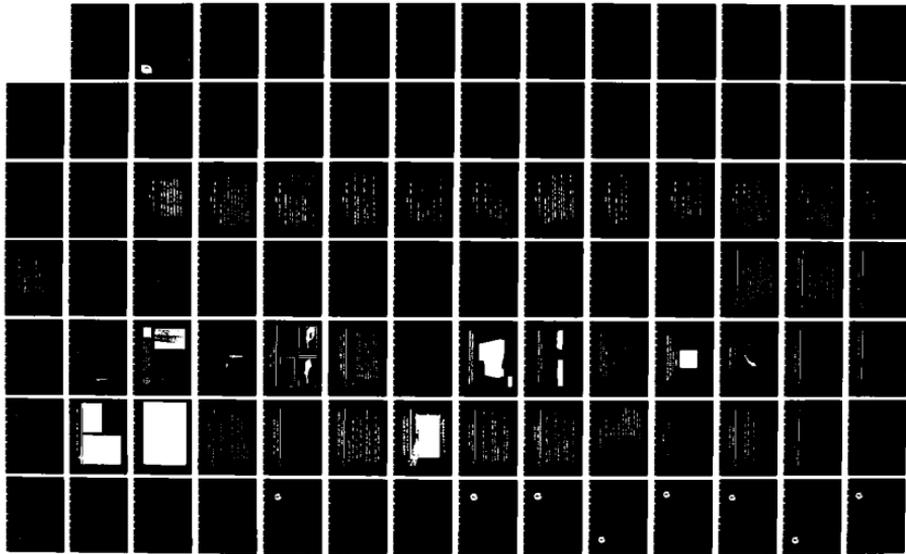
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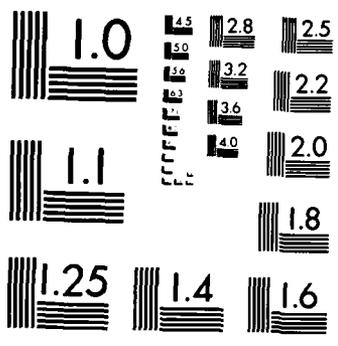
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IDA MEMORANDUM REPORT M-110

REPORT OF THE AD HOC COMMITTEE ON THE POTENTIAL BENEFITS TO U.S. INDUSTRY FROM THE SDI/IST SCIENTIFIC PROGRAM

Bohdan Balko, *Executive Officer*

November 1985

Prepared for
Innovative Science and Technology Office
Strategic Defense Initiative Organization

James Ionson, *Director*

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INSTITUTE FOR DEFENSE ANALYSES
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IDA MEMORANDUM REPORT M-110

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POTENTIAL BENEFITS TO U.S. INDUSTRY FROM
THE SDI/IST SCIENTIFIC PROGRAM

Bohdan Balko, *Executive Officer*

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PREFACE

A workshop on the potential benefits that would accrue to U.S. industry as a result of the Strategic Defense Initiative/ Innovative Science and Technology Program (SDI/IST) was organized and held at the Institute for Defense Analyses (IDA) on June 17 and 18, 1985. This document, prepared under Contract MDA 903 84 C 0031, describes the program, identifies likely technological fallout, and includes copies of the visual aids used by individual speakers at the workshop.

We have attempted to provide an accurate record of the presentations and regret any errors that may have been introduced inadvertently. This Memorandum Report has been reviewed by the committee members listed on page ix.

ABSTRACT

Issues and procedures that the SDI/IST Directorate and its clients (in industry and elsewhere) may profitably use to enhance the status of U.S. industrial productivity and competitiveness in international markets are discussed. This enhancement will obtain from the utilization of the new knowledge and skills derived from SDI/IST programs and activities.

CONTENTS

Preface	iii
Abstract	v
List of Participants	ix
I. Introduction	1
II. Identification of Likely Technological Fallout from the Program of the SDI/IST Directorate	3
III. Issues and Procedures	9
Appendices--Edited Synopses of Presentations and Vugraphs	
Appendix A Ultra-High-Speed Computing Dr. E. Wegman, ONR	A-1
Appendix B SDI Software Requirements Dr. T. Probert, IDA	B-1
Appendix C Advanced Materials and Structures Dr. Robert R. Pohanka, ONR	C-1
Appendix D Space Power and Power Conditioning Mr. J. Farber, DNA	D-1
Appendix E Optical Sensors Dr. F. Quelle, ONR	E-1
Appendix F Optical Sensor Survivability Dr. F. Bartoli, NRL	F-1
Appendix G Discrimination Dr. F. Quelle, ONR	G-1
Appendix H Advanced Accelerator Concepts Dr. C. Roberson, ONR	H-1
Appendix I Ultra-Short Wavelength Lasers Dr. H. Pilloff, ONR	I-1

Appendix J Short Wavelength Chemical Lasers J-1
Dr. C.R. Jones, LANL

Appendix K Free Electron Lasers
Dr. Dwight Duston, SDIO/IST K-1

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THE POTENTIAL BENEFITS TO U.S. INDUSTRY FROM THE
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I. INTRODUCTION

The program of the SDI/IST Directorate represents long-range research activity in support of the development of a non-nuclear, antiballistic missile defense system. It is a program of unprecedented complexity in system design as well as in the development of supporting component technologies. The major program thrusts are directed toward research on:

- (1) novel directed energy concepts;
- (2) novel sensing, discrimination, and data-processing techniques;
- (3) special supercomputing needs for the SDI mission,
- (4) innovations in burst-mode space power and power conditioning;
- (5) advanced materials, propellants, and structures for SDI applications.

The purpose of the program is to investigate scientific concepts that could provide new and powerful technologies for various SDI program needs.

In the past, the technological and scientific challenges represented by difficult innovations have generally not only spawned entirely new industrial developments but have also tended to accelerate the levels of sophistication, efficiency, and hence the competitive edge of U.S. industry in international markets. At the same time, fundamental research of the most challenging type has immeasurably contributed to U.S. pure and applied academic science and engineering, while playing an essential role in the education and training of new generations of scientists and engineers.

The committee believes that a properly managed Innovative Science and Technology program will provide a needed new focus, motivation, and support for advanced technological developments. Even though the primary objective of SDI is constructing an effective antiballistic missile defense system, it is expected that significant benefits from SDI/IST will also accrue to overall U.S. science and technology.

II. IDENTIFICATION OF LIKELY TECHNOLOGICAL FALLOUT FROM THE PROGRAM OF THE SDI/IST DIRECTORATE

It is easy to extrapolate to successful conclusions much of the research supported in identified programmatic areas that will necessarily be chosen in the SDI/IST program. Successful conclusion of research, in turn, implies an opportunity for wide dissemination of new technological discoveries for use by U.S. industry.

A number of important examples of past industrial advances derived from military programs will suffice for this discussion:

1. Nuclear weapons technology led to commercial power reactors, production of radioactive materials for industrial and medical applications, and advances in precision machining and fabrication technology, especially for exotic materials such as beryllium.
2. Military R&D on weapon trajectories, automatic control, flight simulation, and air defense led to the widespread use of digital computers.
3. Microwave radar development during World War II led to commercial applications of many kinds, including air traffic control; physical, chemical, and medical instrumentation (e.g., NMR); and communication systems.
4. Numerically-controlled machine tools were first developed in military R&D programs.
5. R&D in artificial intelligence was largely sustained by DARPA during the 1960s and 1970s and is now reaching the stage of application to both commercial and military needs.
6. Jet engine technology, first developed for military applications, led to the modern jet transports which

dominate the world's airways. Military R&D has been a major factor in driving up the operational turbine inlet temperature from the original 1200°F to today's value of 2500°F through a combination of advanced materials and cooling.

7. While the first integrated circuits were devised by Texas Instruments and Intel, it was military (and NASA) support of production and application technology for the Minuteman II and Apollo guidance systems that launched the microcircuit age.
8. High-strength, high-stiffness fiber composite technology for structures was a direct result of military R&D. Although the fibers themselves (e.g., boron, carbon/graphite, and Kevlar) derive from many sources, the all-important design, fabrication, quality control and operational maintenance technologies were brought to the point of practical application through military programs of the 1960s and early 1970s. High-strength, high-stiffness fiber composites are now found increasingly in military aircraft (e.g., F-14, F-15, F-16, F-18, AV-8B), commercial aircraft (757, 767) as well as spacecraft, and other commercial applications such as tennis racquets and golf clubs.

The following are examples of likely contributions resulting from the current program.

- The SDI/IST program is actively pursuing new and innovative ways of producing and delivering energy. The associated development of shorter wavelength and higher power lasers has generally been encouraged and funded. The IST program in this area includes investigations of the feasibility of developing a γ -ray laser that will operate in the keV energy regime, with unprecedented intensity and high penetrability. The program could therefore provide a new and powerful technique for probing and modifying materials.

Some of the more obvious applications of γ -ray lasers include:

- γ -ray and x-ray spectroscopy with very high resolution, improved contrast, and deeper penetration for inspection of thick materials;
 - holography with very short wavelength, coherent radiation for three-dimensional observations of the structures of molecules, crystals, proteins, genes, and in vivo cellular material;
 - extension into the nuclear regime of precision-frequency and length (sub-nanometer) measurements based on interferometric techniques;
 - imaging techniques (CAT scanners), with reduced doses and higher resolution for discrimination between molecular species;
 - nonlinear effects at short wavelengths, with applications to nuclear studies;
 - modifications of nuclear reactions by using highly monochromatic γ -radiation for selective removal of electrons to produce charge-density modifications at nuclear dimensions;
 - determination of microscopic structure with very short exposures and high collimation at Fresnel-limited resolution;
 - microreplication and fabrication of microelectronic components with high intensity, excellent collimation, and short exposure times;
 - possible advances in materials science using the high intensities of ionizing radiation at very small local scales;
 - fusion research that is facilitated by deep penetration with γ -rays to interrogate high-density matter.
- The following are possible payoffs to the electronic power and other industries:

- improved sensors for monitoring the performance of electrical machinery;
- the development of rapid, high-capacity computers for controlling and monitoring plant operations and outputs.
- Increased knowledge of interactions between high-intensity radiation and materials may produce new manufacturing processes, new instrumentation, new surface treatments and coatings, and new super-hard materials.
- Ultra-precise sensing and measurement technology will facilitate developments of new, automated process control of material flows, distributions, and separations.
- The development of high-resolution, high-speed sensors will be utilized immediately in medical radiological imaging applications (so-called digital PACS, picture archiving and communications systems), remote sensing (oil, gas, and mineral exploration, crop and resource management), digital storage of records, and automated inspection of manufacturing processes. The development of microminiaturized sensor refrigeration devices extends all of these applications (especially remote sensing) into the infrared regime, in a cost-effective, commercially viable way.
- Major advances in optical component design and fabrication of new functional capabilities will provide options for
 - segmented, adaptive optics systems to achieve improved performance and lower cost products;
 - new energy and power management and distribution concepts and systems;
 - advanced optical computations, signal processing, and communications.
- New structural materials and design and fabrication concepts have widespread product potential, including

applications in automotive, maritime, aerospace, and biomedical industries.

- The advanced materials work includes studies on space manufacturing techniques. These techniques can lead to high-purity, very large crystals, (for computer chips, detectors, etc.) and are, at the least, expected to produce commercially viable quantities of gallium arsenides, etc.
- Development of new space-power technologies could lead to energy storage at high power densities and acceptable costs, with future use in transport vehicles;
- The developments in particle-beam generation and control and in laser technologies may be expected to lead to
 - advances in new, safe, and efficient medical diagnostics;
 - applications of advances in the accuracy of pointing and tracking to improve commercial aircraft guidance and control, as well as ground-traffic monitoring, scheduling, and control.
- Tactical forces will benefit from technologies that are developed under the SDI/IST program. Thus,
 - new technologies for tactical air defense may be obtained for air-to-air and surface-to-air applications;
 - we may anticipate designs of improved weapons, energy sources, and of pointing and tracking techniques;
 - there will be improvements in detection, identification, battlefield surveillance, and multi-sensor correlations;
 - advances in sensor hardening will, in many cases, be applicable to tactical as well as strategic systems;

- new software and artificial intelligence applications will facilitate the development of hitherto unattainable autonomous functions in robotic and automated systems for commercial and military uses.
- High-speed computing advances and advanced techniques for writing large fault-free programs will result in a new generation of mainframe computers that, in business, industry, and government will provide faster, more efficient handling of inventories, data, manufacturing, and scientific modeling.

III. ISSUES AND PROCEDURES

The SDI/IST Directorate is constrained to focus its activities and efforts on areas with demonstrable relevance to SDI program goals. Industry goals are usually oriented toward relatively short-term profit objectives, which include planned growth without undue risks. Thus, the long-term research output of the SDI/IST Directorate will generally not be immediately compatible with the relatively short-term needs of industry. However, an overlap of objectives is expected to occur over longer time scales and will become apparent when SDI/IST-derived studies produce new technological advances that are suitable for commercialization. The expected results include both improvements in existing product types and the spawning of entirely new industries, both of which would provide a long-term U.S. competitive edge in international markets. A challenge to the SDI/IST Directorate and to U.S. industry therefore exists, namely, how to optimize beneficial impacts for SDI/IST. Listed below are a number of procedural steps that may be taken to foster this:

1. A concerted effort should be made by the IST Directorate and industrial managers to ensure prompt access to information on SDI/IST program objectives and R&D results. This type of monitoring will provide prompt information flow to interested parties within participating organizations. Early applications will be facilitated by providing competent users with appropriate information on a continuing basis. Implementation of this effort requires not only a free flow

of information but also the distillation of this information in usable form. For this purpose, an IDA/IST newsletter should be created and maintained. This newsletter must be of exceptional quality: accurate, brief, and with a clear accounting of research progress and problems. Clear identification should be given of major program objectives and of the importance of discoveries for (a) SDI goals, (b) scientific progress in general, and (c) applications potential by U.S. industry.

It is important to identify research topics on which the IST Directorate requires special assistance from the industrial and scientific communities. Members of the IDA/IST-Industry Advisory Committee will be invited to contribute their reactions, comments, and suggestions regarding the status and direction of the SDI/IST research programs. Progress reports normally prepared by contractors and program managers for the SDI/IST Directorate will be useful in preparing the newsletter.

In addition to publication and distribution of a quarterly newsletter, it may be desirable to convene the IDA/IST-Industry Advisory Committee about once a year for an in-depth review of progress in the SDI/IST programs and to invite all participants to provide, on a continuing basis, their inputs in maintaining updated lists of likely technological fallouts from the programs of the SDI/IST Directorate and their interests in pursuing specific commercial applications. A central file of industry interests should be maintained to assure continuing communication of pertinent IST program progress to appropriate firms.

2. A program should be developed for industry guest workers at National Laboratories and at laboratories of contractors participating in the SDI/IST programs. The National Laboratories may well serve a special role as intermediaries with industry on special topics of SDI/IST research and development, especially those requiring nearly unique, costly facilities of the types that are often developed, maintained, and used at National Laboratories. SDI/IST-funded research at joint and interdisciplinary laboratories may also provide valuable points of contact within the industrial and university communities.

It may be useful to follow the paradigm used at the Combustion Research Facility of the Sandia Livermore National Laboratory, where guest workers from all over the world learn about new and important applications of laser diagnostics using the best available experimental facilities. The SDI/IST program will inevitably spawn new discoveries that will be sophisticated and difficult to apply. By providing access to these high-payoff and high-risk studies, industrial applications of research results may be greatly facilitated. Initiation of a cooperative program may require only an announcement by the Director of the SDI/IST Directorate to the effect that his Office will assist interested U.S. industry representatives in gaining appropriate access. Arrangements may then be worked out on an ad hoc basis by identifying one or more SDI/IST contacts for each development.

3. The SDI/IST Directorate may profitably announce the successful achievement of milestones in its research programs by convening forums designed to inform interested industry representatives of likely near-term

purchasing objectives resulting from new discoveries or advances in research.

For these open SDI/IST reports, contacts with industry may profitably include liaison with the Federal Science and Technology Committee* of the Industrial Research Institute, which has about 280 corporate members and represents about 80 percent of U.S. industrial R&D.

4. A number of SDI program goals are so complex and demanding that straightforward extrapolations of likely advances in currently known technologies will generally not suffice. There is unusual need for innovation, invention, and entirely new approaches at levels challenging the brightest and best people. These challenges are too readily dismissed as posing impossible requirements; but innovation can lead to new ways of thinking and approaching these tasks. It is especially important that these central topical issues be identified, reviewed, and periodically evaluated by national panels of experts. Examples of SDI needs that require the most demanding types of innovation and, therefore, nationwide academic and industrial participation are the following:

- computing and software,
- space-power requirements,
- midcourse (and upper terminal phase) discrimination

A dedicated national effort in these fields requires exceptional freedoms for highly competent people who are cognizant of the enormous difficulties involved and are willing to follow non-conventional approaches in order to contribute to resolution of the critical issues. Industry participation in these

*The current chairman of this Committee is Peter Cannon, Sr., Vice President of Rockwell International.

endeavors must be justified in terms of the magnitude of the potential rewards.

The committee recommends that the SDI/IST Directorate develop a special program within U.S. industry for supporting especially competent and innovative individuals who are nominated for participation in this program by their supervisors. Funding for this Innovative Industry SDI/IST program should be moderate (approximately \$500,000 per year) but stable (i.e., 3 to 5 years in duration).

Because utilization by SDI of large numbers of scientific personnel with critical skills could reduce the availability of these professionals for both military and non-military uses, the committee recommends that significant and long-term commitments be made to appropriate educational institutions to ensure the training and availability of scientists to fill anticipated critical skill shortages. Less than about 5 percent of the proposals received have been accepted because of SDI/IST funding restrictions for FY 85 and 86. Many relevant high-quality proposals for research in the SDI/IST program could not be funded. This fact illustrates the present acute shortage for research funding in high-technology areas in the U.S. and shows that the presumed siphoning off of high-technology experts by SDI has not yet occurred and is not likely to occur at all in view of the ability of universities to augment trained manpower in critical disciplinary areas within short periods (approximately 4 years) compared to the SDI implementation schedule (more than 20 years).

EDITED SYNOPSES OF
PRESENTATIONS AND VU-GRAPHS

APPENDIX A
ULTRA-HIGH SPEED COMPUTING

Dr. E. Wegman, ONR Washington

Ultra High Speed Computing
Edward Wegman (202) 696-4310

Space-based defense systems will create a computationally intensive environment, with demands for software and hardware performance far beyond current technology. Computing requirements will include computation for such functions as large space structure control; control of a large, complex communication network; ultra-high resolution image processing; real-time radar processing; adaptive digital electronic countermeasures; synthetic aperture radar; targeting; and fire control and navigation. Conservatively estimated, SDI image processing will require speeds on the order of 5 GIGAOPS, while high-resolution ISAR requirements may be as high as 1000 GIGAOPS. The architectures necessary to achieve such speeds are radically different from today's high-speed, general-purpose architectures. Software problems associated with such novel architectures are also expected to be extremely difficult. Since it is expected that some 10 million lines of error-free code will be required to operate a space-based defense system successfully, a revolutionary rather than incremental approach to software development must be invented.

The area of highly parallel architectures is intended to exploit the modern VLSI and submicron electronic device capability for high-speed computational purposes. Such devices have two salient features. First, the small feature size precludes manual design of all circuitry on the device. Thus, a relatively simple processor replicated over the entire surface of the chip is an extremely attractive design approach. Second, facilities for interconnection and connection to external circuits are extremely limited compared to the number of transistor elements available. Therefore, a design replicating simple processors with minimal connections seems ideal.

These characteristics are hallmarks of systolic architecture. In addition, simple linear algebra algorithms map very well into systolic architectures. Since numerical linear algebra forms the underpinning of modern signal processing, special-purpose, high-speed systolic devices are prime candidates for achieving the computational requirements. Specific objectives are to (1) redesign fundamental arithmetic processors to minimize connections and maximize speed, (2) develop algorithms for control, communications, image and radar processing, countermeasures, navigation, and targeting which may be embedded in systolic architectures, and (3) develop fundamental techniques for mapping algorithms into systolic architectures.

The thrust in optical computing is intended as an exploration of a technological alternative to electronics which will have an extremely high payoff if successful. Optical computing is conceptually capable of extremely high speeds, massive parallelism, and inherent hardness to nuclear radiation. Analogue optical processing, however, is limited because of dynamic range limitations due to internal scattering (30 dB), limited ability to implement algorithms (convolution, correlation, and Fourier transformation), and difficulty in interfacing with electronic components. The objectives of this thrust are to (1) develop basic optical computing architectures designed to exploit the inherent assets of optics (speed, parallelism, etc.), (2) develop ultra-high-speed devices for conversion between electronic and optical formats, and (3) search for optical implementation of the systolic concept.

The thrust in software research is motivated by the requirement for 10 million lines of error-free code. With present language and software development tools, this goal is not achievable. It is believed that additional methodological studies, new application programming languages, or related incremental approaches will be unsuccessful. We therefore seek to change the process by which large-scale software systems

are developed. Our guiding philosophy is a heavy, early expenditure of computing cycles to develop the software. This approach implies a very-high-level language which, when compiled, is optimized for very high speed. Our single objective is to create orders of magnitude more sophisticated software development tools.

SDIO
ULTRA HIGH SPEED COMPUTING

**SPACE-BASED DEFENSE SYSTEMS
WILL CREATE A COMPUTATIONALLY
INTENSIVE ENVIRONMENT WITH
DEMANDS FOR SOFTWARE AND
HARDWARE PERFORMANCE ORDERS
OF MAGNITUDE BEYOND CURRENTLY
AVAILABLE TECHNOLOGY.**

SDIO

ULTRA HIGH SPEED COMPUTING

COMPUTATION FOR:

- **LARGE SPACE STRUCTURE CONTROL**
- **LARGE, DISTRIBUTED LPI COMMUNICATIONS NETWORK**
- **ULTRA HIGH RESOLUTION IMAGE PROCESSING**
- **ADAPTIVE DIGITAL COUNTERMEASURE**
- **SYNTHETIC APERTURE SURVEILLANCE RADAR**
- **ULTRA PRECISE NAVIGATION**
- **REAL TIME ULTRA PRECISE TARGETING AND FIRE CONTROL**

SDIO

ULTRA HIGH SPEED COMPUTING

SOME TYPICAL REQUIREMENTS:

- **ULTRA HIGH RESOLUTION IMAGE PROCESSING** 5 GIGAOPS
- **REAL TIME DIGITAL RADAR PROCESSING** 15 GIGAOPS
- **COMMUNICATIONS WITH BEAM FORMING TO NULL JAMMERS** 100 GIGAOPS
- **HIGH RESOLUTION ISAR** 1000 GIGAOPS
- **CRAY XMP** 1/2 GIGAOPS

SDIO
ULTRA HIGH SPEED COMPUTING

**NEW ARCHITECTURES IMPLY UNPRECEDENTED
SOFTWARE DEVELOPMENT**

- **SOFTWARE TO EXPLOIT HIGHLY PARALLEL
ARCHITECTURES**
- **10 MILLION LINES OF ERROR-FREE CODE**

SDIO

ULTRA HIGH SPEED COMPUTING

EMPHASIS AREAS:

- **HIGHLY PARALLEL ARCHITECTURES**
 - **SYSTOLIC**
 - **COMMUNICATIONS**
 - **FAULT TOLERANCE**
- **OPTICAL COMPUTING**
 - **LINEAR ALGEBRA**
- **INNOVATIVE SOFTWARE DEVELOPMENT TOOLS**

SDIO

ULTRA HIGH SPEED COMPUTING

- **EXPLOIT VLSI AND SUBMICRON ELECTRONIC DEVICES**
- **TRADE NUMBER OF PROCESSORS FOR SPEED**
- **SALIENT FEATURES**
 - **SIMPLE PROCESSORS REPLICATED**
 - **MINIMAL INTER CONNECTIONS**
- **SYSTOLIC ARRAYS**

SDIO

ULTRA HIGH SPEED COMPUTING

OBJECTIVES FOR HIGHLY PARALLEL ARCHITECTURES

- **REDESIGN FUNDAMENTAL ARITHMETIC PROCESSORS
TO MINIMIZE CONNECTIONS AND MAXIMIZE SPEED**
- **DEVELOP ALGORITHMS FOR CONTROL,
COMMUNICATIONS, RADAR AND IMAGE PROCESSING,
ETC. WHICH MAY BE EMBEDDED IN SYSTOLIC
ARCHITECTURES**
- **DEVELOP FUNDAMENTAL TECHNIQUES FOR MAPPING
ALGORITHMS INTO ARCHITECTURES**

SDIO ULTRA HIGH SPEED COMPUTING

ANALOGUE PROCESSING

- **LIMITED DYNAMIC RANGE (30dB) DUE TO SCATTERING**
- **LIMITED ABILITY TO IMPLEMENT ALGORITHMS**
 - **CONVOLUTION**
 - **CORRELATION**
 - **FOURIER TRANSFORMATION**

SDIO ULTRA HIGH SPEED COMPUTING

OPTICAL COMPUTING

- **CONCEPTUALLY CAPABLE OF EXTREMELY
HIGHSPEEDS**
- **MASSIVELY PARALLEL**
- **INHERENTLY HARD TO NUCLEAR RADIATION
EFFECTS**

SDIO

ULTRA HIGH SPEED COMPUTING

OBJECTIVES FOR OPTICAL COMPUTING

- **DEVELOP BASIC OPTICAL COMPUTING ARCHITECTURES TO EXPLOIT ASSETS OF OPTICS**
- **DEVELOP ULTRA HIGH SPEED DEVICES FOR CONVERSION BETWEEN OPTICAL AND ELECTRONIC FORMATS**
- **SEARCH FOR OPTICAL IMPLEMENTATION OF SYSTOLIC CONCEPT**

SDIO

ULTRA HIGH SPEED COMPUTING

SOFTWARE DEVELOPMENT TOOLS

- **10 MILLION LINES OF ERROR-FREE CODE**
- **PRESENT LANGUAGE AND SOFTWARE DEVELOPMENT TOOLS INADEQUATE**
- **SOFTWARE IS THE MOST LIKELY SOURCE OF FAILURE FOR THE SDI CONCEPT**
- **INCREMENTAL APPROACHES UNSUCCESSFUL**
- **HEAVY UP-FRONT EXPENDITURE OF COMPUTER CYCLES TO DEVELOP SOFTWARE**

SDIO

ULTRA HIGH SPEED COMPUTING

SOFTWARE DEVELOPMENT TOOLS

APPROACH:

- **SUPERCOMPUTER ORIENTED DEVELOPMENT TOOLS**
- **VERY HIGH LEVEL LANGUAGE**

OBJECTIVE:

- **CREATE ORDERS OF MAGNITUDE MORE
SOPHISTICATED SOFTWARE DEVELOPMENT TOOLS**

SDIO ULTRA HIGH SPEED COMPUTING

MANAGEMENT

- **FLEXIBLE MANAGEMENT**
- **CONSORTIA BASED**
- **UNCONSTRAINED BRAINSTORMING**
- **INTERDISCIPLINARY**
- **CONTACT:**

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APPENDIX B
SDI SOFTWARE REQUIREMENTS
(Not an IST Program)

Dr. T. Probert, IDA

**IDA
AND
THE JASON SDI**

Summer Study

Visiting Committee

June 13, 1985

THE PROBLEM

1. THE BATTLE MANAGEMENT SYSTEM SOFTWARE
 - 19 to 35 million lines of code
 - Excludes support software
2. NO SOFTWARE SYSTEM > 1/4 MILLION LINES OF CODE HAS BEEN
 - Delivered on time, *and*
 - Delivered on budget, *and*
 - Met original requirements
3. OVER 80% OF PROJECTED DoD WEAPON SYSTEMS WILL BE CRITICALLY DEPENDENT UPON SOFTWARE
 - Plus U.S. government
 - Plus private sector
4. FEWER THAN 2000 PHD COMPUTER SCIENTISTS ARE PRODUCED EACH YEAR IN THE U.S.
 - Number is decreasing
 - Important in the long term
 - Metric on research and production ability

6-12-85-4

THE STUDY

OBJECTIVE: TO EVALUATE THE SCOPE OF THE SOFTWARE PROBLEM AND RECOMMEND SOLUTION STRATEGIES AND TIMELINES

**WHEN: July 1, 2 LaJolla, CA (Part 1)
 July 29 LaJolla, CA (Part 2)**

WHO: { A. Despain - Berkeley
 J. Cuadrado - IDA/Octy
 T. Probert - IDA
 10 internationally recognized software/computer scientists

Part 1 {

Part 2 { A. Despain Prepare
 J. Cuadrado Final
 T. Probert Report

COST: TRAVEL AND TIME FOR PROBERT, CUADRADO AND 5 PARTICIPANTS

THE ANALYSIS

Boehm COConstructive COst MOdel (COCOMO)

2.8 (KDSI) 1.2 = nominal effort

1.43 = productivity/cost multiplier

2.5 (Adjusted Effort) 0.32 = minimum time

BEST CASE 19 MILLION LINES OF CODE

→ 45,480 person years of effort

→ 14 years minimum time to deliver

WORST CASE 35 MILLION LINES OF CODE

→ 94,666 person years of effort

→ 18 years minimum time to deliver

BEST CASE WITH SUPPORT SOFTWARE (3:1)

→ 118,858 people years over 22 years

WORST CASE WITH SUPPORT SOFTWARE

→ 247,402 people years over 28 years

6-12-85-3

APPENDIX C
ADVANCED MATERIALS AND STRUCTURES

Dr. R. Pohanka, ONR Washington

Advanced Materials and Structures
Robert Pohanka (202) 696-4401

Advanced space defense systems are in need of materials and structures research because such systems require:

(1) lightweight, dimensionally stable, highly damped structures that are able to survive a hostile environment; (2) reliable electrical and mechanical components; (3) devices capable of high-speed electronic signal processing and computation; and (4) efficient power and propellant schemes. The primary focus of this program is to make significant advances in the materials required for the technologies of interest to SDI. Emphasis will be on understanding the complex relationships between processing, structure, and properties. Such understanding will serve as the basis for new materials with greatly improved properties such as increased vibration damping in metal matrix composites, improved efficiency of rocket fuels, and reliable bearings and seals in space structures.

Research will be considered in the following major areas:

(1) composites with advanced fiber and matrix materials (metal, ceramic, and carbon); (2) energetic materials (highly efficient, reliable, reproducible rocket fuels); (3) tribology - with emphasis on mechanisms of long-term wear and degradation in a space environment; (4) electronic and optical materials, emphasizing advanced electronic packaging materials and high-power dielectric materials; (5) interactions of energy (e.g., laser) and materials, with special emphasis on hardening.

Major focused research efforts are expected to be undertaken at "University Centers," with additional work being done at other universities, industrial laboratories, and government laboratories.

The objectives of the composites materials research thrust will be to develop fundamental understanding of processing-structure-property relationships for advanced ceramic-, metal-, and carbon-matrix composites, and to use such insights to synthesize advanced composite materials. Specific areas to be addressed include: (1) improving fatigue-resistant metal composites; (2) enhancing static and dynamic resistance to crack growth in advanced ceramic matrix composites; (3) investigating the thermodynamics and kinetics of processes at fiber-matrix interface to engineer mechanical properties of composites; (4) examining the mechanisms of conversion of polymers to SiC, Si₃N₄, BN refractory ceramic fibers; (5) improving the damage tolerance of carbon matrix composites; and (6) analyzing material systems to develop a predictive capability for deformation and failure processes. The main objective of the energetic materials thrust is to provide the science base for advanced high-energy rocket propellants that may be continuously and precisely manufactured at high rates and minimum cost. Included will be efforts to develop: (1) the material science of advanced rocket propellant binders and (2) an understanding of the fluid physics that control their processing behavior. The effort is expected to provide an understanding of the polymer molecular structure-property relationships for new energetic thermoplastic elastomers that are necessary for fail-safe propellant processing of filled composites. Further, investigations of thermoplastic materials such as multiblock polymers with energetic functional groups such as azido [N₃zO, nitramino (N-N)₂] and carbonanyl (B₁₀C₂H₁₂) are expected. The polymer fluid physics effort will develop an understanding of the local stresses, velocities, and temperatures of solid propellant slurried polymer melts in the flow and mixing channels representative of continuous, polymer melt processing equipment. This approach is necessary for efficient and safe process designs.

The main thrust of tribological research will be concerned with advancing understanding of friction and wear processes, and applying such knowledge to production of new materials with superior performance and reliability. Research areas include: (1) mechanics and material science aspects of highly loaded concentrated contacts such as occur in rolling element bearings, emphasizing elastic and plastic behavior under high loads for long periods where small angular motions are involved; (2) fundamental wear and friction mechanisms in metal and ceramic composite materials, and in surface-modified alloys with superior wear resistance; (3) basic processes in electrical brush contacts that determine wear rates, friction losses, and long-term durability; (4) fundamental aspects of wear in cryogenic and reactive liquids; (5) physical and chemical mechanisms determining the load capacity of advanced liquid lubricants; (6) development of a scientific basis for improved solid film lubricants having superior friction performance and long-term stability, and for improving wear and friction properties in dimensionally stable composite materials.

The objective of the electronic and optical materials thrust will also be to develop understanding and advanced materials important to SDI technologies. Specific areas include: (1) exploring new multiphase ceramic composites to be used as electronic packaging materials. For example, investigation of complex microstructures that minimize the dielectric constant for high-speed communication between semiconductor chips and maximize heat transfer; (2) investigation of new high-strain materials (piezoelectric and electrostrictive) for microdisplacive devices such as active optics, or for active control of mechanical vibrations.

The main focus of energy - materials interaction research will be to develop an understanding of the material degradation processes such as ablation that take place during high energy interactions with materials. Such understanding is expected

to be used to develop advanced material hardening concepts. Classes of materials of interest to this program include metal-, polymer-, and ceramic-matrices, and carbon-carbon materials.



SDI

NEEDS: MATERIALS FOR HIGH PERFORMANCE SDI USES

**GOALS: ADVANCE THE SCIENCE AND TECHNOLOGY OF
MATERIALS TO IMPROVE PERFORMANCE, RELIABILITY,
AND FABRICATION CAPABILITIES**

**APPROACH: UNDERSTAND PROCESSING/STRUCTURE/
PROPERTY RELATIONSHIPS IN COMPLEX
MATERIALS FOR ANTICIPATED ENVIRONMENTS
AND CONDITIONS**

**SEARCH FOR MATERIALS (COMPOSITES)
WITH IMPROVED PROPERTIES**



SDI MATERIALS PROGRAM

COMPOSITE MATERIALS

ENERGETIC MATERIALS

TRIBOLOGICAL RESEARCH

ELECTRONIC AND OPTICAL MATERIALS

ENERGY-MATERIALS INTERACTIONS



COMPOSITE MATERIALS

MATERIAL TYPE

PROPERTIES

SDI RELEVANCE

METAL MATRIX

- GRAPHITE REINFORCED ALUMINUM, MAGNESIUM

- HIGH COEFFICIENT OF DAMPING
- HIGH STRUCTURAL RESONANT FREQUENCY
- LIGHT WEIGHT
- STIFF
- HIGH THERMAL CONDUCTIVITY
- LOW THERMAL EXPANSION

HIGHLY DAMPED, LIGHT, STIFF SUPPORT STRUCTURES FOR LASERS, MANEUVERING SATELLITES, ANTENNAS, ETC.

CERAMIC MATRIX

- GRAPHITE REINFORCED GLASS-CERAMICS, GLASSES, CERAMICS

- DAMAGE TOLERANT
- REFRACTORY
- WEAR RESISTANT
- THERMAL SHOCK RESISTANT
- HIGH TEMPERATURE RESISTANCE

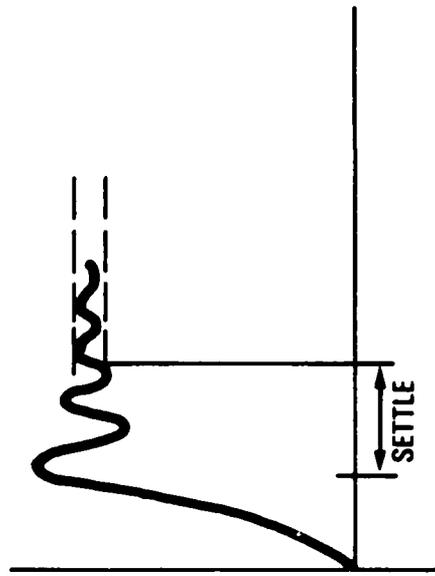
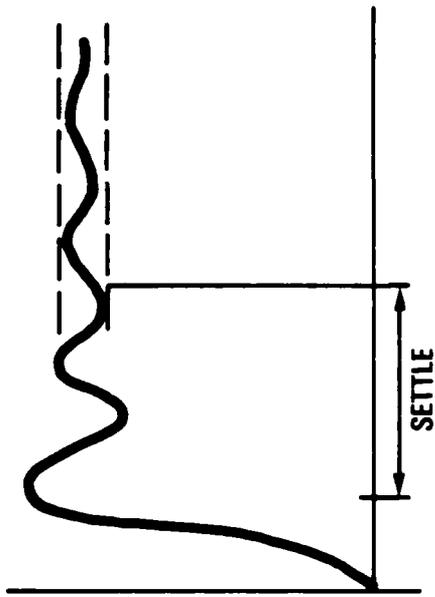
SURVIVABLE STRUCTURAL COMPONENTS FOR SATELLITES, SPACE STRUCTURES, ETC.

CARBON MATRIX

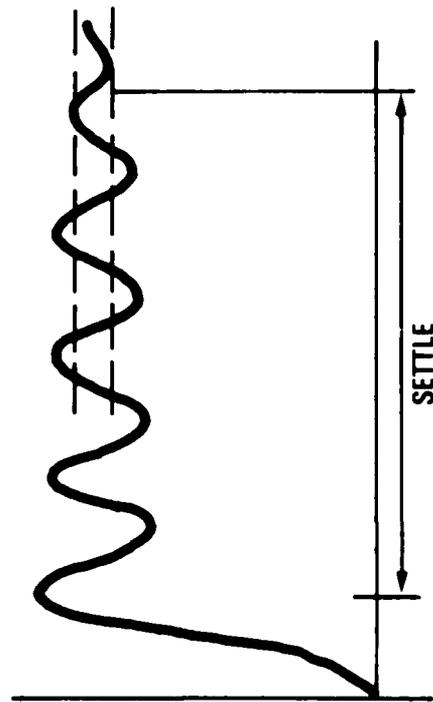
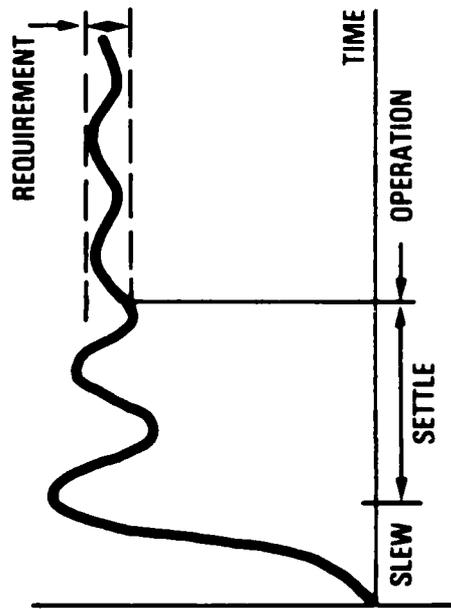
- GRAPHITE REINFORCED

- HIGH TEMPERATURE STRUCTURAL STRENGTH, STIFFNESS
- LIGHT WEIGHT
- THERMAL SHOCK RESISTANT
- NO OUTGASSING
- STIFF

LASER DAMAGE RESISTANCE



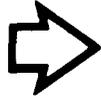
**EFFECT OF STRUCTURAL
FREQUENCY**



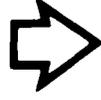
**EFFECT OF STRUCTURAL
DAMPING**

DESIGN

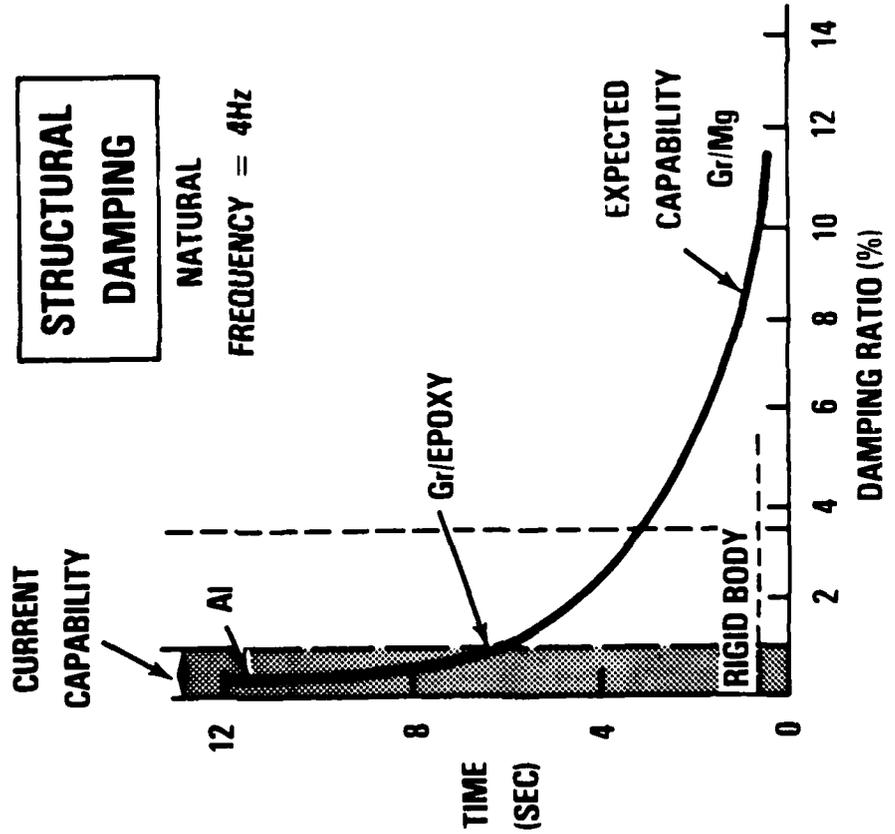
MATERIALS TECHNOLOGY



ENHANCED DAMPING



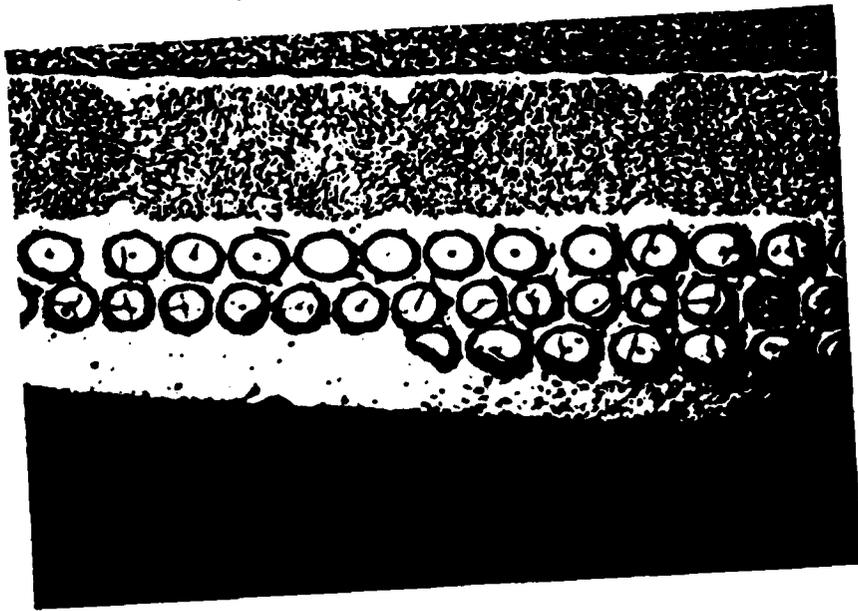
IMPROVED PERFORMANCE



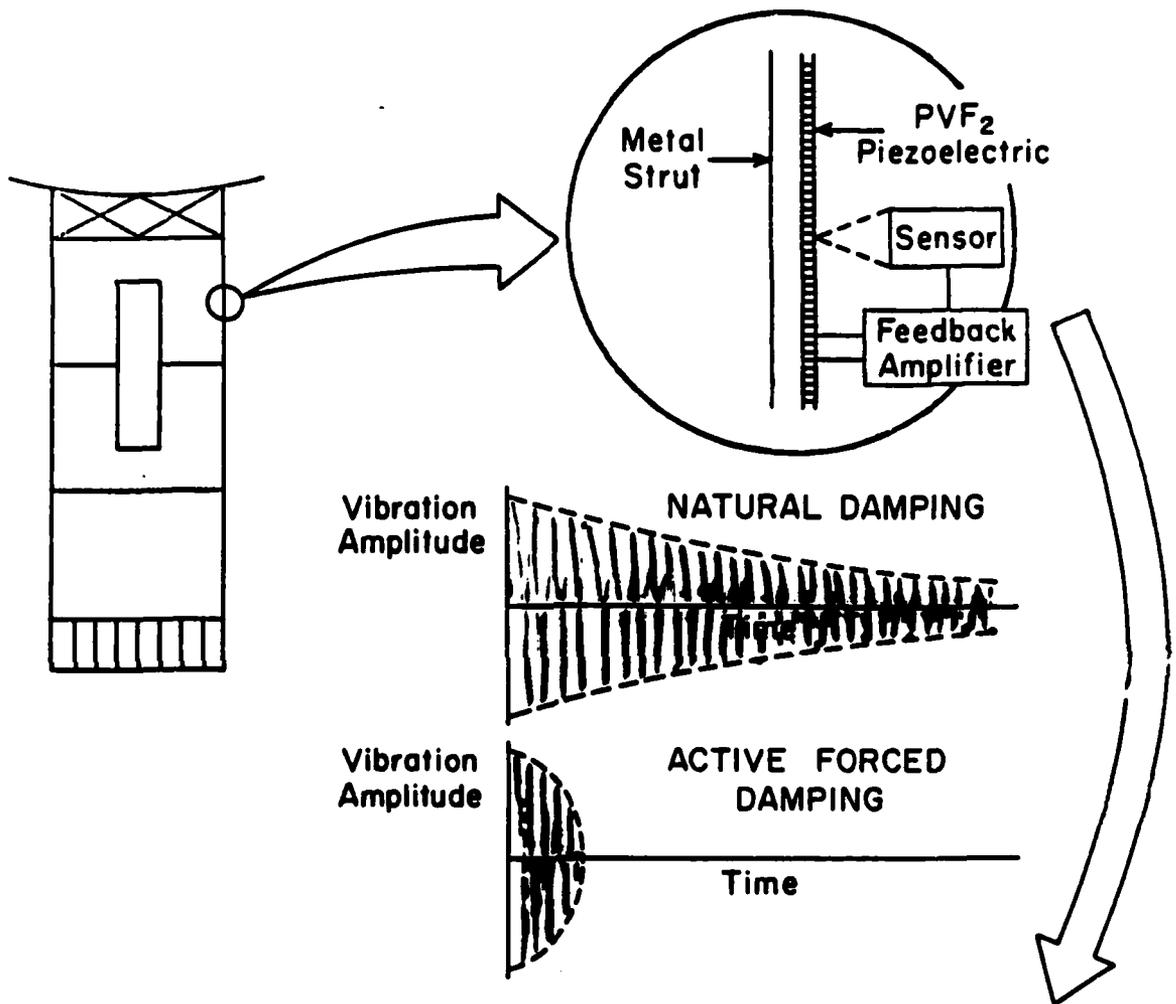


METAL MATRIX COMPOSITE MATERIAL VARIABLES, INTERNAL FRICTION

- **MATRIX**
- **GRAIN SIZE**
- **COMPOSITION**
- **FIBER**
- **VOLUME %**
- **INTERFACE**
- **HYBRIDIZATION**
- **FOIL/MATRIX**



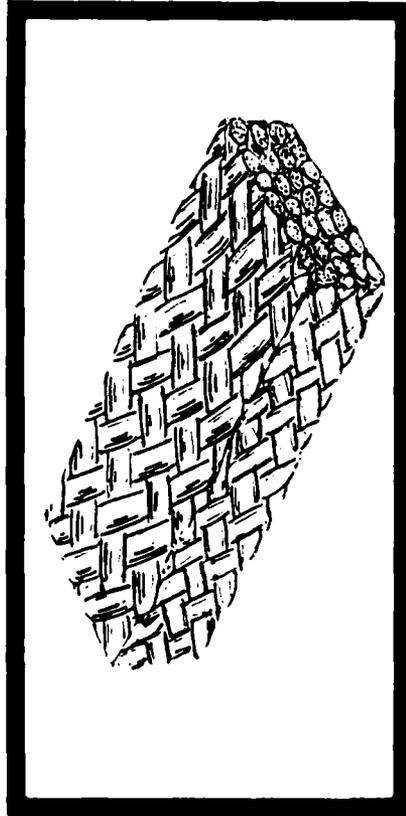
VIBRATION DAMPING IN LARGE SPACE STRUCTURES



<p>PVF₂ POLYMERS <u>NOT</u> STABLE IN THE SPACE ENVIRONMENT</p>	<p>NEW PIEZOELECTRIC GLASS/CERAMIC COMPOSITES</p>
<p style="text-align: right; margin-right: 50px;">Oriented Polar Crystals</p> <p style="text-align: right;">← Metal Strut</p>	
<p>VERY STABLE AGAINST TEMPERATURE, RADIATION, ETC.</p>	

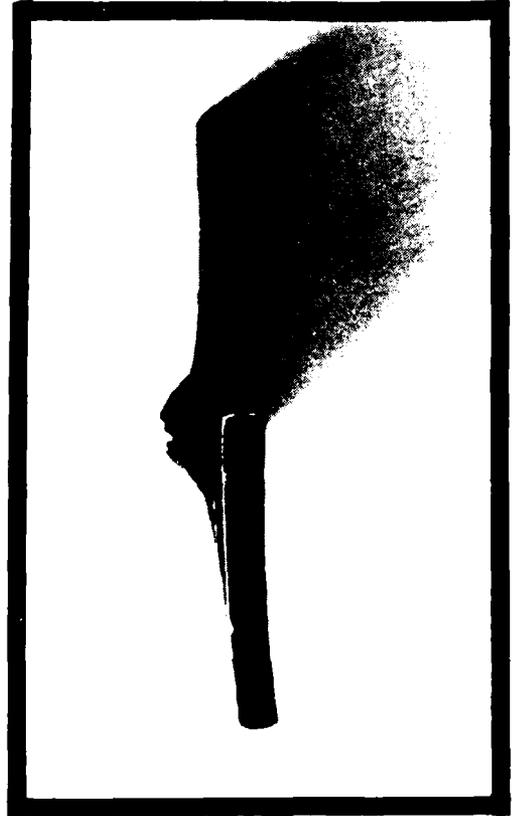
IMPACT PROPERTIES OF 3D WEAVE COMPOSITES

BRAIDED Al₂O₃/Al-Li COMPOSITE VS UNIDIRECTIONAL COMPOSITE

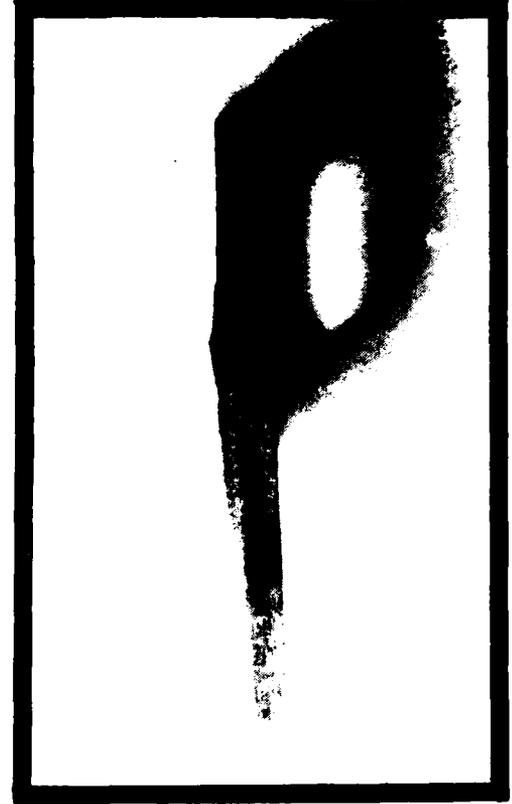


INTEGRATED NATURE OF 3-D BRAID

	<u>3D BRAID</u>	<u>UNIDIRECTIONAL</u>
FIBER VOL	17	34%
DROP WT IMPACT	116	94 FT-LB
MAX LOAD	2565	2639 LB



3D BRAIDED FP/Al COMPOSITE



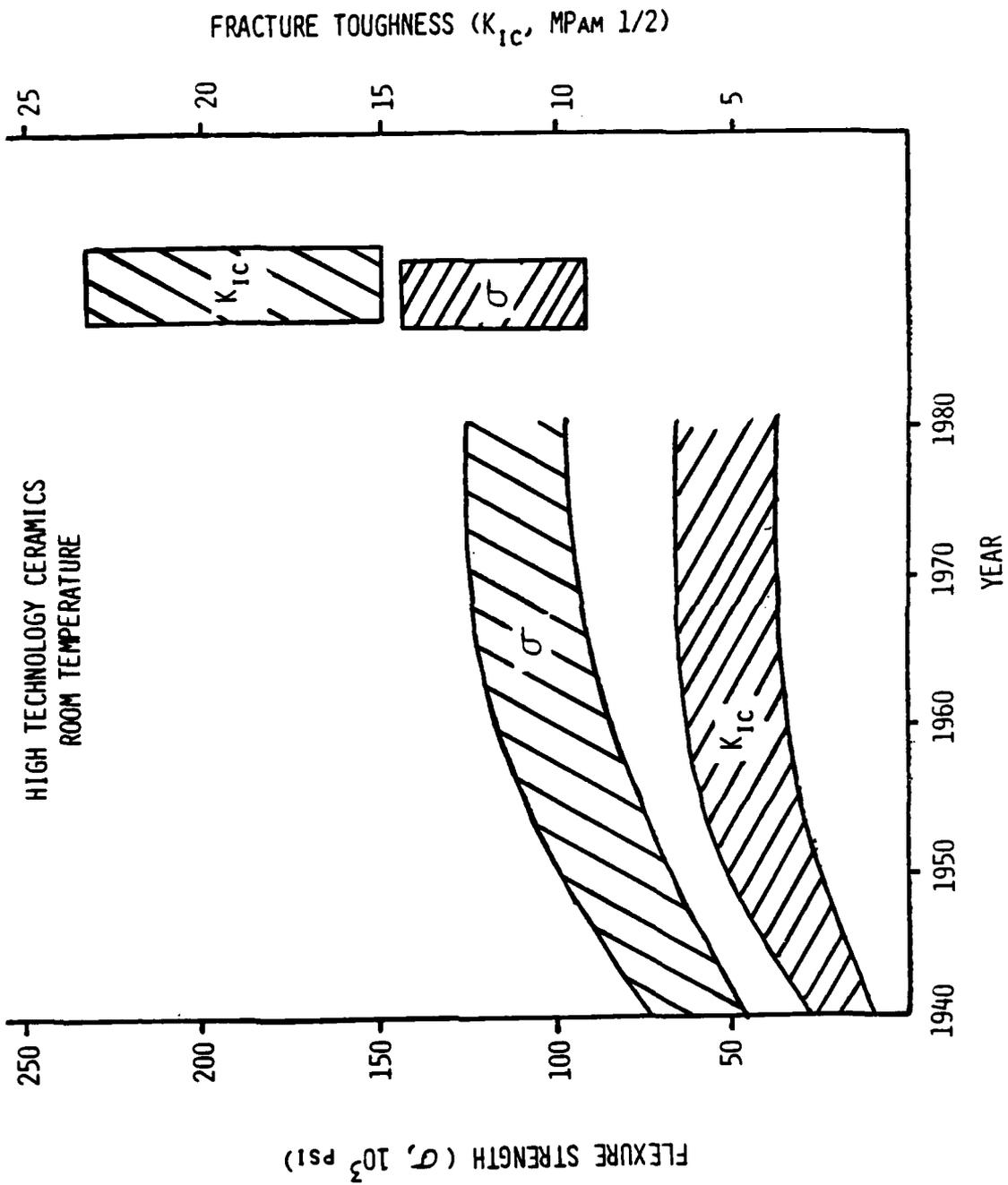
UNIDIRECTIONAL FP/Al COMPOSITE



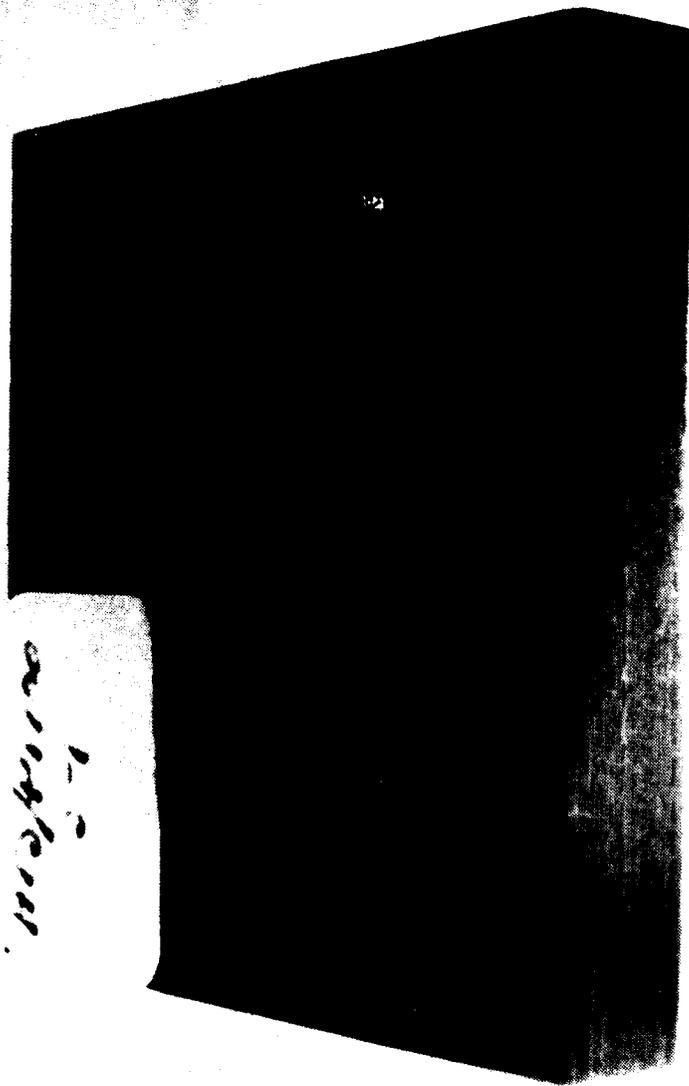
CERAMIC COMPOSITES FOR SURVIVABLE SPACE STRUCTURES

OBJECTIVES:

- **ESTABLISH UNDERSTANDING LEADING TO DEVELOPMENT OF THIN SECTIONS OF TOUGH, FRACTURE RESISTANT CERAMIC COMPOSITES**
- **DEMONSTRATE SURVIVABILITY OF CERAMIC COMPONENTS SUBJECTED TO IMPACT, LASER AND THERMAL SHOCK**
- **ESTABLISH DESIGN METHODOLOGY FOR DIMENSIONALLY STABLE CERAMIC COMPOSITE STRUCTURES**



**OVERALL VIEW OF GRAPHITE REINFORCED
THERMOPLASTIC AFTER IRRADIATION**



**CROSS SECTION OF DAMAGED GRAPHITE
REINFORCED GLASS**



HIGH POWER LASER PENETRATION RESISTANCE OF GRAPHITE REINFORCED COMPOSITES

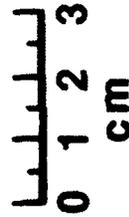
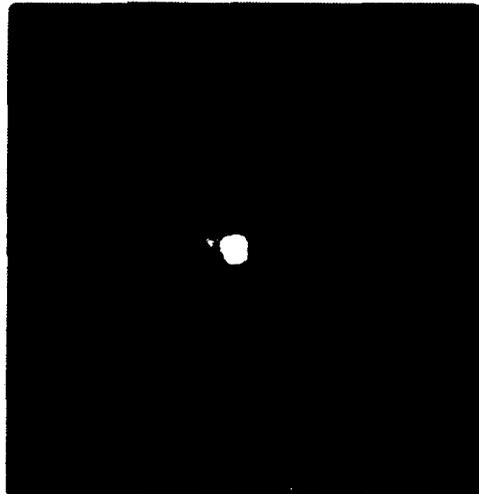
Beam size $\sim 0.75 \text{ cm}^2$

Test conditions

<u>Radiation level</u>	<u>Time</u>	<u>Material</u>	<u>Results</u>
C	20 sec	Gr/thermoplastic	Surface burn
C	20 sec	Gr/borosilicate glass	No effect
D	20 sec	Gr/thermoplastic	Penetration & local delamination
D	20 sec	Gr/borosilicate glass	Melt surface glass
E	20 sec	Gr/thermoplastic	Deep penetration & extensive delamination
E	20 sec	Gr/borosilicate glass	Deep penetration but no delamination

FIBER REINFORCED GLASS-CERAMIC COMPOSITES EXHIBIT MULTIPLE STRIKE CAPABILITY

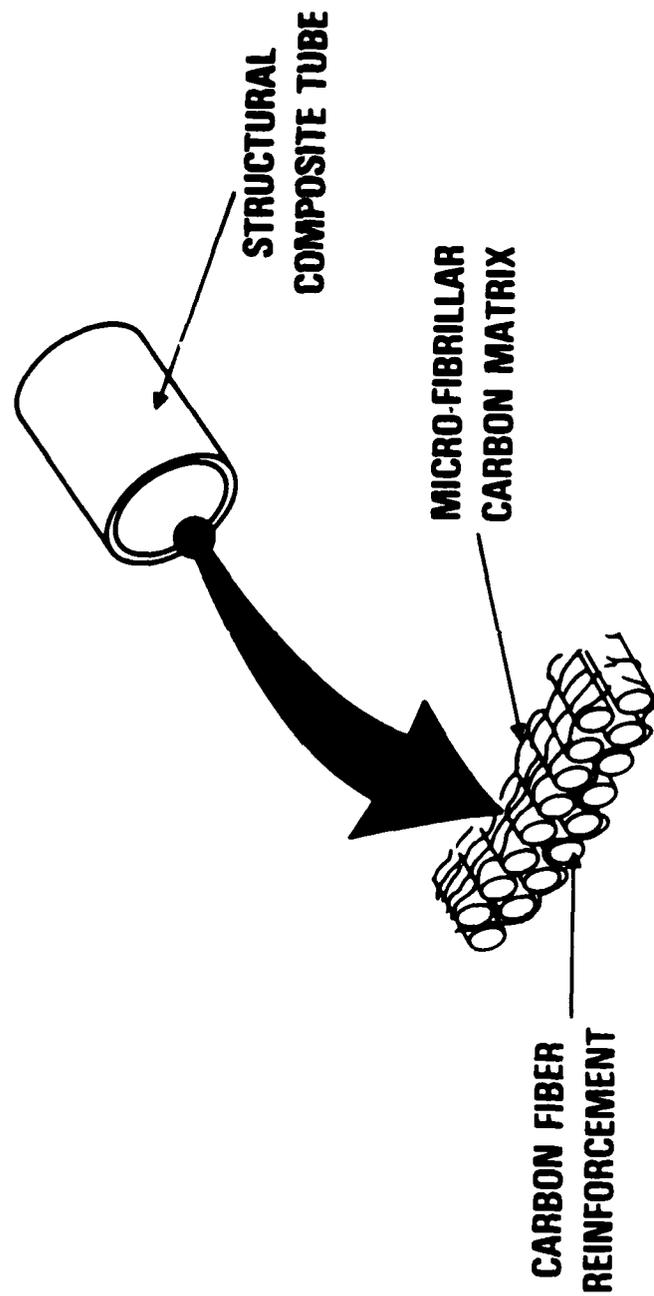
(AMMRC Tests)



80-7-83-7

INTRINSIC HARDENING

CONCEPT OF "HIGH CARBON COMPOSITES"



MICRO-FIBRILLAR STRUCTURE OF THE CARBON MATRIX RESULTS IN IMPROVED MECHANICAL PROPERTIES IN OFF-AXIS DIRECTIONS

ENERGETIC MATERIALS -- ROCKET FUELS



OBJECTIVE: HIGH ENERGY ROCKET PROPELLANTS (HIGH RATE, HAZARD CONTROLLED, PRECISE, LOW COST)

MATERIAL SCIENCE: ENERGETIC THERMOPLASTIC ELASTOMERS

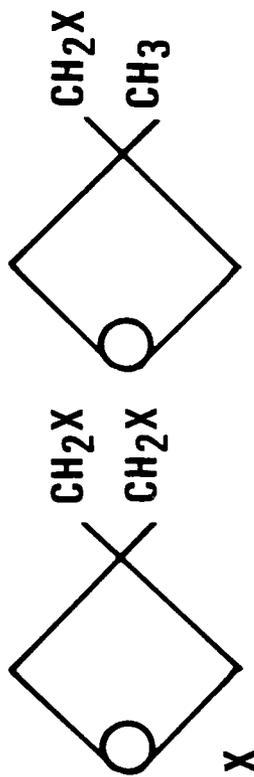
- NITROAMINO, CARBONANYL, AZIDO FUNCTIONALITY
- ENDOTHERMIC DEPOLYMERIZATION - HOT SPOT CONTROL
- MELT VISCOSITY CONTROL

FLUID PHYSICS: PRESSURE, STRESS AND VELOCITY GRADIENTS IN PROCESSING FLOWS

- QUANTITATIVE MEASURES AT VELOCITY AND STRESS FIELDS
- NUMERICAL METHODS FOR HIGH STRESS GRADIENTS
- VALIDATION OF MODELS

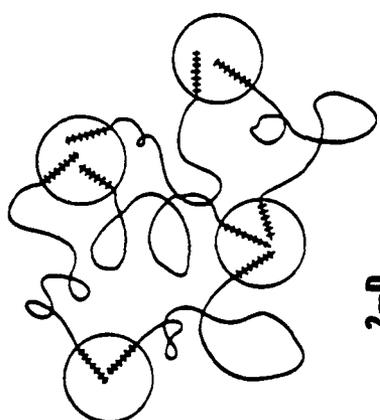


ENERGETIC OXETANE MONOMERS

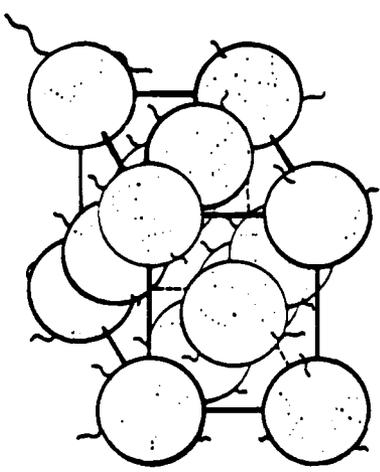


CYANO NITRAMINO	-- N -- NO_2 $\text{C} \equiv \text{N}$	BCNO	MCNO
METHYL NITRAMINO	-- N -- NO_2 CH_3	BMNO	MNMO
NITRATE ESTER	-- O -- NO_2	BNMO	NMMO
AZIDO	-- N_3	BAMO	AMMO
OXYALKYL	$\text{-- OC}_2\text{H}_5$	BEMO	—
	-- OCH_3	BMMO	—
	$\text{-- O(CH}_2)_7\text{CH}_3$	—	OMMO
	$\text{-- O(CH}_2)_2\text{OCH}_3$	BMEMO	—

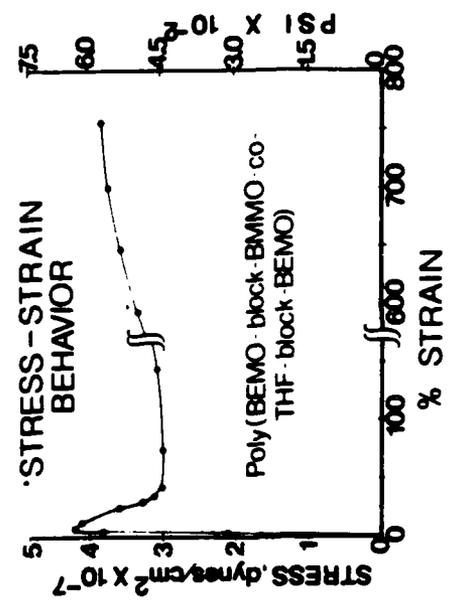
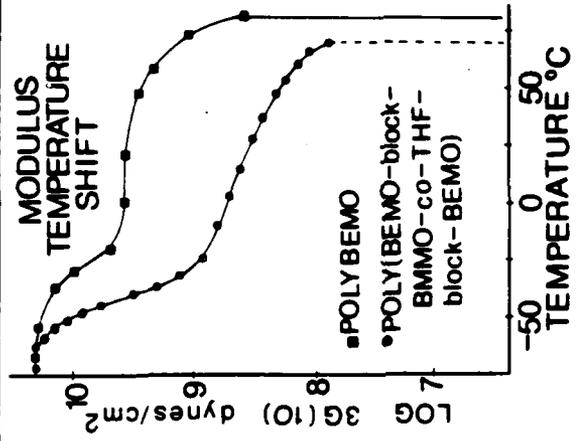
POLY(ETHER) THERMOPLASTIC ELASTOMERS



2-D

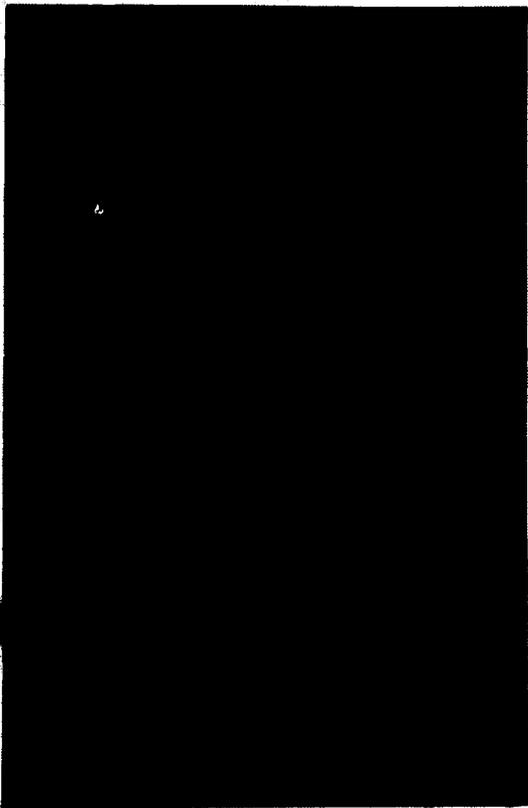


3-D

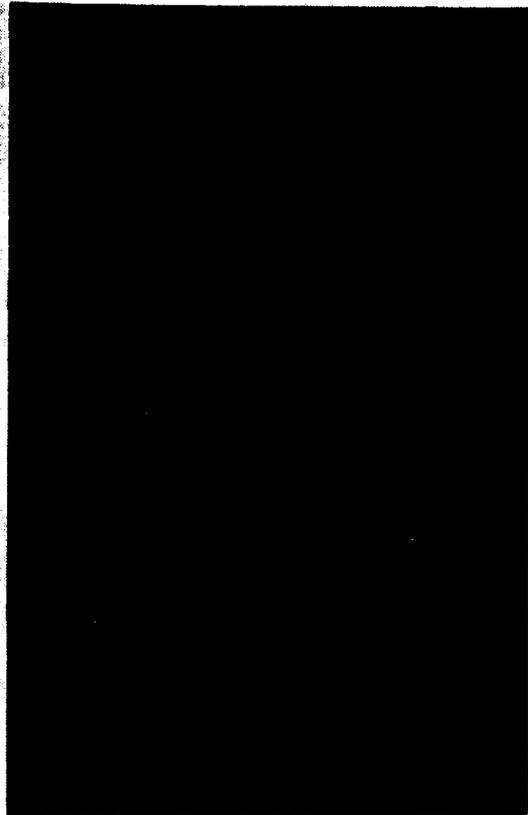




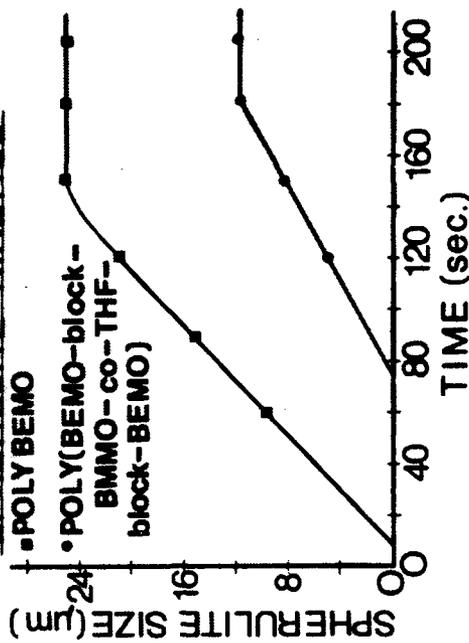
POLY (BIS(ETHOXY) METHYL) OXETANE



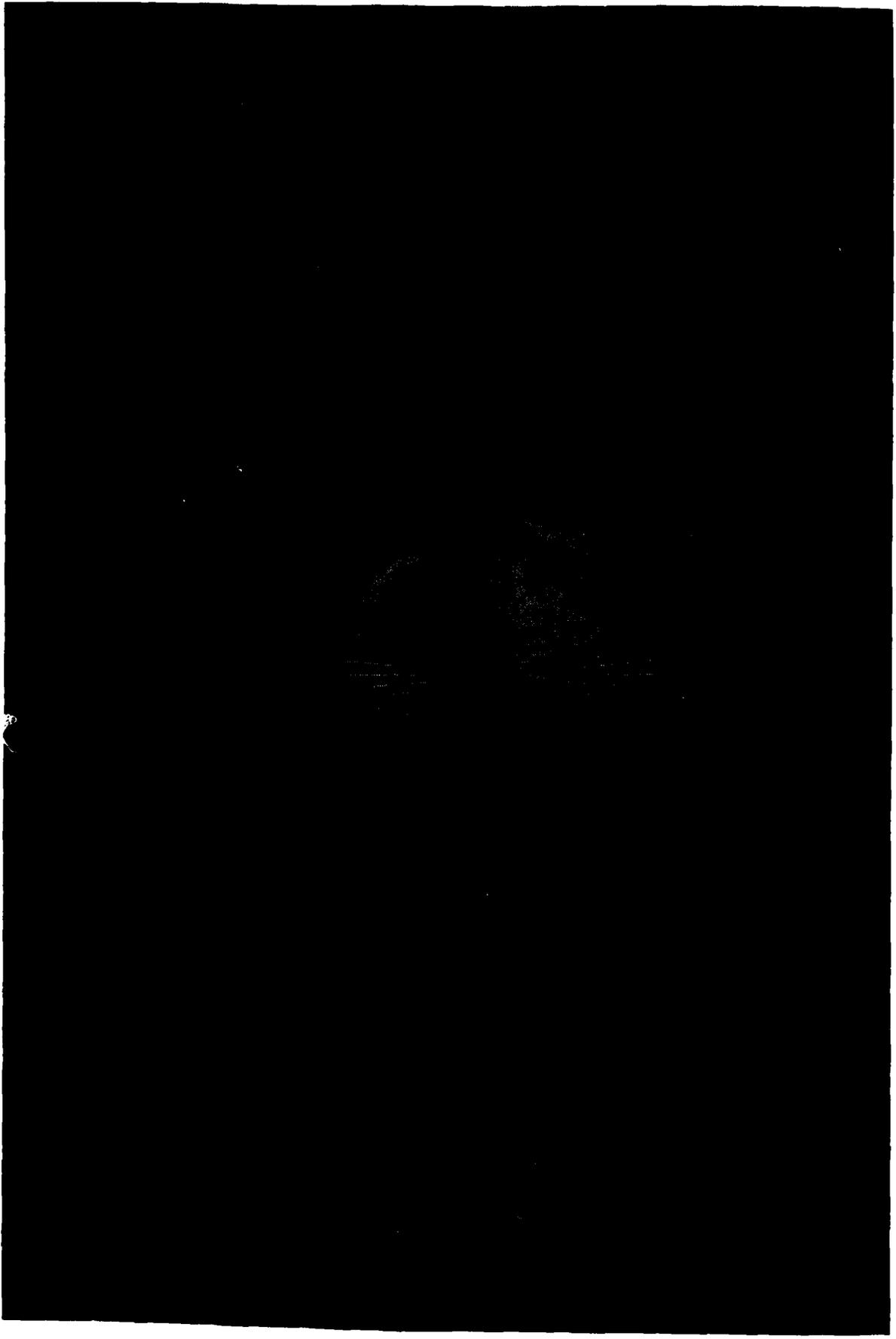
PolyBEMO forms hexagonal single crystals. Electron diffraction yields a hexagonal cell containing six mers.



SPHERULITE KINETICS



PolyBEMO, above, forms spherulites of 20-30 μ in 3-3 minutes after cooling.



C-26



TRIBOLOGY RESEARCH

**OBJECTIVES: UNDERSTAND FRICTION AND WEAR PROCESSES
INVESTIGATE NEW MATERIALS**

THRUSTS

- **HIGH PERFORMANCE ROLLING ELEMENTS BEARING MATERIALS**
- **FRICTION AND WEAR IN CERAMICS AND COMPOSITES**
- **STABLE, HIGH LOAD CAPACITY LUBRICANTS**
- **HIGH PERFORMANCE ELECTRIC BRUSH AND RING MATERIALS**

ROLLING ELEMENT BEARING MATERIALS RESEARCH



RESEARCH

METALS

- NEW ALLOYS
- COATINGS
- SURFACE PROCESSING
- WEAR RATES
- LOAD CAPACITY
- RELIABILITY

NON-METALS

- CERAMICS
- COMPOSITES
- DESIGNS

PROPERTIES

ELASTIC AND PLASTIC DEFORMATION

HIGH PRECISION

- HIGH FRACTURE TOUGHNESS
- CREEP RESISTANCE
- THERMAL STABILITY

- HIGH STIFFNESS (ELASTIC)
- THERMAL STABILITY

SDI APPLICATIONS

- IMPROVED POINTING
ACCURACY
- LONG TERM RELIABILITY
- LOW WEAR RATES
- SMALL COMPACT
SYSTEMS
- INTERRUPTED
OPERATING PERIODS

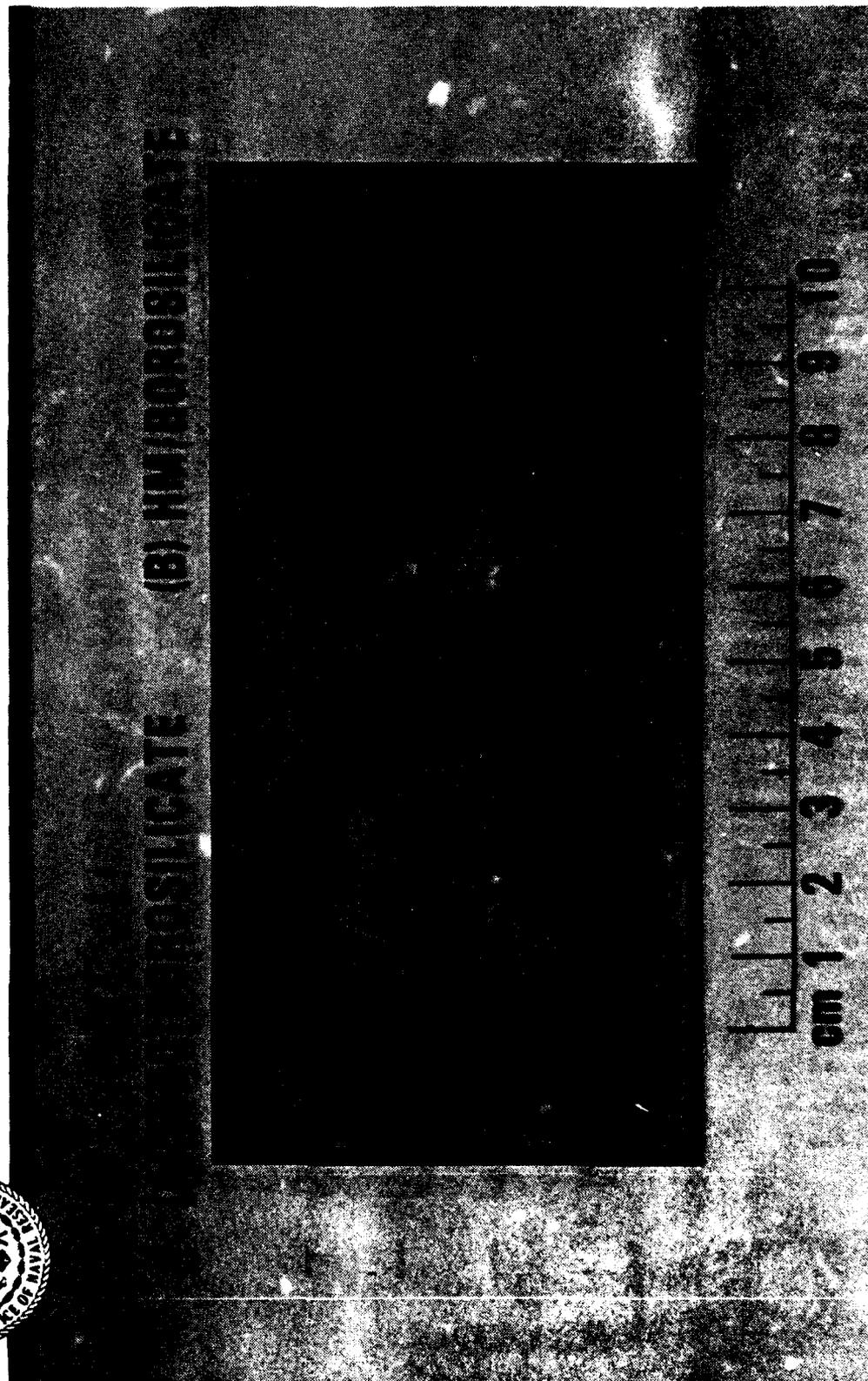
- LOW WEAR RATE
- WITHSTAND SEVERE
TEMPERATURE CYCLES
- NEW CONCEPTS NEEDED

FRICION AND WEAR IN CERAMICS AND COMPOSITES



- **WEAR MECHANISMS**
 - **ROLLING AND SLIDING CONDITIONS**
 - **MULTIAXIAL STRESSES AND FATIGUE**
 - **SURFACE FINISH AND ANISOTROPY**
- **RELATIONSHIPS BETWEEN SURFACE FINISHING
AND FABRICATING METHODS**
- **NEW CHEMICALLY INERT MATERIALS FOR
PUMPS, GEARS, BEARINGS AND SEALS**

GRAPHITE FIBER REINFORCED GLASS SEAL SPECIMENS



STABLE HIGH LOAD CAPACITY LUBRICANTS



- **DEGRADATION MECHANISMS OF SOLID FILM LUBRICANTS**
- **NEW STABLE LIQUID FILM LUBRICANTS FOR HIGH TEMPERATURES AND EXTREME ENVIRONMENTS**
- **HIGH LOAD CAPACITY LUBRICANTS FOR COMPACT BEARING DESIGNS**

ELECTRONIC AND OPTICAL MATERIALS



- **MULTIPHASE CERAMICS FOR ELECTRONIC
PACKAGING**
- **ELECTROSTRICTIVE/PIEZOELECTRIC MATERIALS
FOR MICRODISPLACIVE DEVICES**
- **GLASS-CERAMIC PIEZOELECTRICS FOR
VIBRATION DAMPING**
- **RELIABILITY OF DIELECTRIC MATERIALS**

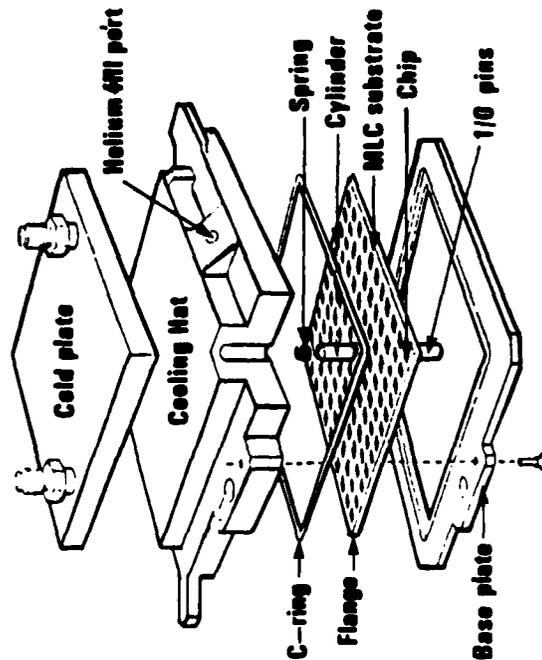
ELECTRONIC PACKAGES

TECHNOLOGY DIRECTIONS

- SMALLER SIZE
- HIGH DENSITY

MATERIALS RESEARCH

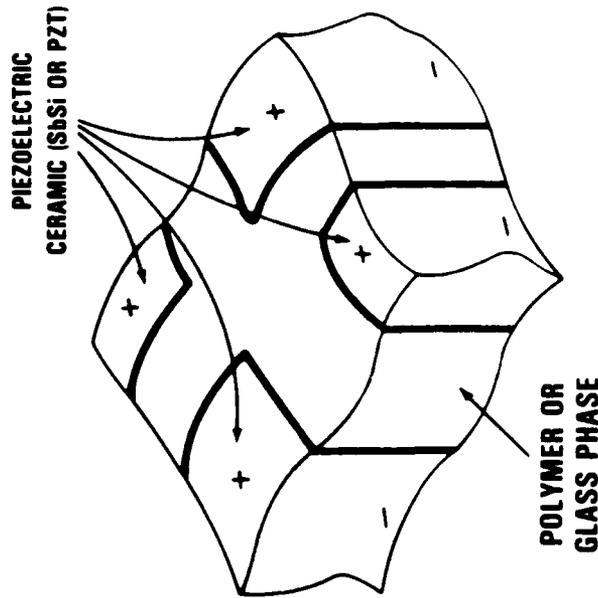
- LOW DIELECTRIC CONSTANT
- CONTROLLED THERMAL EXPANSION
- CAPACITORS INCORPORATED INTO SUBSTRATE
- MICROSTRUCTURAL WAVEGUIDES
- GLASS CERAMIC PROCESSING
- SOL-GEL PROCESSING



Exploded view of TCM assembly

COMPOSITES

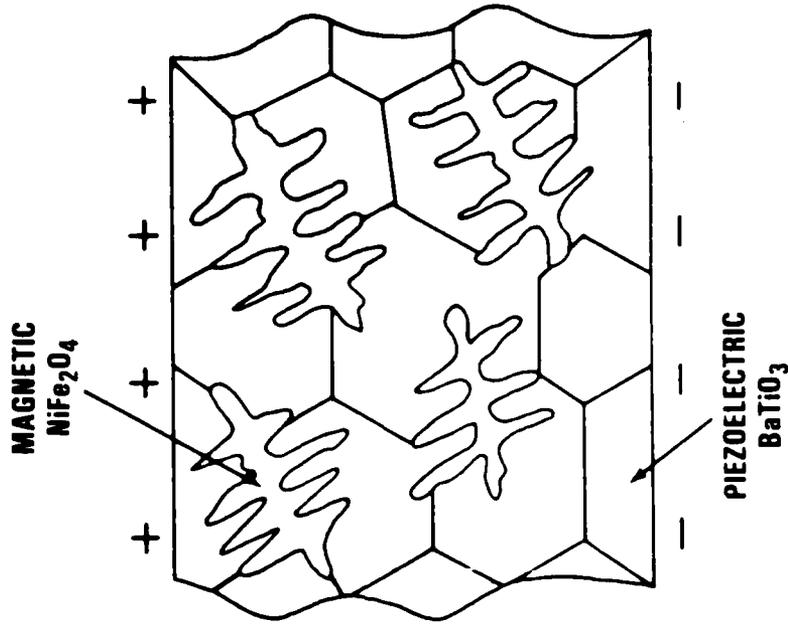
PYROELECTRIC



COMPOSITE PYROELECTRICS THERMAL EXPANSION MISMATCH BETWEEN TWO CONSTITUENTS ONE OF WHICH MUST BE PIEZOELECTRIC

$$P_3 = i_{vj}j_{p3} + j_{vj}j_{p3} + \frac{i_{vj}j_{\alpha_{33}} - i_{\alpha_{33}}(j_{d33} - j_{d33})}{i_{vj}s_{33} - j_{vj}s_{33}}$$

MAGNETOELECTRIC



COMPOSITE MAGNETOELECTRIC

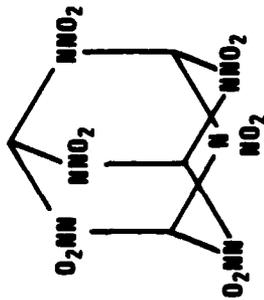
ENERGY-MATERIALS INTERACTIONS



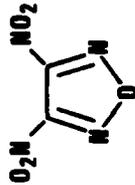
- **LASER-MATERIALS INTERACTIONS
(DEGRADATION AND DAMAGE MECHANISMS)**
- **NOVEL CONCEPTS FOR HARDENING**



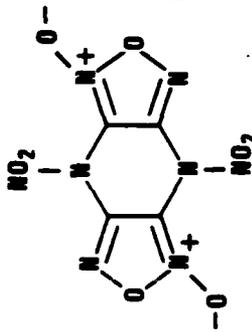
TARGET DENSE EXPLOSIVES



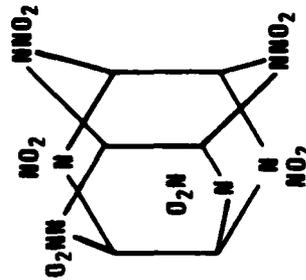
den 2.1 g/cm³
PCJ 434 kbar
Hexanitrohexaazaadamantane



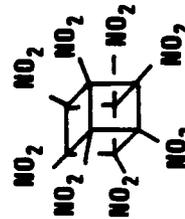
den 1.98 g/cm³
PCJ 468 kbar
3,4-dinitrofurazan



den 2.18 g/cm³
PCJ 460 kbar
Furoxano fused nitramine

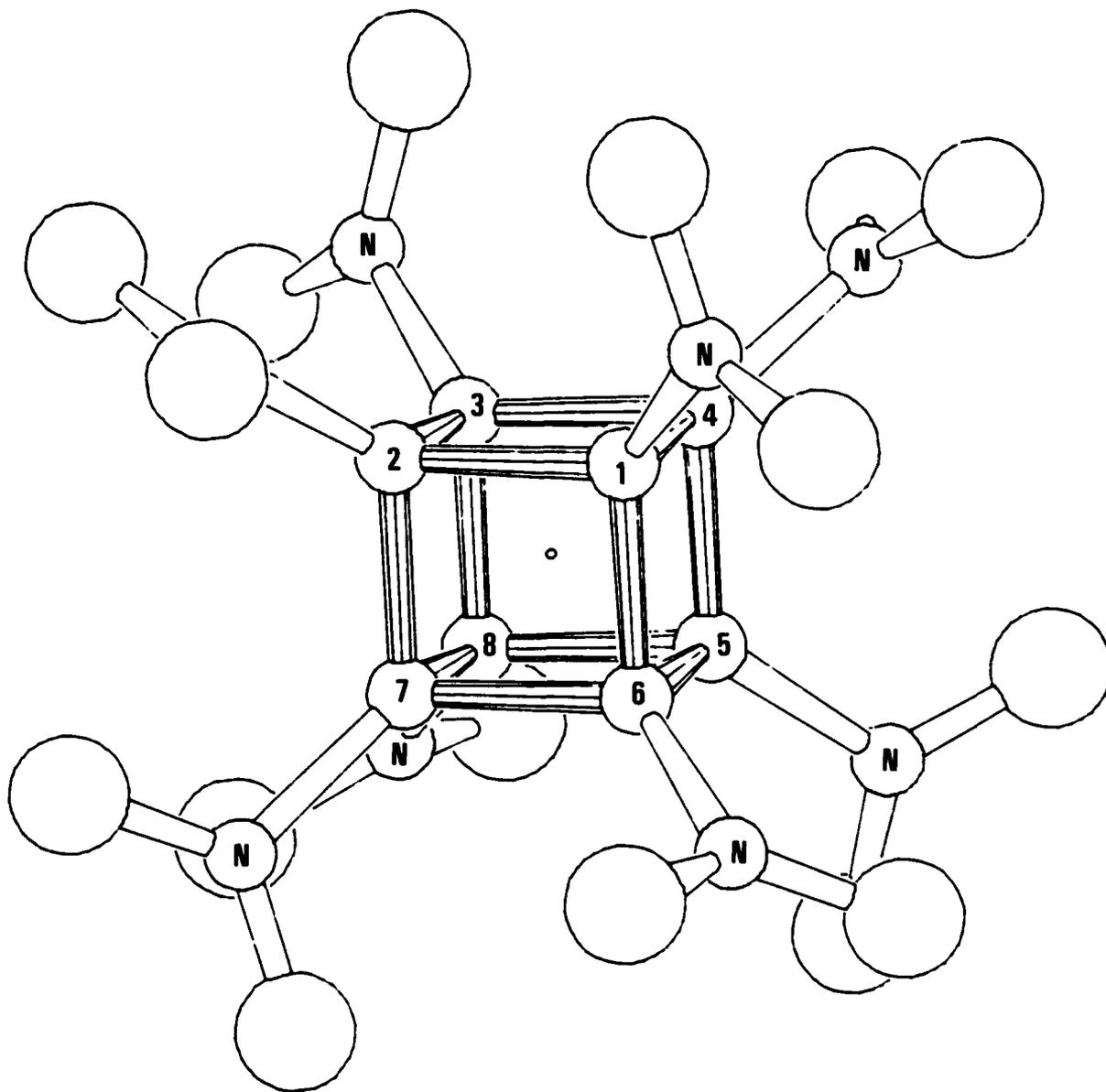


den 2.0 g/cc
PCJ 420 kbar
Hexanitrohexaazawurtzitame



den 2.1 g/cm³
PCJ 467 kbar
Octanitrocubane

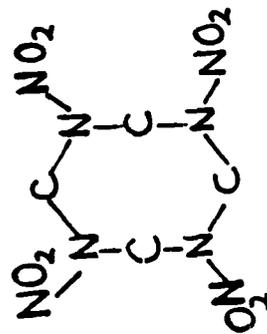
OCTANITRO CUBANE



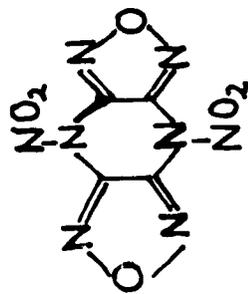


EXPLOSIVE SOLID

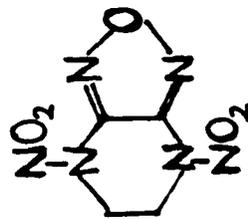
	DENSITY, G/CC	Δ HF, CAL/G	I _{SP}	$\rho^{3/4} I_{SP}$
<chem>C1CN(CN(CN1)[N+](=O)[O-])[N+](=O)[O-]</chem>	1.9	61	265	429
<chem>O=[N+]([O-])c1nc2c(nc12)[N+](=O)[O-]</chem>	2.0	586	277	465
<chem>C1CN(CN(CN1)[N+](=O)[O-])[N+](=O)[O-]</chem>	1.83	319	257	405



HMX



DNDFP



CL 7.5

APPENDIX D
SPACE POWER AND POWER CONDITIONING

Mr. J. Farber, DNA

Space Power and Power Conditioning
Jon Farber (202) 325-7088

Power and conditioning requirements for space-based SDI systems are widely diversified, running from the kilowatt level for sensors which continually monitor the terrestrial and near-earth space environment to burst-mode multi-megawatt levels for advanced directed and kinetic energy systems concepts. The IST space power program consists of both nuclear and non-nuclear thrusts.

The non-nuclear project is involved in addressing several key issues of interest to the SDIO. These include:

- Materials studies for the development of high-speed switches at large current densities,
- Design studies of configurations for advantageously using A.C. as well as D.C. power for space applications,
- Stress and vibration load evaluation of possible power systems on structural space support platforms,
- Identification of the limitations of output power and efficiency in klystrons,
- Feasibility of gyrotron-like devices for lower frequency SDI applications,
- Avoidance of surface flashover in photo-conductive devices,
- Designs for extending thyratron operation into the tens of megawatt range,
- Studies of the reliability/maintainability/availability of components for SDI systems,
- Development of new and improved techniques for increasing the energy density in capacitors,
- Vacuum and dielectric breakdown investigations,
- Heat dissipation in space-based power systems,

- High-current rail gun and spark-gap electrode materials problems, and
- MHD generator designs.

The IST nuclear power program seeks to extend the power limitations of space reactors into the multi-megawatt range. Initially, the proposed reactor type may be thermoelectric, thermionic, gas core, or Stirling cycle concept, including the materials issues associated with each of these concepts. Energy conversion schemes (such as chemo-nuclear) are also of interest as a way of isolating the reactor from the power conditioning and/or sensor environment. Also of importance are the safety/reliability/maintainability/survivability of nuclear power systems in space.



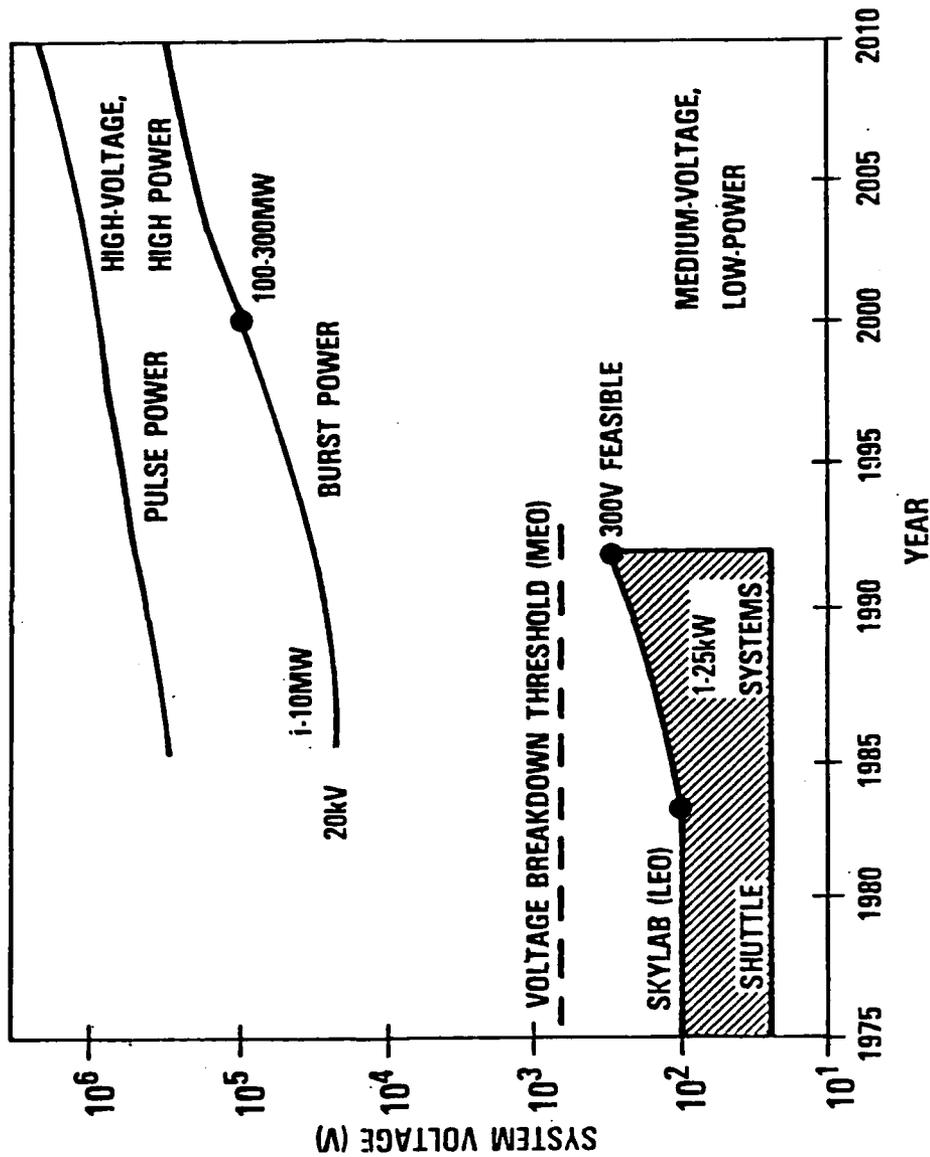
GENERAL ASSUMPTIONS

- U.S. IS SERIOUS ABOUT POSSIBILITY OF SPACE DEPLOYMENT
- SPACE DEMONSTRATORS WILL BE CONSTRUCTED
- MORE THAN ONE WEAPON TYPE WILL BE FLOWN OR AT LEAST BE CANDIDATES
- AFTER "WEAPON EFFECT" DEMONSTRATED MAJOR PROBLEM IS POWER ENGINEERING
- WEAPON WILL BE REQUIRED TO LAST ON STATION FOR 7 YEARS
- STATION MAY BE REPAIRABLE BUT MORE DESIRABLE TO BE AUTONOMOUS
- STATION WILL NEED "HOUSEKEEPING" AND "IMPULSE" POWER WHICH MAY OR MAY NOT SHARE COMPONENTS
- MISSION TIME 200 SECONDS

THE TERRESTRIAL SPACE ENVIRONMENT- EFFECTS ON SPACE SYSTEMS-

<u>ENVIRONMENTAL FACTOR</u>	<u>EFFECTS</u>
GRAVITY	ACCELERATION, TORQUES
SUNLIGHT AND ALBEDO	HEATING, POWER, DRAG, TORQUES, PHOTOEMISSION, MATERIAL DAMAGE, SENSOR NOISE
METEORIDS	MECHANICAL DAMAGE, ENHANCED PLASMA INTERACTIONS
NEUTRAL ATMOSPHERE	DRAG, TORQUE, MATERIAL DEGRADATION, HEATING
FIELDS	TORQUES, DRAG, SURFACE CHARGES, POTENTIALS
PLASMAS	CHARGING, INDUCED ARCING, POWER LOSSES, POTENTIALS, ENHANCED CONTAMINATION, CHANGE OF E-M REFRACTIVE INDEX
FAST CHARGED PARTICLES	RADIATION DAMAGE, ARCING, SINGLE EVENT UPSETS, NOISE, HAZARD TO MAN
SYSTEM GENERATED	SYSTEM DEPENDENT: NEUTRALS, PLASMAS, FIELDS
ENHANCED	EMP AND RELATED, EFFLUENT, TORQUE THRUST, VIBRATION

SPACE SYSTEM VOLTAGE REQUIREMENT





SYNERGISM

SPACE ENVIRONMENT

- METEORIDS
- RADIATION
- SPACE PLASMAS
- GAS PRESSURE

POWER SYSTEM

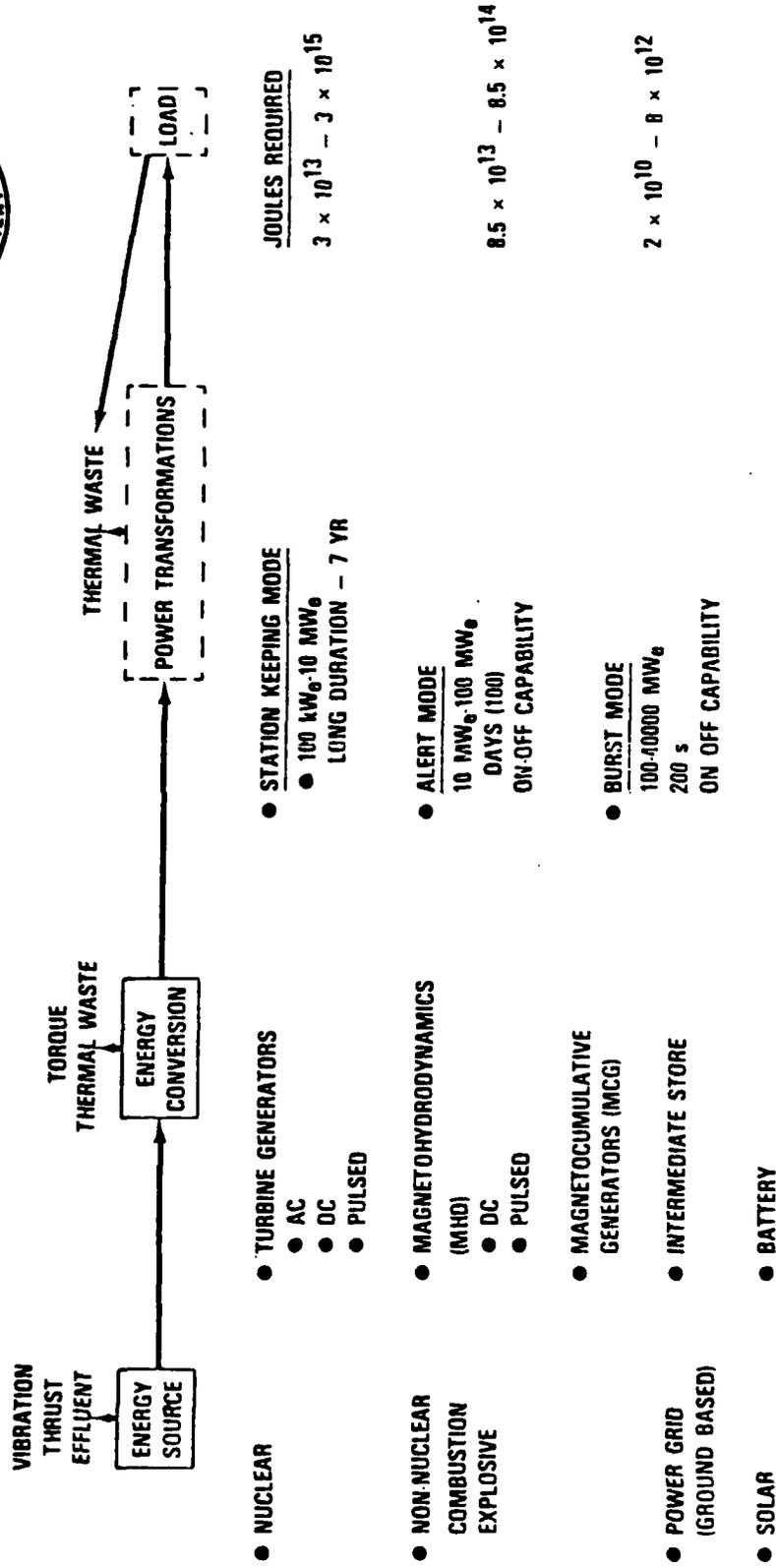
- EFFLUENT
- VIBRATION
- TORQUE
- THRUST
- WEIGHT
- VOLUME

PLATFORM

- FIRE CONTROL SYSTEM
- LOAD
- STRUCTURAL INTEGRITY
- PLASMA SHIELDS
- METEROID SHIELDS



POWER CHAIN





PRIME POWER TECHNOLOGY SUMMARY

	STATE OF THE ART	SDI WEAPONS MODE REQUIREMENTS	CRITICAL ISSUES
NUCLEAR	A FEW kW	100-40,000 MWe	<ul style="list-style-type: none"> ● MANY TECHNOLOGIES MUST BE INVENTED ● HIGH TEMPERATURE REACTOR/TURBINE ● SELECTION, DESIGN, DEVELOPMENT AND TEST
COMBUSTION TURBINE	4 MWe 100s (sec) 1600 deg F	100-40,000 MWe	<ul style="list-style-type: none"> ● EFFLUENT MANAGEMENT ● RESTARTABLE GAS GENERATOR/TURBINE ● HIGH INTERNAL TEMPERATURES
A-C GENERATOR	20 MWe 30 kV 400 Hz	100-40,000 MWe >100 kV 1000-3000 Hz	<ul style="list-style-type: none"> ● STRUCTURAL MATERIALS
D-C GENERATOR	4 MWe 1 MA	>5 MA 100-40,000 MWe	<ul style="list-style-type: none"> ● HIGH CURRENT COLLECTORS
PULSED GENERATOR	0.3 MJ 0.5 MA 4 Hz 0.5 s	100 MJ 5 MA 5 Hz	SAME

* 40,000 MW REQUIREMENT IS FOR EXCIMER LASER IN GROUND BASED MODE



SUMMARY OF REQUIREMENTS

WEAPON TYPE	PRIME POWER	POWER CONDITIONING	POWER TRANSFORMATION	ENERGY ON TARGET (1 s)
KINETIC ENERGY	0.1 to 1000 MW _o	(AVERAGE POWER) 10-1000 MW _o 50-500 MJ/PULSE 2 ms 4 Hz	RAILS	$10^8 \cdot 10^9$ JOULES
NEUTRAL PARTICLE BEAM	SAME	100-1000 MW _o 10-100 MW _{rf}	KLYSTRONS SEMICONDUCTOR SOURCES	10^7 JOULES
FREE ELECTRON LASER ● R.F. LINAC ● INDUCTION LINAC	SAME SAME	100-1000 MW _o 10-100 MW _{rf} 10-100 MW _o <10 KJ/PULSE: 5-20 ns >10,000 Hz	SEMICONDUCTOR SOURCES KLYSTRONS AND SWITCHES INDUCTION COUPLING	10^7 JOULES < 10^3 JOULES/PULSE
EXCIMER LASER ● HIGH REP RATE	40 GW	100-5000 MW _o 1-10 MJ/PULSE 1 μs 100 Hz	ELECTRON BEAMS	10^5 JOULES/PULSE

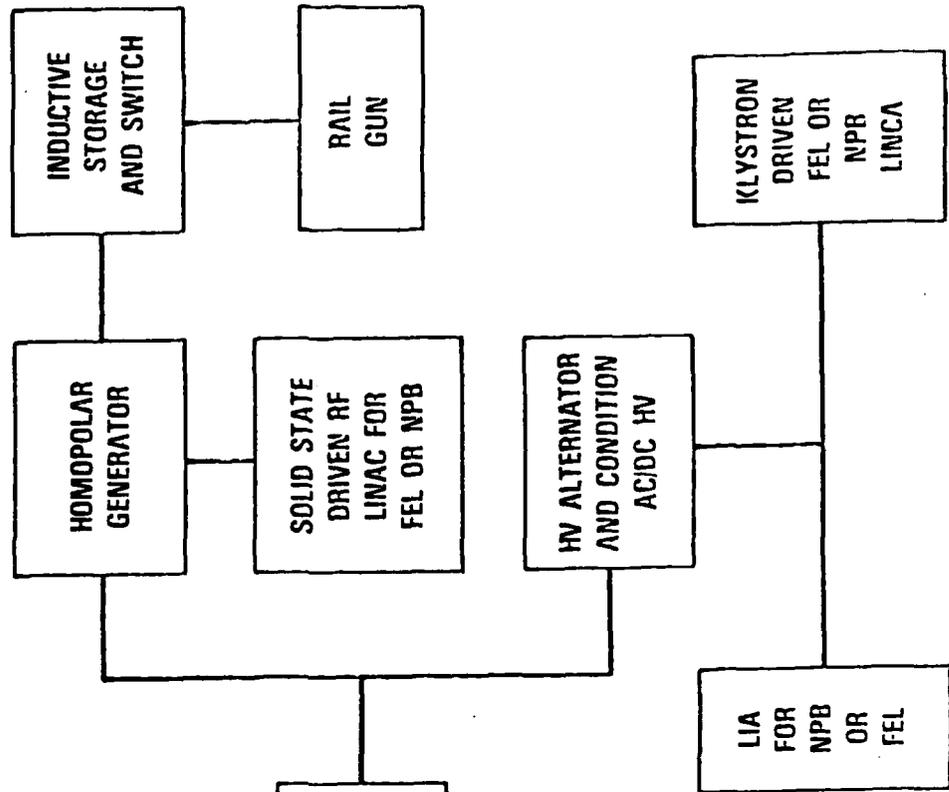


GENERIC ISSUES

- SPACE ENVIRONMENT
 - RADIATION
 - METEOROID DAMAGE
 - SYSTEM GENERATED ENVIRONMENTAL FACTORS
 - EFFLUENT
 - TORQUE/THRUST
 - THERMAL MANAGEMENT
 - EXTERNAL LOADING (THERMAL EXPANSION)
 - RELIABILITY/MAINTAINABILITY
 - SYSTEM REDUNDANCY
 - SELF DIAGNOSING SYSTEM (HAL)
 - MATERIALS
 - OUTGASSING
 - DEGRADATION
 - WEIGHT AND VOLUME
 - HV/Hi DISTRIBUTION SYSTEMS
 - ASSEMBLY IN SPACE
 - ONE WE FORGOT
 - HIGH FLOW RATE FLUIDS
- THERMAL
 - GAS PRESSURE
 - VIBRATION
 - EMP
 - STATION STATUS
 - DORMANCY
 - STRUCTURAL
 - ELECTRONIC
 - SPACE CRAFT CHARGING
 - INTERNAL (DUE TO WEAPONS, etc.)



TURBINE DRIVEN ROTATING MACHINERY



DISADVANTAGES

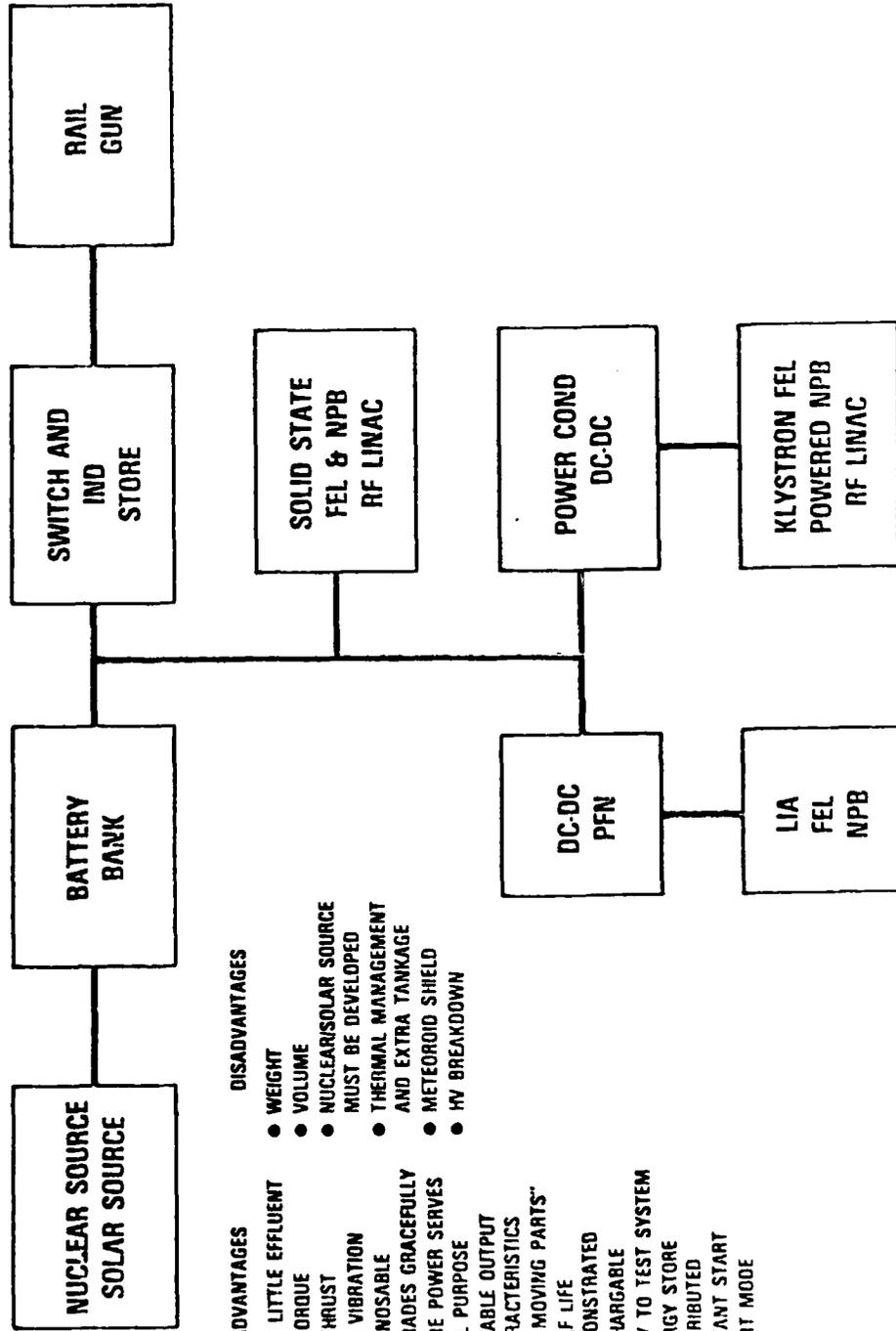
- STILL NEED HOUSEKEEPING POWER
- TANKAGE/CRYOGENIC
- THRUST
- EFFLUENT
- TORQUE
- VIBRATION
 - ROTATING
 - COMBUSTION
- METEOROID SHIELD
- BEARINGS
- CURRENT COLLECTION
- HV BREAKDOWN
- HARD TO EXERCISE SYSTEM
- SELF DIAGNOSIS DIFFICULT
- CHEMICAL ATTACK

ADVANTAGES

- FUEL CAN BE USED IN THERMAL MANAGEMENT
- WEIGHT AND VOLUME
- CONCEPTS WELL DEVELOPED
- DEMONSTRATION DEVICES SCHEDULED (HAVE STING)
- GOOD TECH BASE



BATTERY BANK

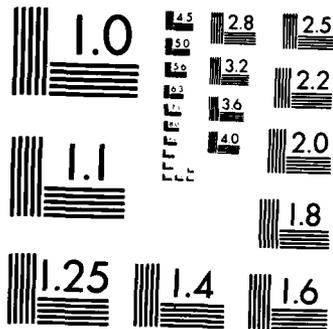


ADVANTAGES

- VERY LITTLE EFFLUENT
- NO TORQUE
- NO THRUST
- LESS VIBRATION
- DIAGNOSABLE
- DEGRADES GRACEFULLY
- PRIME POWER SERVES DUAL PURPOSE
- VARIABLE OUTPUT CHARACTERISTICS
- "NO MOVING PARTS"
- SHELF LIFE
- DEMONSTRATED
- RECHARGABLE
- EASY TO TEST SYSTEM
- ENERGY STORE DISTRIBUTED
- INSTANT START
- ALERT MODE

DISADVANTAGES

- WEIGHT
- VOLUME
- NUCLEAR/SOLAR SOURCE MUST BE DEVELOPED
- THERMAL MANAGEMENT AND EXTRA TANKAGE
- METEOROID SHIELD
- HV BREAKDOWN



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

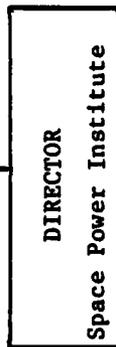
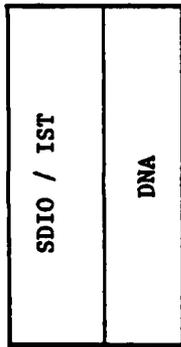


Defense Nuclear Agency



UNIVERSITY CONSORTIUM ON SPACE POWER/CONDITIONING

- CONTRACTS TO BE AWARDED ABOUT 1 APRIL
- PARTICIPANTS
 - AUBURN (LEAD)
 - TEXAS ARLINGTON
 - TEXAS TECH
 - SUNY BUFFALO
 - NEW YORK POLY
- EMPHASIS ON TECHNOLOGY TRANSFER
- STARS FOR CY 85
 - CAN KLYSTRONS MEET POWER REQUIREMENTS FOR NPB
 - ASSIST IN DEVELOPMENT OF IMPREGNANTS FOR SUPER-CAPACITORS
 - MINIMIZE THE RAIL EROSION PROBLEMS FOR HIGH-VELOCITY EMLS
 - HANDLING OF HIGH VOLTAGES IN SPACE
 - RELIABILITY/MAINTAINABILITY OF SPACE SYSTEMS



INDUSTRY

UT/A TTU AUBURN SUNY/AB PINY

GOVERNMENT

UNIVERSITY CONSORTIUM ON SPACE POWER

APPENDIX E
OPTICAL SENSORS

Dr. F. Quelle, ONR Boston

Optical Sensors
F.W. Quelle (617) 451-3171

The objectives of this program are to: (a) devise new, innovative optical techniques for detecting, identifying, and tracking armed intercontinental ballistic missiles and (b) develop the science/technology base necessary for implementing these techniques. Both passive and active approaches are to be considered.

Appropriate passive techniques might include (but are not limited to) the use of non-imaging (e.g., interferometric) sensors and/or oversampling and clever data preprocessing to reduce receiver aperture size and quality requirements. The use of techniques and sensors that exploit regions of the spectrum that are usually precluded because of the necessity for viewing through the atmosphere (e.g., vacuum UV and far IR) are also candidates. Possible passive sensor technology areas that might be pursued include the development of large detector arrays with on-chip preprocessing (to reduce system size, complexity, and cost) as well as research on the cryogenic systems necessary for space operation of such arrays.

The active discrimination facet of the program will support innovative ideas for employing active illumination of a potential space threat (e.g., by a laser or particle beam) for discrimination purposes. Possible approaches include (but are not limited to) optical radar, optical imaging radar, remote laser velocimetry, and remote laser vibrometry. Methods that remotely infer mass through the observation of changes in body dynamics or radiant emittance will also be considered.

In addition to active discrimination approaches, the program will support related technology developments. The latter could include radiation sources (such as high peak-power short-pulse lasers and highly frequency stable CW lasers). New

technology ideas for rapidly redirecting multi-kilowatt optical beams over large angles are also solicited.

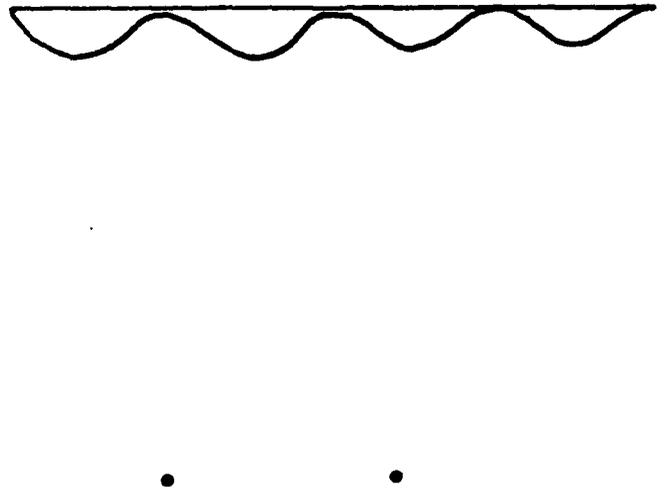
SENSORS

. ONGOING PROGRAM

. FUTURE DIRECTIONS

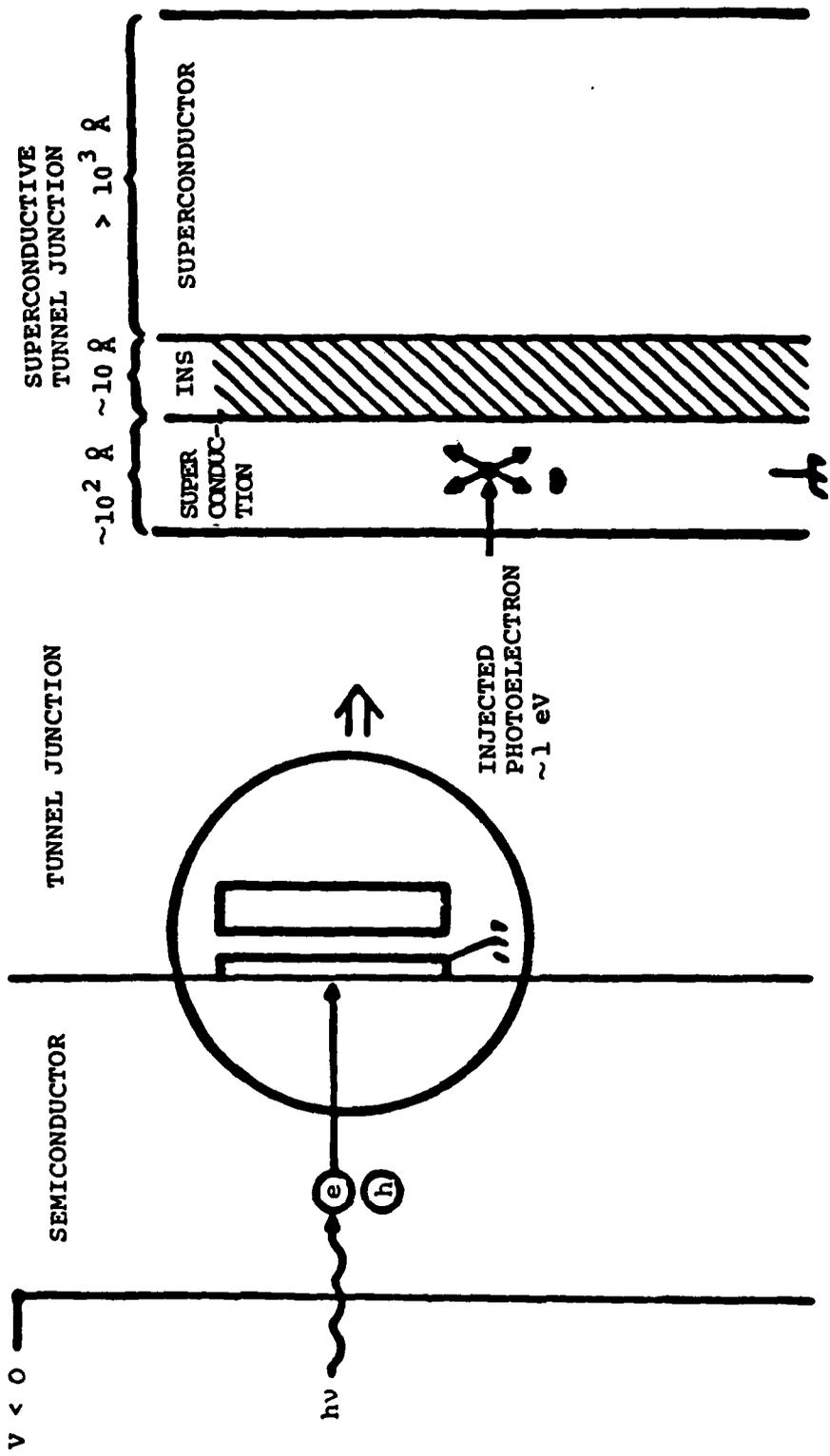
INTERFEROMETRY

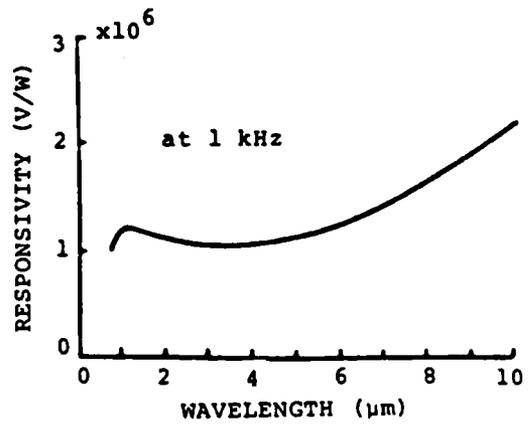
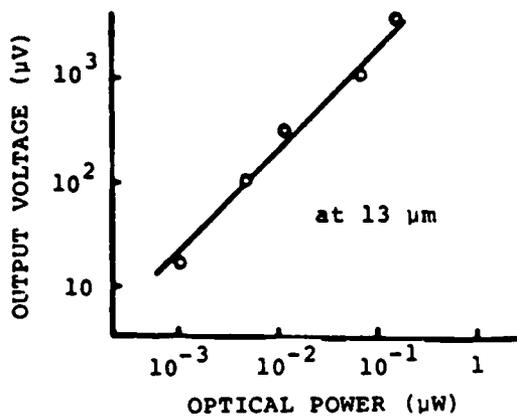
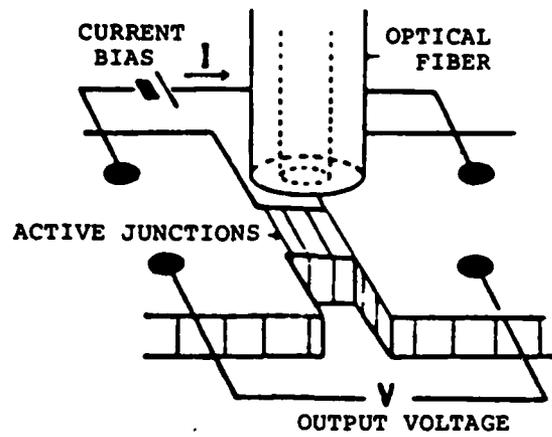
- LARGE DIFFRACTION-LIMITED OPTICS
- 10 METER D-L @ 3μ = 45 CM RESOLUTION @ 15,000 KM
- MULTI-APERTURE INTERFEROMETER
- MONOCHROMATIC YOUNG'S SLIT



DETECTORS

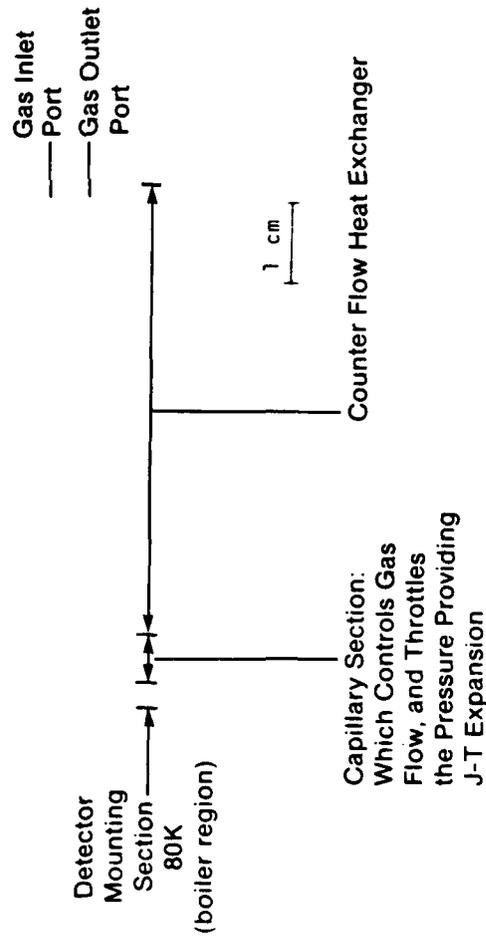
- . LARGE ARRAYS
- . THERMAL IR 8-30 μ
- . THERMAL PLUMES 1-5 μ
- . EXTENDED PHOTOEMISSIVE
- . SUPERCONDUCTOR/SEMICONDUCTOR-SUPERCONDUCTOR



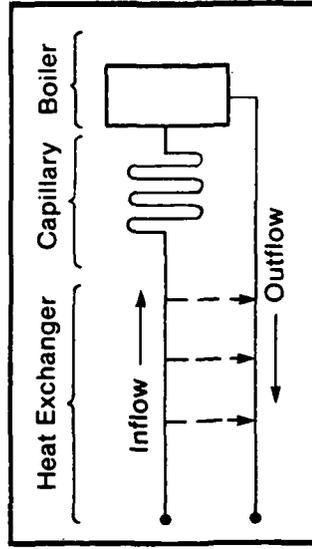


MICROMINIATURE REFRIGERATOR DESIGN

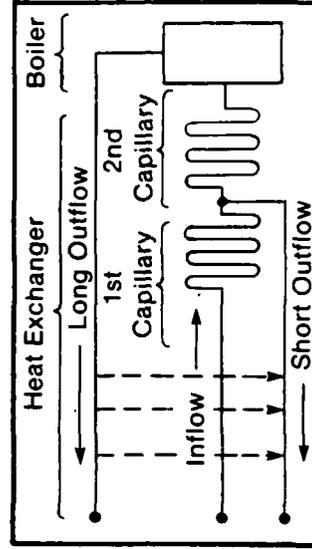
EARLY REFRIGERATION MODEL



SINGLE CIRCUIT DESIGN



MULTIPLE CIRCUIT DESIGN

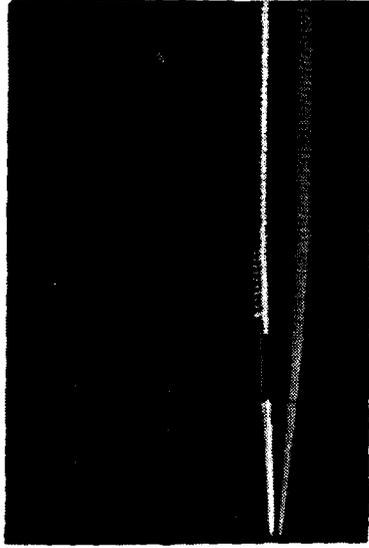


MMR

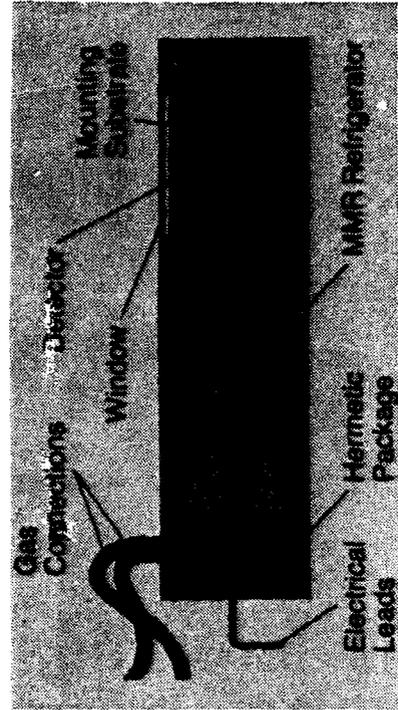
LOW FLOWRATE MICROMINIATURE REFRIGERATORS

I. TAILOR REFRIGERATORS TO APPLICATION OPTIMIZE PERFORMANCE

- 25 MILLIWATTS NET AT 80K
 - .1 LITERS/MIN. OF NITROGEN GAS, STP
 - 18 HRS. FROM A 25 IN³ BOTTLE (6000 psig)
- 50 MILLIWATTS AT 80K
 - .2 LITERS/MIN. OF NITROGEN GAS, STP
 - 9 HRS. FROM A 25 IN³ BOTTLE (6000 psig)

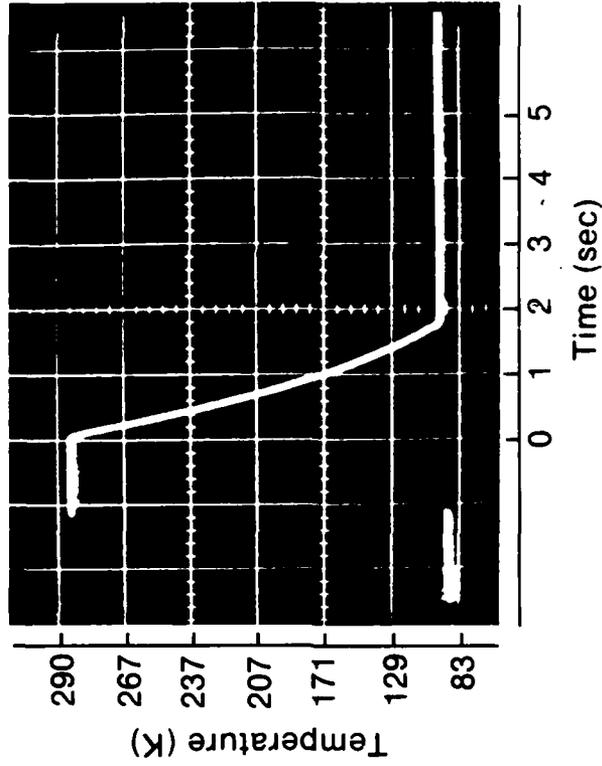
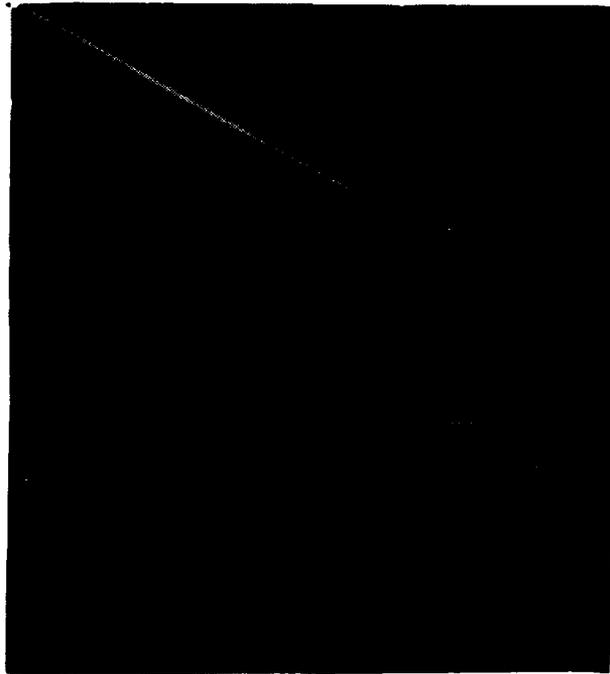


II. LOW COST HERMETIC PACKAGE



MMR

FAST COOLDOWN MICROMINIATURE REFRIGERATION

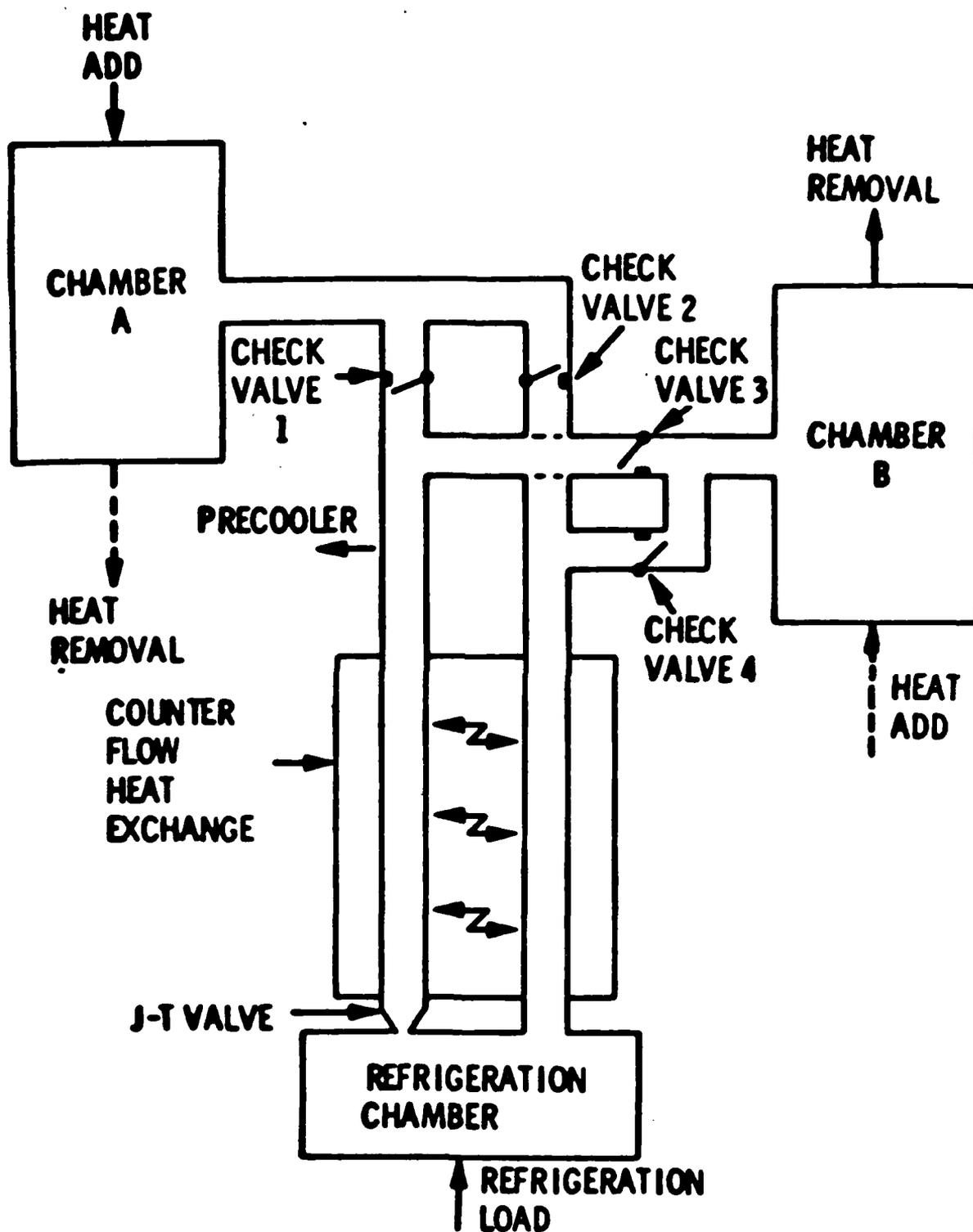


BENEFITS:

- LOW COST
- SMALL SIZE & WEIGHT
- RUGGED TO WITHSTAND HIGH 'G' FORCES
- ALLOWS ON-GIMBAL COOLING

CHARACTERISTICS:

- .6" ACTIVE AREA DIAMETER
- COOLDOWN TO 90K IN 2 SECONDS USING 4,000 PSI ARGON



APPENDIX F
OPTICAL SENSOR SURVIVABILITY

Dr. F. Bartoli, NRL

Optical Sensor Survivability
F. Bartoli (202) 767-3276

In space defense systems, optical sensors play central roles in the performance of tasks such as surveillance, acquisition, tracking, etc. The reliability of any future space-based military system will therefore critically depend on vulnerability of its sensors and other optical components to bombardment by intense signals arising from sources such as explosion-related electromagnetic radiation and an increasingly sophisticated array of hostile laser weapons. A new generation of hardening devices employing novel optical materials with highly adaptable nonlinear properties must be developed if the survivability of future systems is to be assured (e.g., fast shutters and optical limiters). Promising new optical materials include superlattices (both composition-modulated and doping-modulated), organic crystals, new ternary and quaternary semiconductor alloys, photochromics, encapsulated liquid crystals, solids containing rare earth and transition metal ions, inhomogeneous materials, and fast-tunable IR filters.

The objective of this program is to characterize the electrical, optical, and nonlinear optical properties of new materials both experimentally and theoretically in order to identify the best candidates for use in the next generation of hardening devices. Physical mechanisms leading to optical heating, low-level degradation, and severe physical damage will be studied, not only to improve the degree of protection and dynamic range achievable from new devices, but also to provide a better understanding of the optical susceptibility of those materials employed in components of present systems. Emphasis will be on the development and characterization of new classes of optical materials having "designable" properties which may be optimized to provide the maximum degree of hardening against optical threats.

OPTICAL SENSOR SURVIVABILITY

SDI/IST

F. BARTOLI, NRL

(202-767-3276)

**OBJECTIVE: TO DEVELOP NEW CLASSES OF NONLINEAR OPTICAL (NLO)
MATERIALS FOR USE IN NEXT GENERATION LASER HARDENING
DEVICES FOR SPACE BASED OPTICAL SENSORS**

OPTICAL SENSOR SURVIVABILITY - BACKGROUND

SDI SENSOR HARDENING ISSUES:

- o ADEQUATE PROTECTION REQUIRED FOR MAJOR SPACE SENSORS
WITH EMPHASIS ON LWIR SPECTRAL REGIONS
(IR DETECTORS: HgCdTe, InSb, Extr. Si, PbS)
- o PROTECTIVE DEVICES NEEDED FOR WIDE RANGE OF OPTICAL
INTENSITIES, PULSE DURATION, & WAVELENGTH; IMPOSES
STRICT REQUIREMENTS ON MATERIALS PROPERTIES
- o UNIQUE SDI NLO MATERIALS WILL REQUIRE INNOVATIVE
CONCEPTS AND APPROACHES

OPTICAL SENSOR SURVIVABILITY - BACKGROUND

CURRENT MATERIALS TECHNOLOGIES

- o NONLINEAR OPTICAL MATERIALS (E.G. TRANSMITTING AT LOW INTENSITY & OPAQUE AT HIGH INTENSITY)
- o MANY CONCEPTS ALREADY INVESTIGATED, INVOLVING PROCESSES SUCH AS MULTI-PHOTON ABSORPTION, PLASMA AVALANCHE, SATURATION OF ABSORPTION, METAL-INSULATOR TRANSITION
- o AT PRESENT, TECHNOLOGY IS LIMITED BY INTRINSIC MATERIALS PROPERTIES, YIELDING UNACCEPTABLE SWITCHING TIMES, INSERTION LOSS OR SWITCH DAMAGE THRESHOLD; A NEW CLASS OF NLO SWITCHING MATERIALS IS REQUIRED

OPTICAL SENSOR SURVIVABILITY

NONLINEAR OPTICAL PROCESSES:

$$P = P_0 + \chi^{(1)} E + \chi^{(2)} E^2 + \chi^{(3)} E^3$$

$\chi^{(1)}$ LINEAR

$\chi^{(2)}$ SECOND ORDER (NONCENTROSYMMETRIC)

SECOND HARMONIC GENERATION, THREE WAVE MIXING,
PARAMETRIC OSCILLATION, PHOTO-REFRACTION,
ELECTRO-OPTIC EFFECT

$\chi^{(3)}$ THIRD ORDER (ANY SYMMETRY, WEAKER)

TWO PHOTON ABSORPTION, NONLINEAR REFRACTION,
SELF-FOCUSING, STIMULATED BRILLOUIN SCATTERING,
STIMULATED RAMAN SCATTERING, PHASE CONJUGATION,
SELF-PHASE MODULATION, FOUR WAVE MIXING,
THIRD HARMONIC GENERATION

OPTICAL SENSOR SURVIVABILITY - APPROACH

INVESTIGATE TECHNIQUES FOR NLO MATERIALS "ENGINEERING" TO OBTAIN MATERIALS PROPERTIES TAILORED FOR SENSOR PROTECTION NEEDS

- o SUPERLATTICE AND QUANTUM WELL STRUCTURES
(PROPERTIES UNLIKE THOSE OF EITHER CONSTITUENT)
- o ORGANIC MATERIALS, LIQUID CRYSTALS - EXTREMELY LARGE χ_2 & χ_3
(HIGH DEGREE OF MOLECULAR ENGINEERING POSSIBLE)
- o NEW TERNARY AND QUATERNARY ALLOYS (INCLUDING MAGNETIC IONS),
INHOMOG. MATERIALS (NLO MATL. IMBEDDED IN LINEAR HOST), ETC.
- o INTEGRATED OPTICAL LIMITER / DETECTOR CONCEPTS

OPTICAL SENSOR SURVIVABILITY

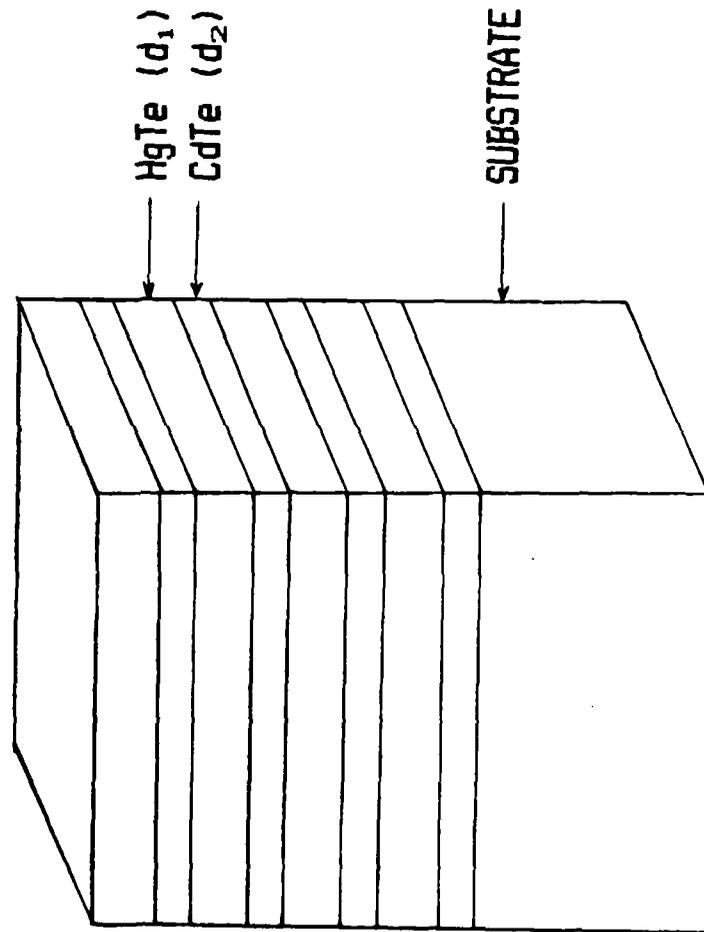
EVOLUTION OF SEMICONDUCTOR MATERIALS TECHNOLOGY:

- A. ELEMENTAL SEMICONDUCTORS -- Si, Ge
- B. COMPOUND SEMICONDUCTORS -- GaAs, CdTe, InSb
(WIDER RANGE OF BANDGAPS)
- C. TERNARY, QUATERNARY ALLOYS -- $Ga_{1-x}Al_xAs$, $Hg_{1-x}Cd_xTe$
(COMPOSITION TUNING OF BANDGAP, LONGER WAVELENGTH IR DEVICES)
- D. SUPERLATTICES -- GaAs/ $Ga_{1-x}Al_xAs$, HgTe/CdTe
(ENTIRELY NEW RANGE OF PROPERTIES)

SUPERLATTICES HAVE PROMISE OF ELIMINATING INTRINSIC SEMICONDUCTOR LIMITATIONS

OPTICAL SENSOR SURVIVABILITY

HgTe/CdTe Superlattice



OPTICAL SENSOR SURVIVABILITY

ORGANIC MATERIALS -- NONLINEAR PROCESSES

- o ORGANIC SOLIDS (CRYSTALLINE AND POLYMERIC)
ELECTRONIC KERR EFFECT (DELOCALIZED PI-ELECTRON)
- o ORGANO-METALLICS
CHARGE TRANSFER COMPLEXES
- o LIQUID CRYSTALS
ORIENTATIONAL KERR EFFECT
ELECTRONIC KERR EFFECT

OPTICAL SENSOR SURVIVABILITY

POTENTIAL BENEFITS TO INDUSTRY AND TACTICAL FORCES:

- o ENHANCED SURVIVABILITY OF TACTICAL SENSOR SYSTEMS
EMPLOYING SIMILAR DETECTOR MATERIAL & SPECTRAL BAND
- o NEW TYPES OF EO TRANSMITTERS, MODULATORS, MULTIPLEXERS & DETECTORS
- o HIGH SPEED TELECOMMUNICATIONS; ULTRA LOW LOSS FIBER TECHNOLOGY
- o NEW CLASS OF MATERIALS FOR IR LASER AND DETECTOR APPLICATIONS
- o NOVEL SEMICONDUCTOR STRUCTURES FOR NEW FUNDAMENTAL STUDIES OF
THE PHYSICS OF ELECTRONIC AND OPTICAL PROCESSES
- o INTEGRATED MULTIFUNCTION DEVICES (E.G. DETECTOR/SWITCH STRUCTURES)
FOR GREATER MINIATURIZATION

APPENDIX G
DISCRIMINATION

Dr. F. Quelle, ONR Boston

DEPLOYMENT OBSERVABLES

- HIGH RESOLUTION IMAGING
- KINEMATICS OF DEPLOYMENT

POST PENAID DEPLOYMENT

- IMPOSSIBLE TO SEPARATELY DISCRIMINATE EACH OBJECT
- ENMASS MEASUREMENTS ONLY PRACTICAL POSSIBILITY
- OTHERWISE CONCENTRATE ON DEPLOYMENT PERIOD

TECHNOLOGIES OF IMPORTANCE

- DIRECT IMAGING
- RANGE DOPPLER IMAGING
 - VISIBLE
 - MILLIMETER - SUBMILLIMETER WAVE

BOOST-DETECTION

- CURRENTLY FOCUSED ON THERMAL IR 1-5 μ
- SUPER RESOLUTION
- UV SOLAR BLIND
- 550 GHz



APPENDIX H

ADVANCED ACCELERATOR CONCEPTS

Dr. C. Roberson, ONR Washington

Advanced Accelerator Concepts
C.W. Roberson (202) 696-4222

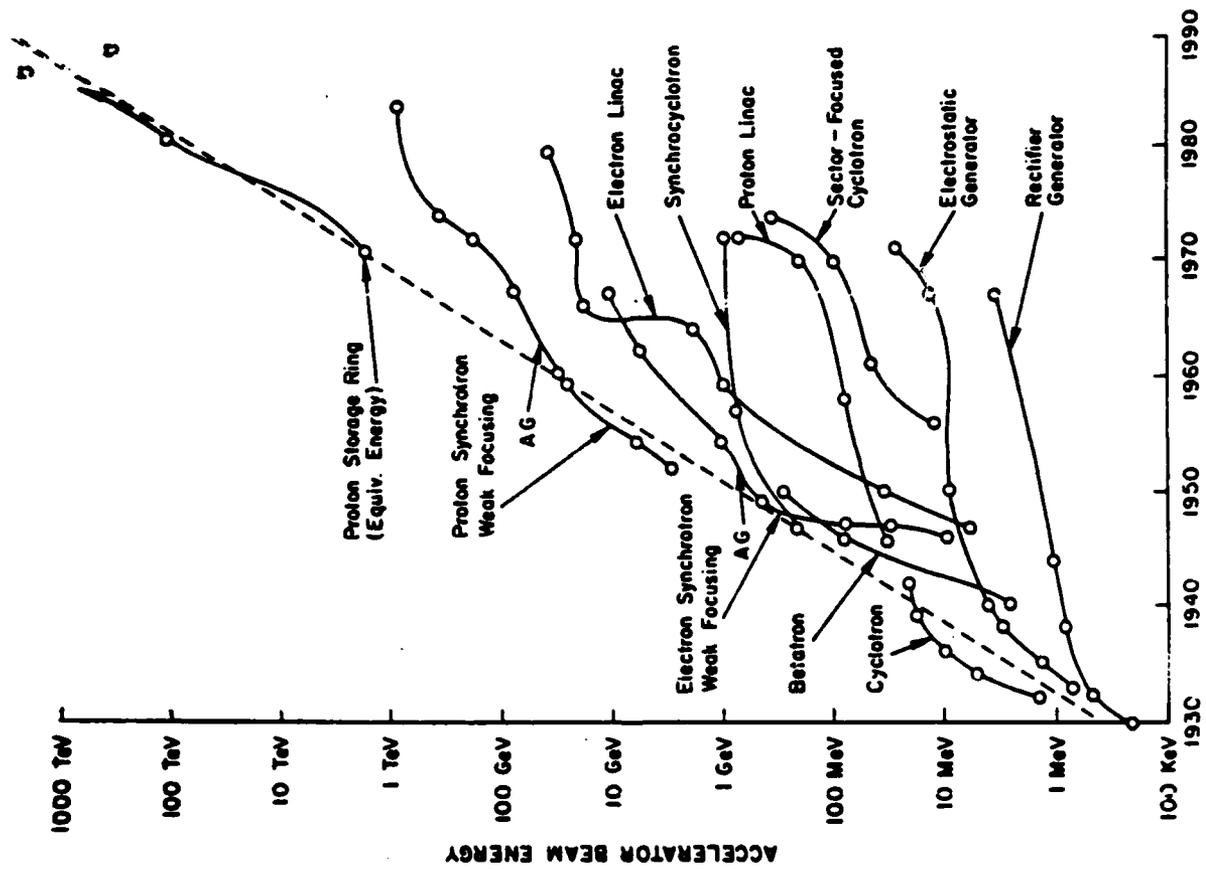
The advanced accelerator program will concentrate on proof-of-principle experiments of new high-current accelerator concepts. The primary emphasis will be on high currents (1 kA or more) in accelerators that can be scaled to energies of a few hundred megavolts. High beam quality, light weight, and high accelerating gradients are other important considerations.

S D I O

ADVANCED ACCELERATOR CONCEPTS

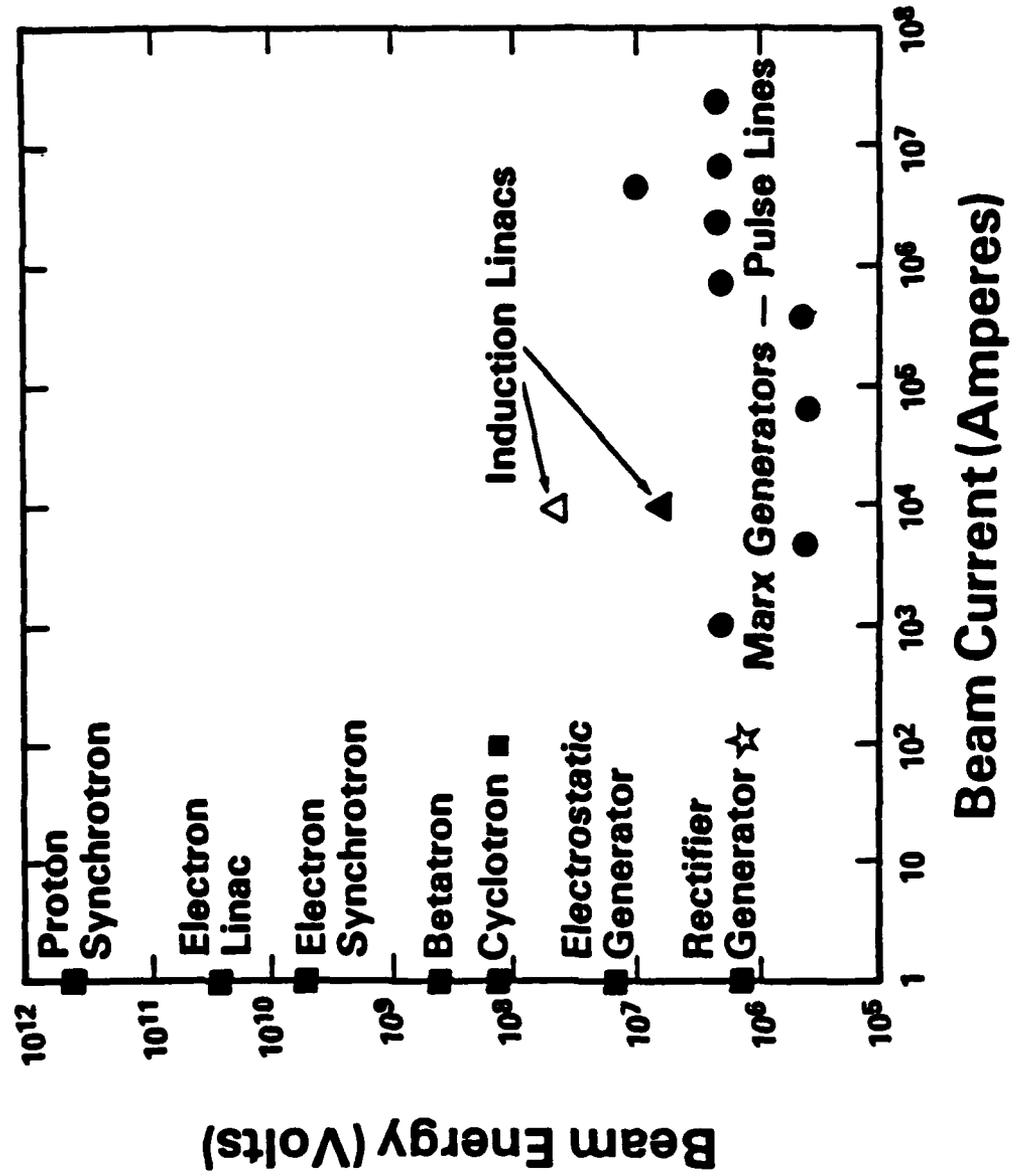
C. W. ROBERSON

OFFICE OF NAVAL RESEARCH



Energy growth of accelerators and storage rings

ACCELERATOR DEVELOPMENT



BEAM PARAMETERS

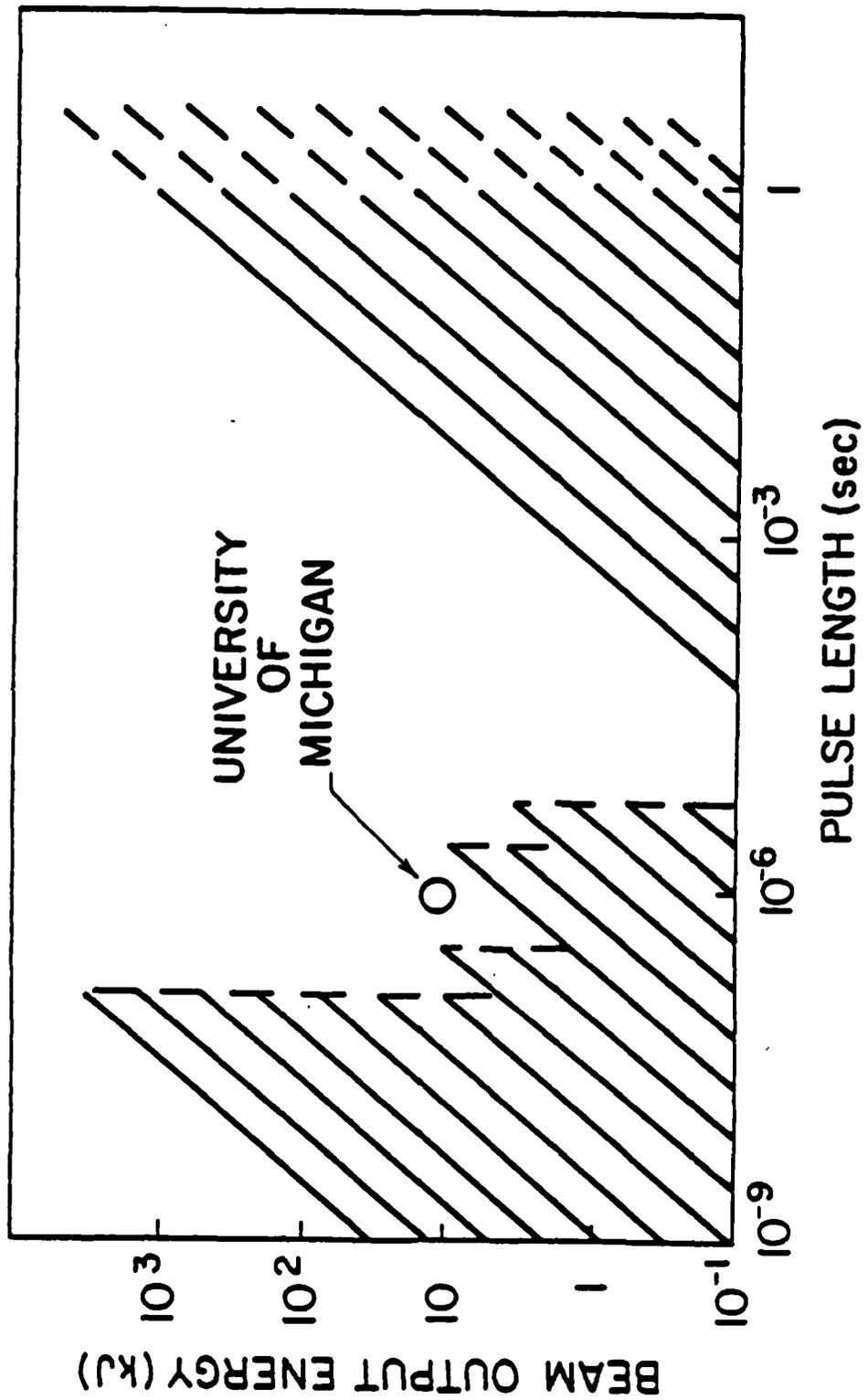
V, Voltage

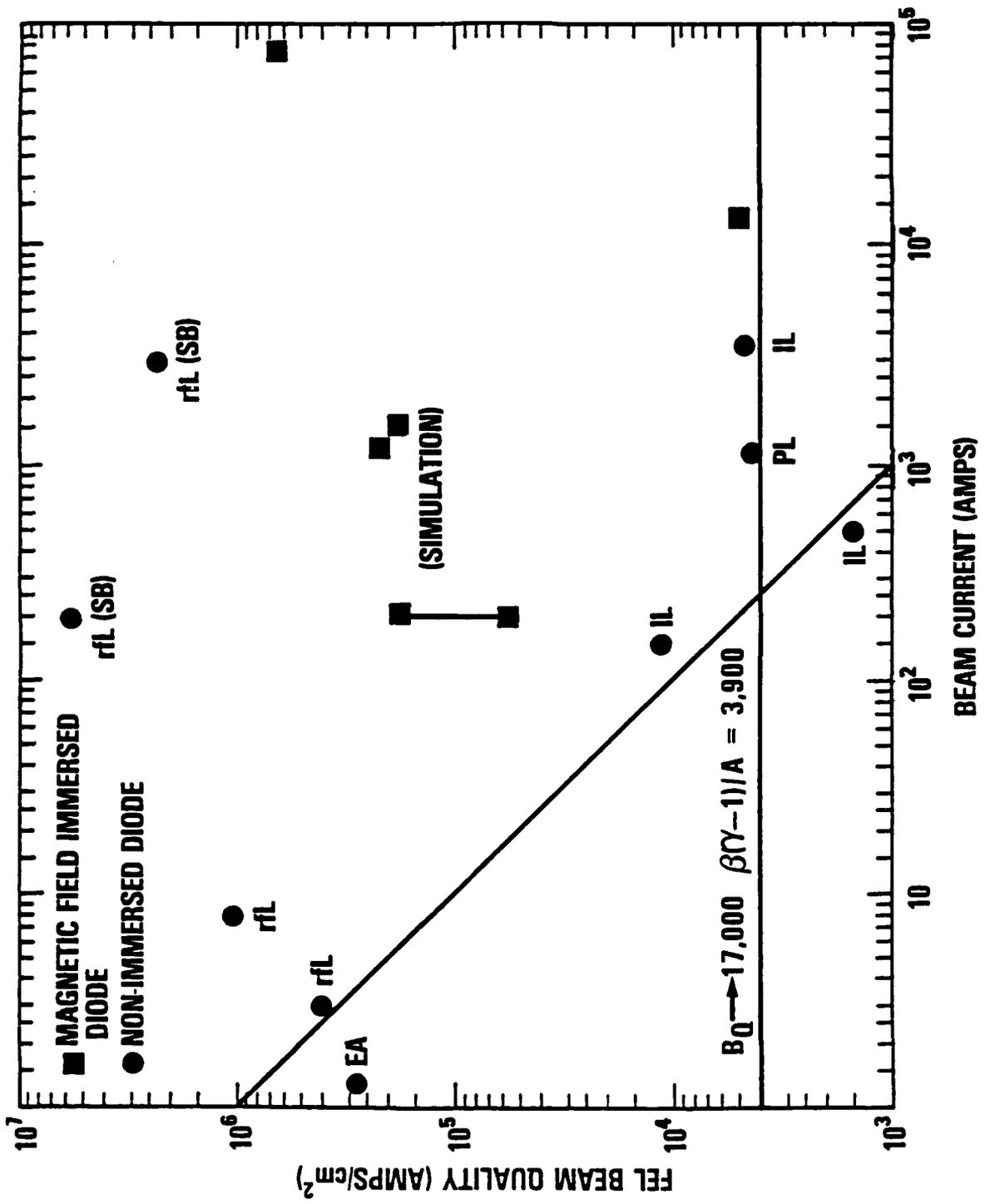
I, Current

τ , Pulse length (Rep Rate)

$\Delta\gamma/\gamma$, Relative Energy Spread

Bq = $J/\Delta\gamma\gamma$, Beam Quality







HIGH CURRENT INJECTION (10 k A)



**ATA - (50MeV)
Conventional
Betatron**



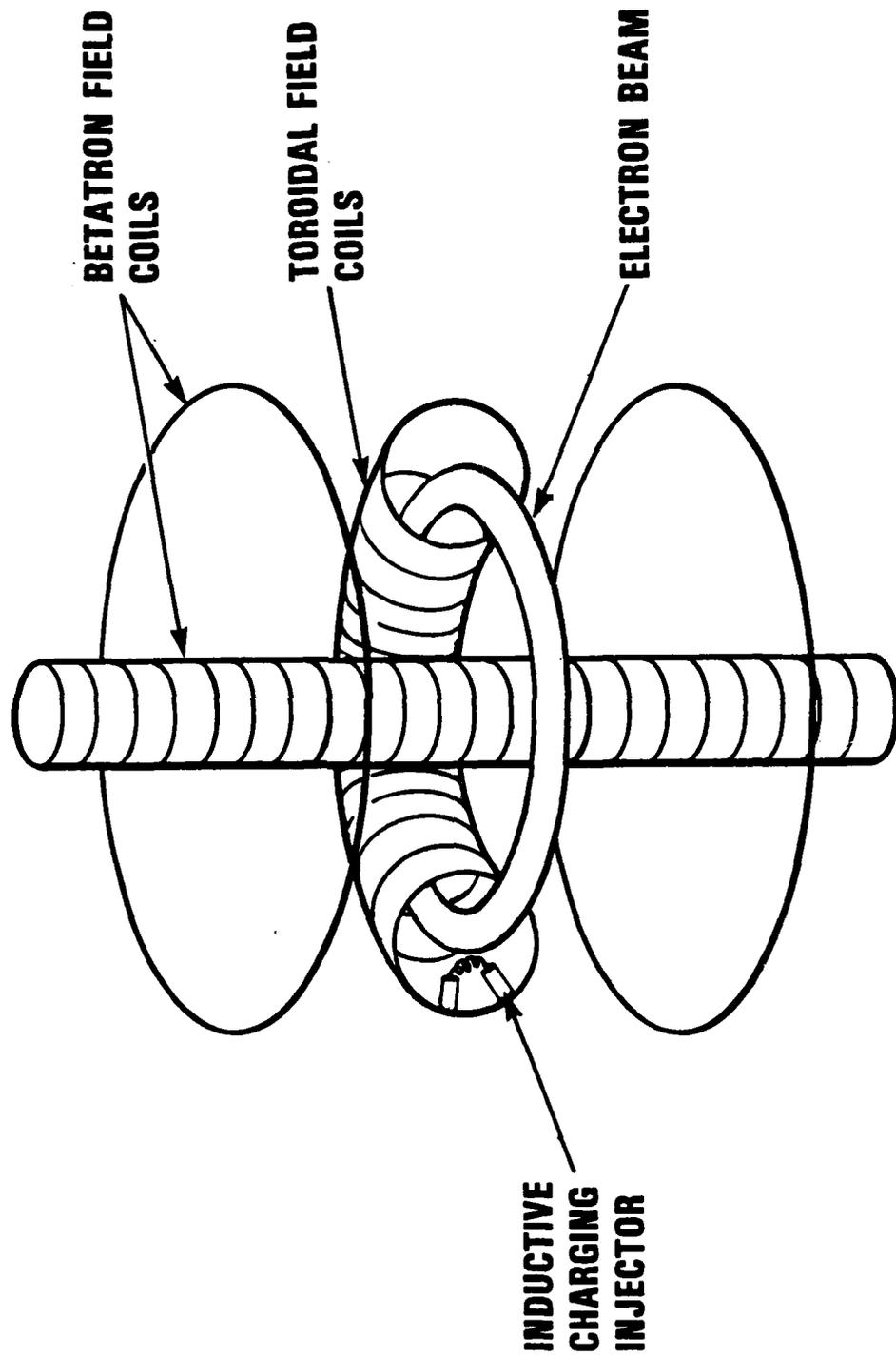
**Marx
Pulse Line (3 MeV)**



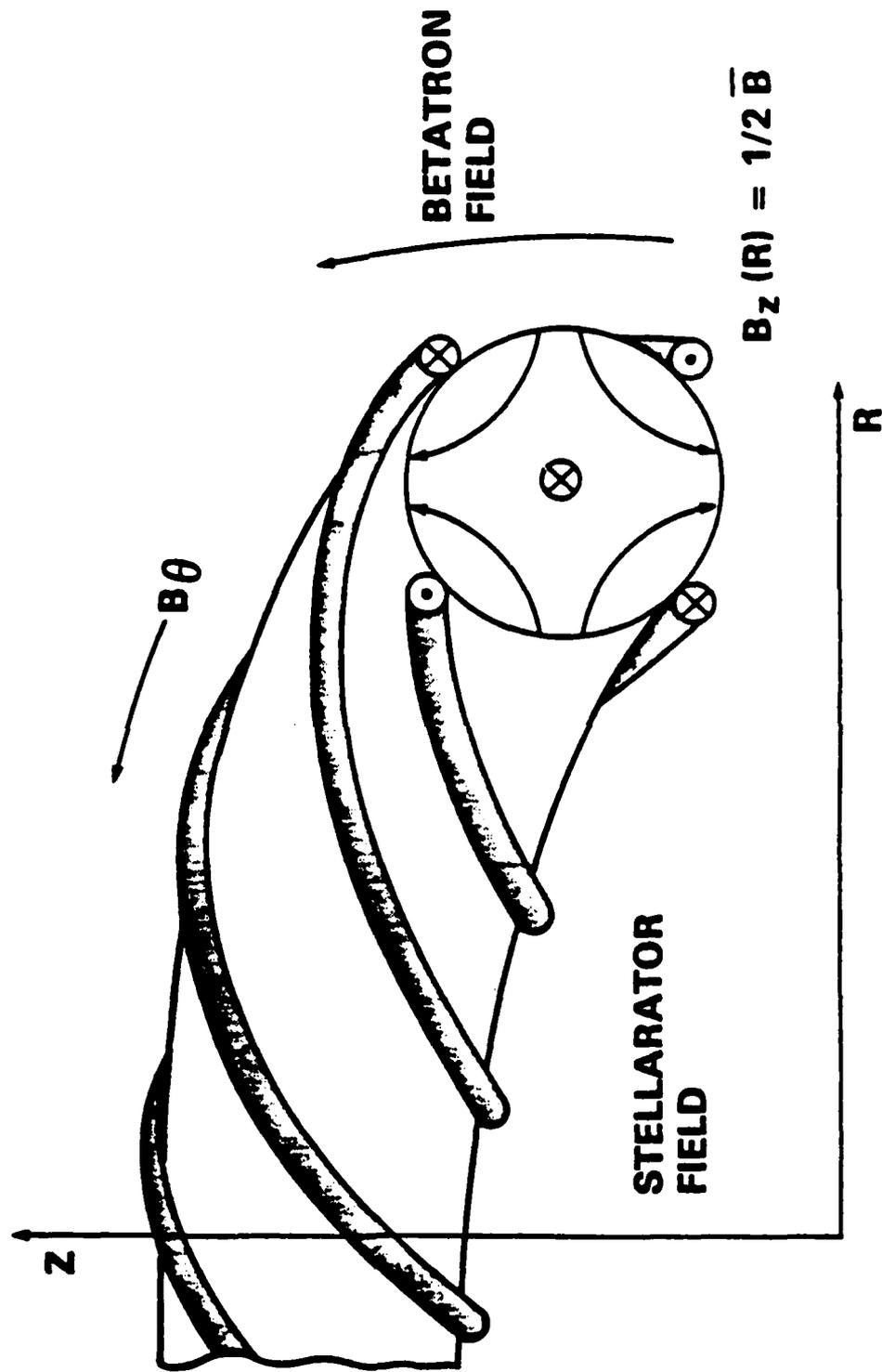
**Inductive Charging (0.1 MeV)
Modified Betatron**

**SCALE
1cm - 2m**

U.C. IRVINE MODIFIED BETATRON

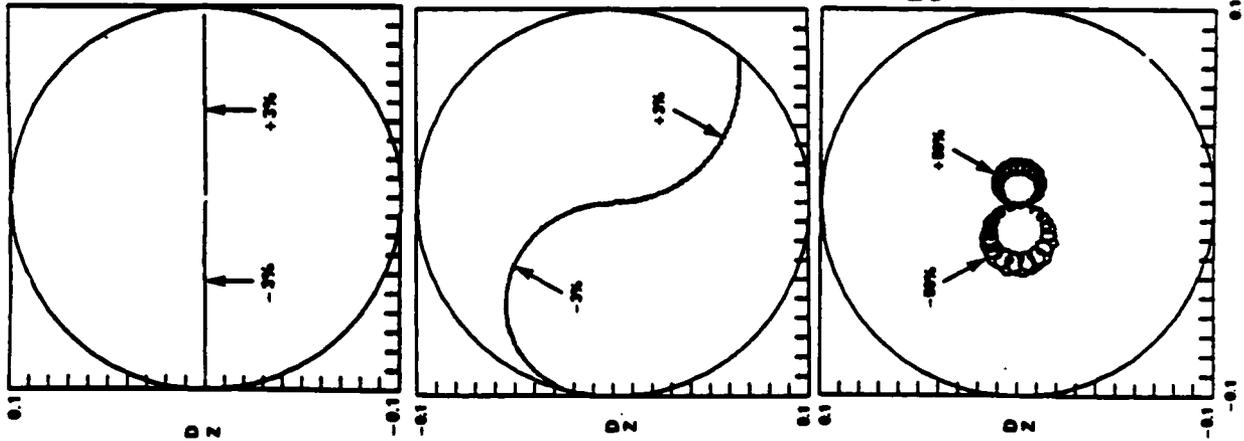


$l = 2$ SYSTEM — "STELLATRON"



PARTICLE ORBITS

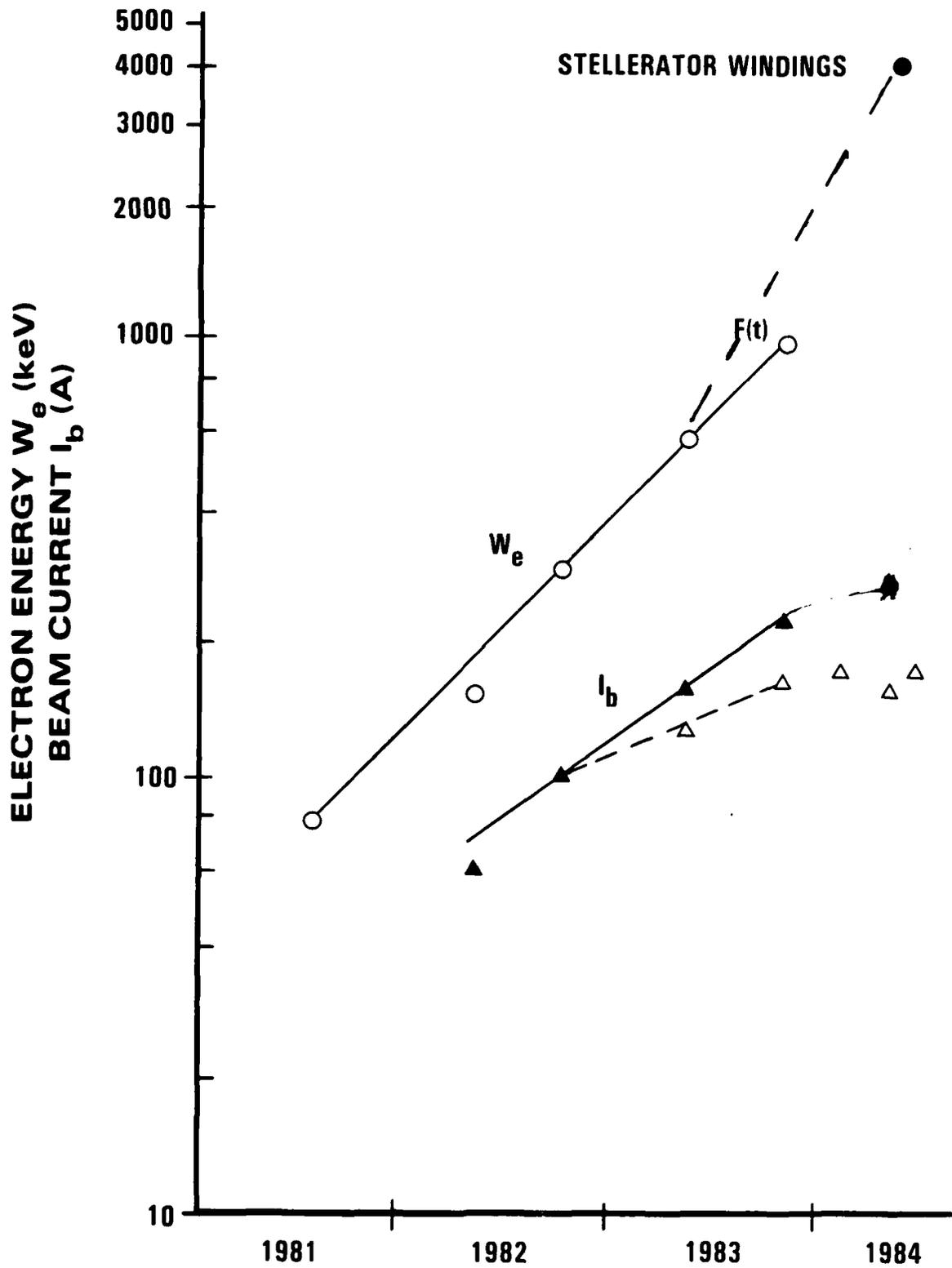
$$\Delta \gamma / \gamma$$

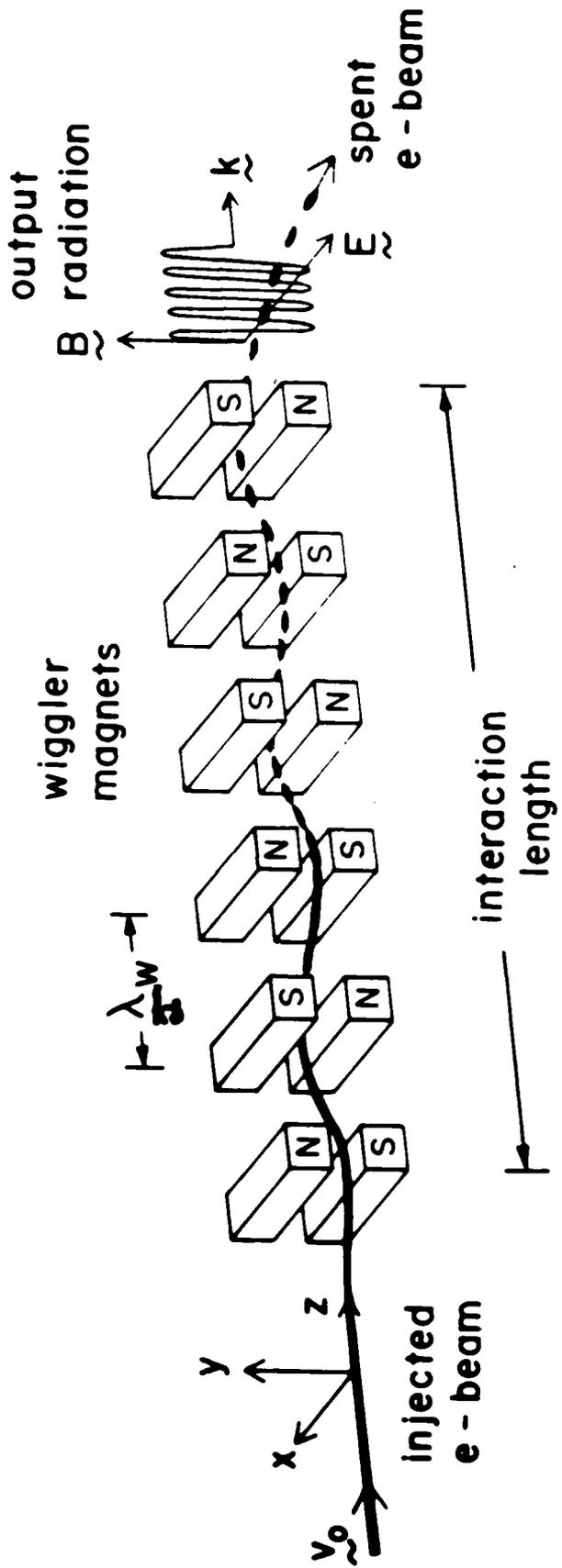


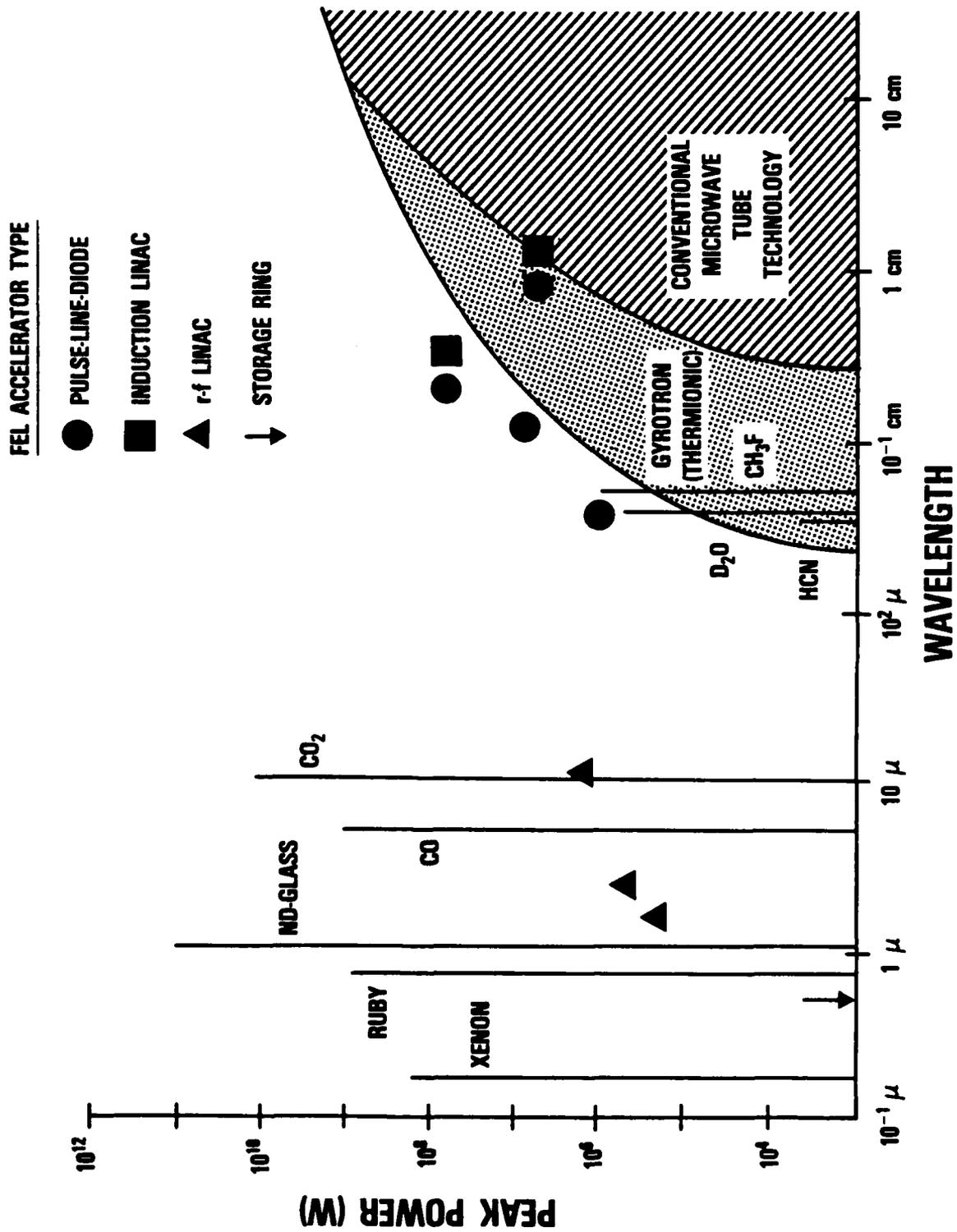
BETATRON
 $\pm 3\%$

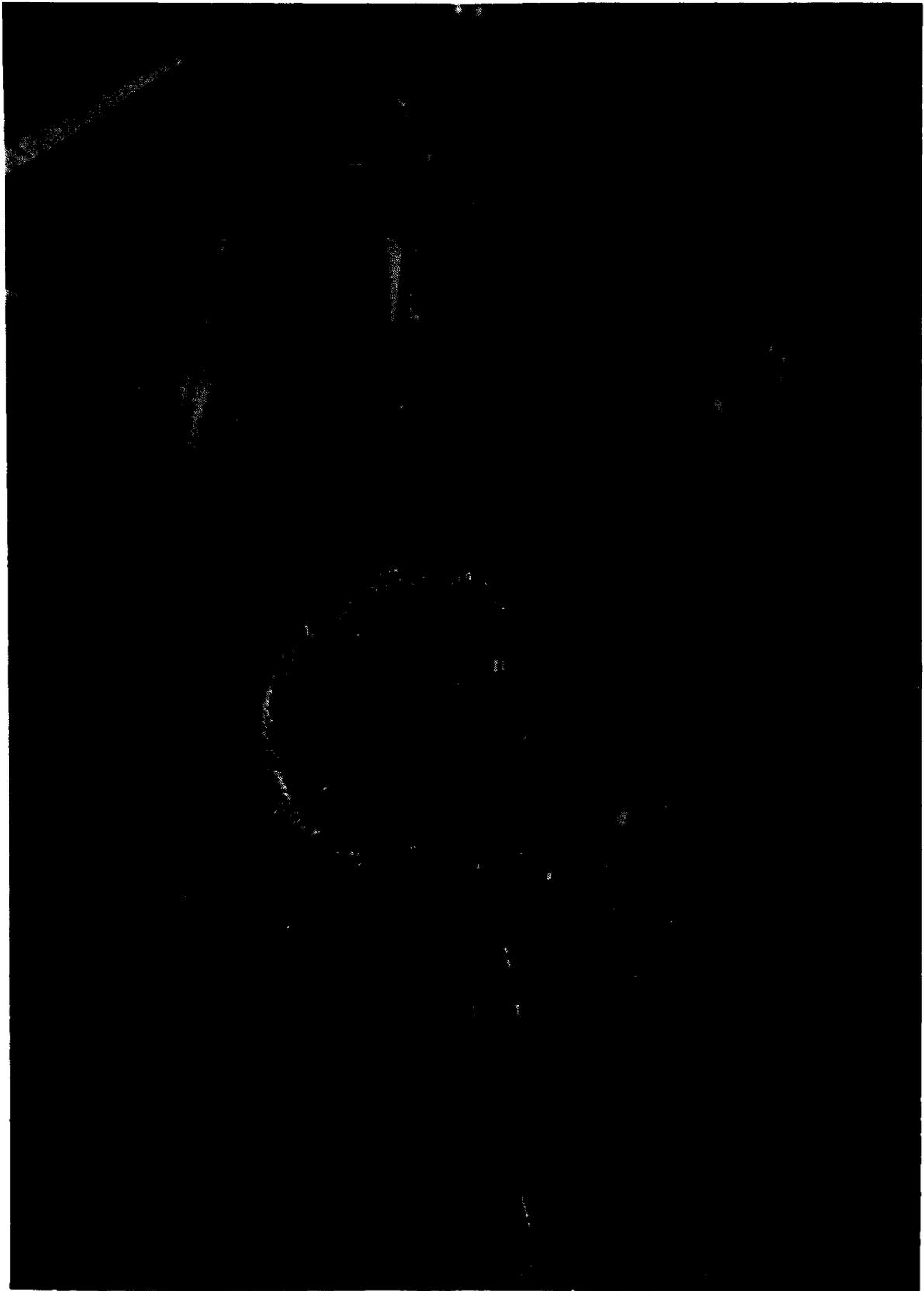
**MODIFIED
BETATRON**
 $\pm 3\%$

STELLATRON
 $\pm 50\%$



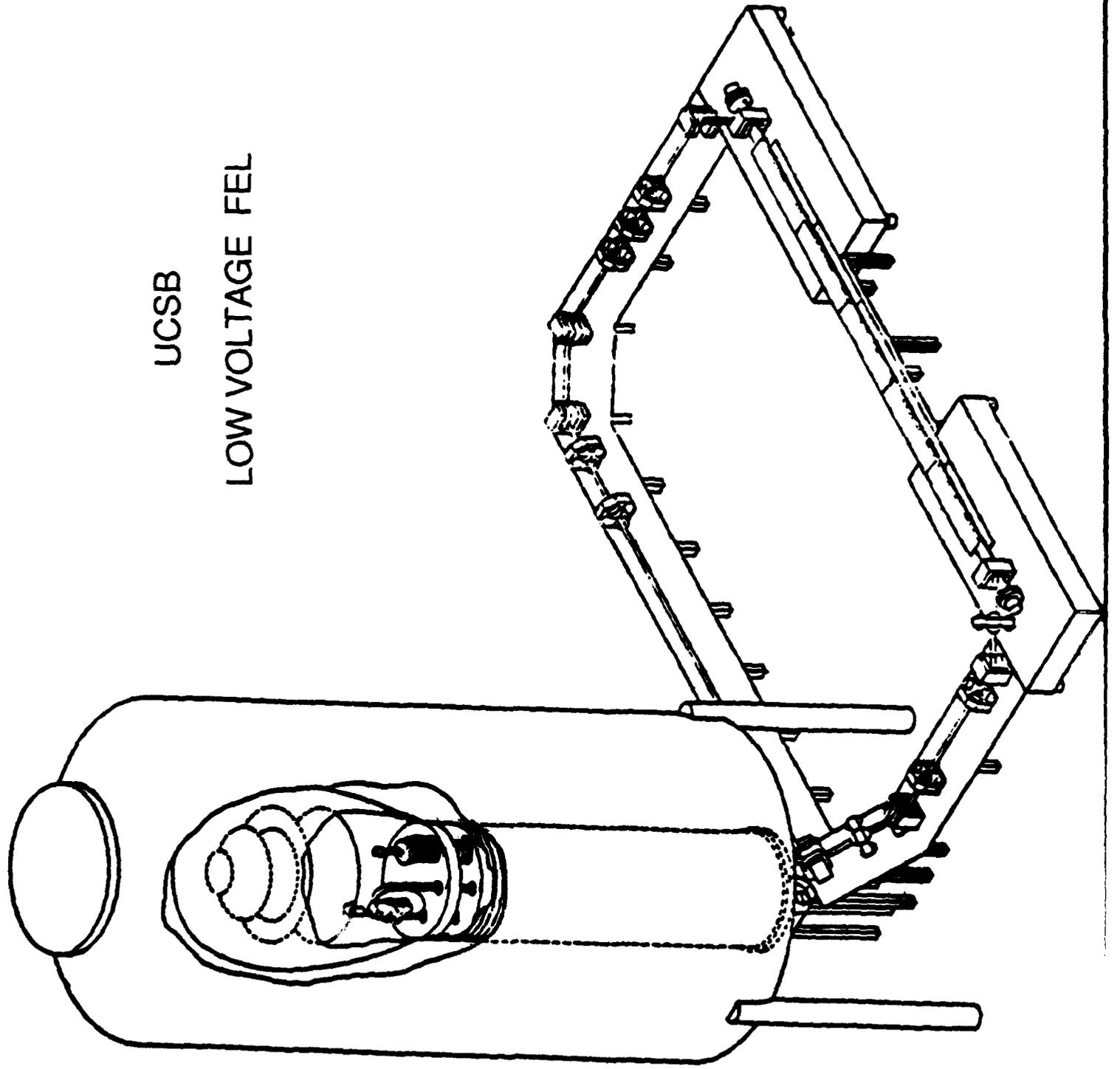


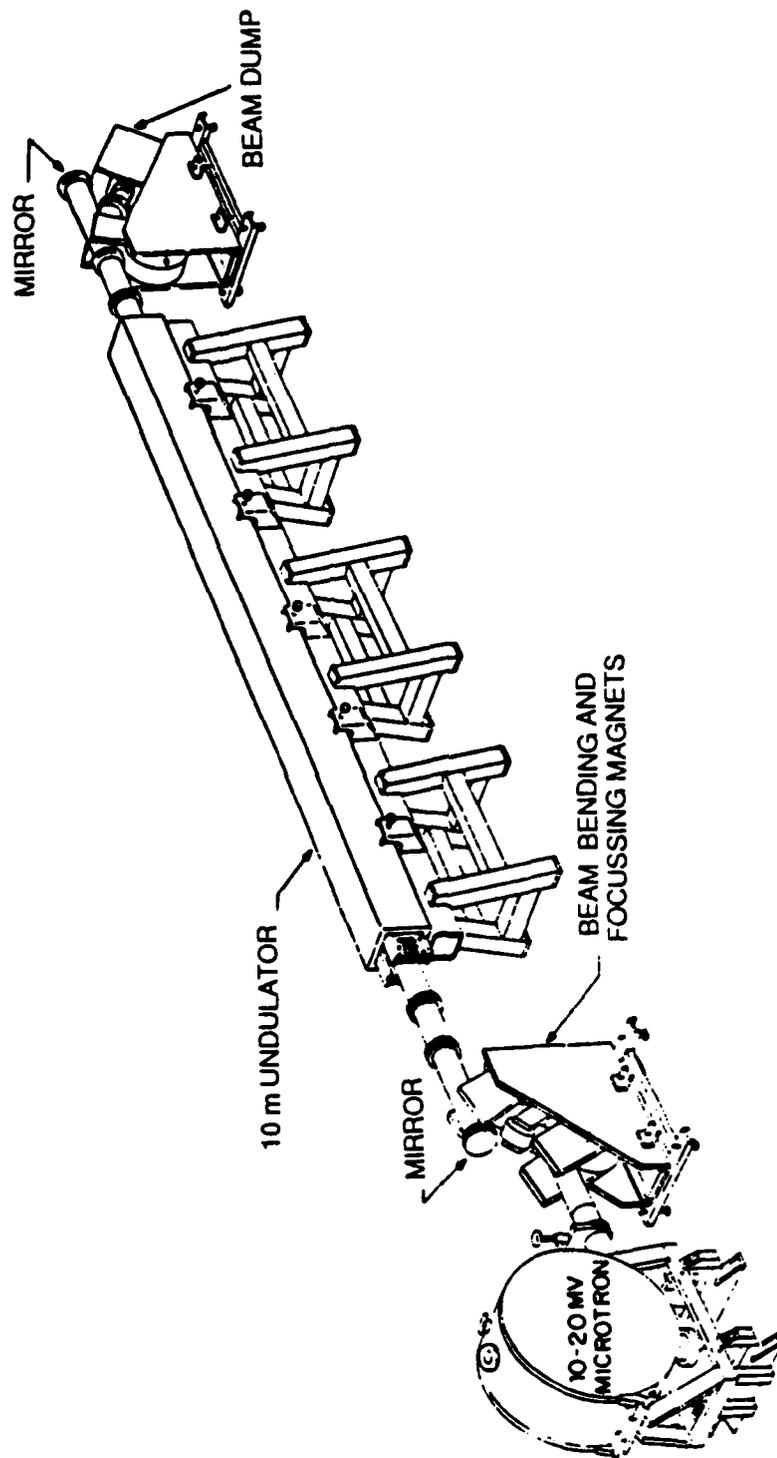




H-17

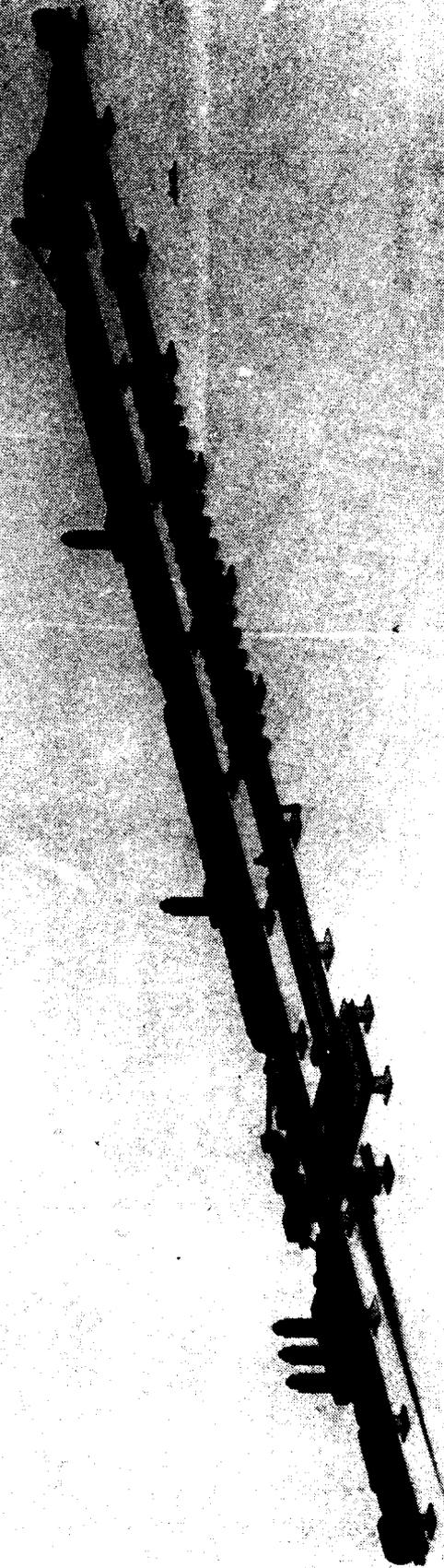
UCSB
LOW VOLTAGE FEL



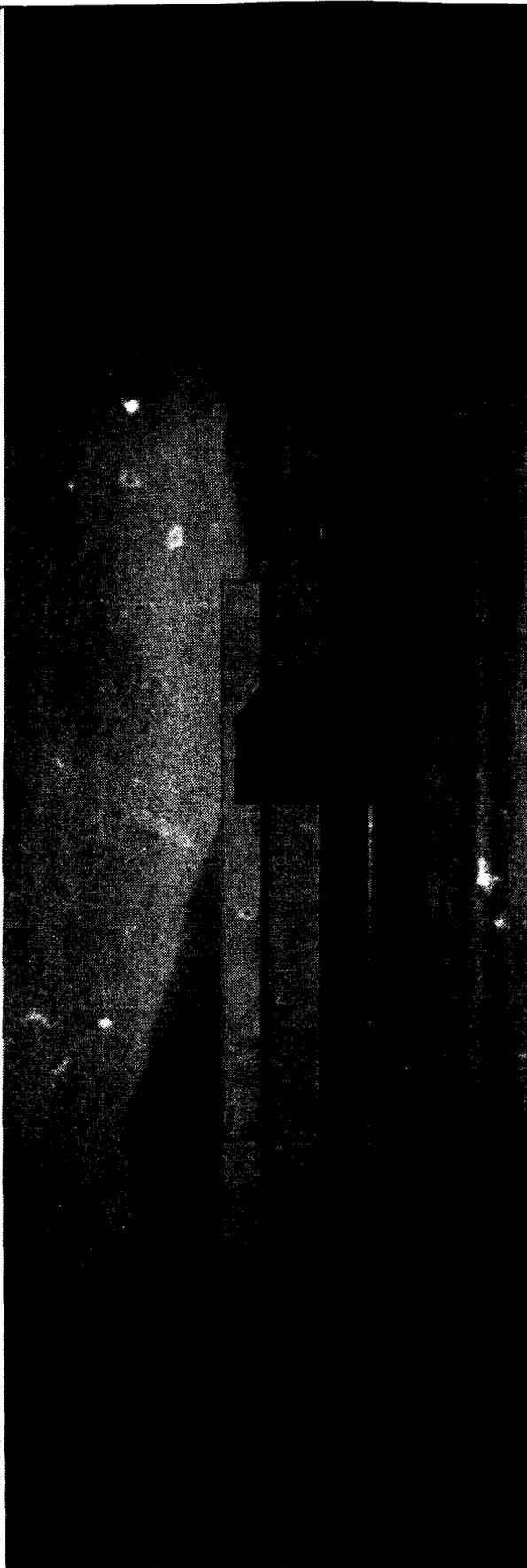


The FEL at Bell Laboratories, showing the microtron (left), the two bending and focusing magnets, the undulator (13 m), and two mirrors.

HIGH POWER FREE-ELECTRON LASER



**ADVANCED TEST ACCELERATOR
(SCHEMATIC)**



- BEAM ENERGY 50 MeV
- BEAM CURRENT 10 kA
- PULSE LENGTH 70 nsec
- REPETITION RATE 1 (10) kHz

APPENDIX I

ULTRA-SHORT WAVELENGTH LASERS

Dr. H. Pilloff, ONR Washington

Ultra-Short-Wavelength Lasers
H.S. Pilloff (202) 696-4223

The objective of this program is to identify and evaluate new innovative concepts and approaches for non-nuclear pumped ultra-short-wavelength lasers. Such lasers are of importance to SDI both as potential directed energy weapons and as laboratory tools for materials characterization and simulation of weapons effects.

The program is concerned with the investigation of innovative schemes for producing suitable population inversions and for efficiently extracting coherent short wavelength radiation. The work will include relevant theoretical analysis, computer simulations, and proof-of-principle laboratory demonstrations/evaluations. Appropriate approaches include (but are not limited to) multiphoton excitation of inner shell transitions in gases, rapid energy transfer from metastable states, and multiphoton excitation of nuclear states.

**ONR/IST Programs
in
Advanced Optics
and
Ultra-Short Wavelength Lasers**

**Presented at IDA/IST Workshop
June 17-18, 1985**

Herschel Pilloff

Code 412

ONR

OUTLINE

Advanced Optics

<Coherent Laser Beam Combining & Beam Clean-up>

Optical Phase Conjugation

Stimulated Raman Scattering

2-Wave Mixing

Ultra-Short Wavelength Lasers

Soft X-Ray Lasers

Gamma Ray Laser Concept

Coherent Laser Beam Combining

Energy on Target

Energy scaling & economics

Correct for optical aberrations

Optical Phase Conjugation

OPTICAL PHASE CONJUGATION

$$E_1(r,t) = \text{Re}[\psi(r)e^{i(\omega t - kz)}] \quad (1)$$

Scalar wave equation

$$\nabla^2 E + \omega^2 \mu \epsilon(r) E = 0 \quad (2)$$

$$\nabla^2 \psi + [\omega^2 \mu \epsilon(r) - k^2] \psi - 2i \frac{\delta \psi^*}{\delta z} = 0 \quad (3)$$

Complex conjugate (3)

$$\nabla^2 \psi^* + [\omega^2 \mu \epsilon(r) - k^2] \psi^* + 2i \frac{\delta \psi}{\delta z} = 0 \quad (4)$$

Soln. (4)

$$E_2(r,t) = \text{Re}[\psi^*(r)e^{i(\omega t + kz)}] \quad (5)$$

Propagates -z with Amp Comp Conj E_1

One-to-one correspondence between the two waves. Equivalent to time reversal in propagation of conj. beam, i.e., the conj. beam is equiv. to the incident beam traveling backward in time.

OPTICAL PHASE CONJUGATION

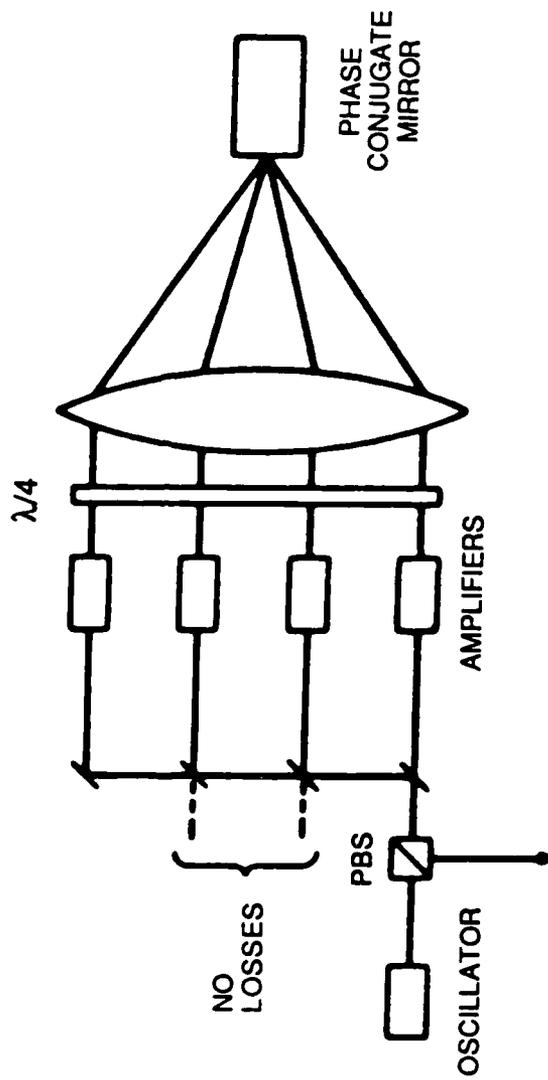
$$E_1 = 1/2 \left[4(r)e^{i(\omega t - kz)} + 4^*(r)e^{-i(\omega t - kz)} \right]$$

$$E_2 = 1/2 \left[4^*(r)e^{i(\omega t + kz)} + 4(r)e^{-i(\omega t + kz)} \right]$$

TIME REVERSAL

$$E_2 = 1/2 \left[4^*(r)e^{-i(\omega(-t) - kz)} + 4(r)e^{i(\omega(-t) - kz)} \right]$$

BEAM COMBINING OF MULTIPLE AMPLIFIERS VIA A PHASE CONJUGATE MIRROR



Hughes Research Laboratory

SBS PHASE CONJUGATION

Eliminates pump beams req. for 4-wave mixing

Technical Issues:

Stress-induced birefringence

Vector SBS phase conjugation

Backward seeded injection locking

Auxiliary pumping--near forward, strong beam

Multiple beam, common focus SBS

Optimal beam combining geometries

Laser gain media

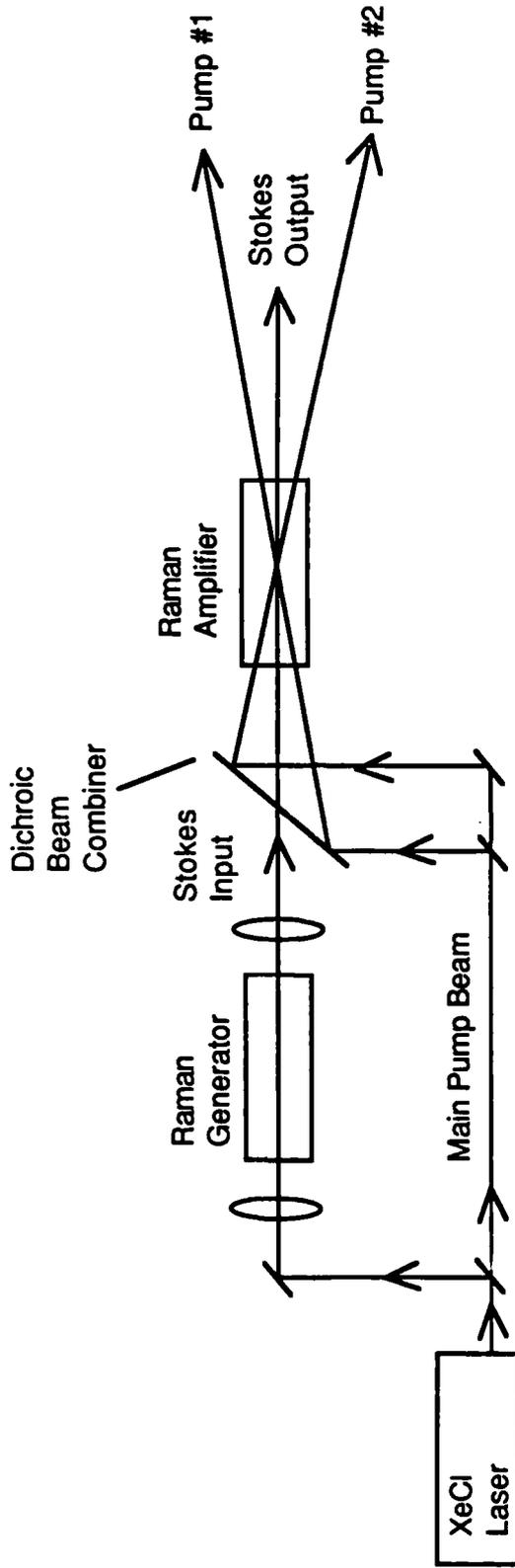
Gain, intensity, bandwidth

Conjugator material

Response time, coupling coeff.,

power handling, competing nonlinearities

APPROACH



--Input Stokes beam obtained from Raman generator

--Stokes beam and pump beam(s) can be colinear or at angle in Raman amplifier

Beam Combining via SRS

Technical Issues:

Effect on Raman gain of:

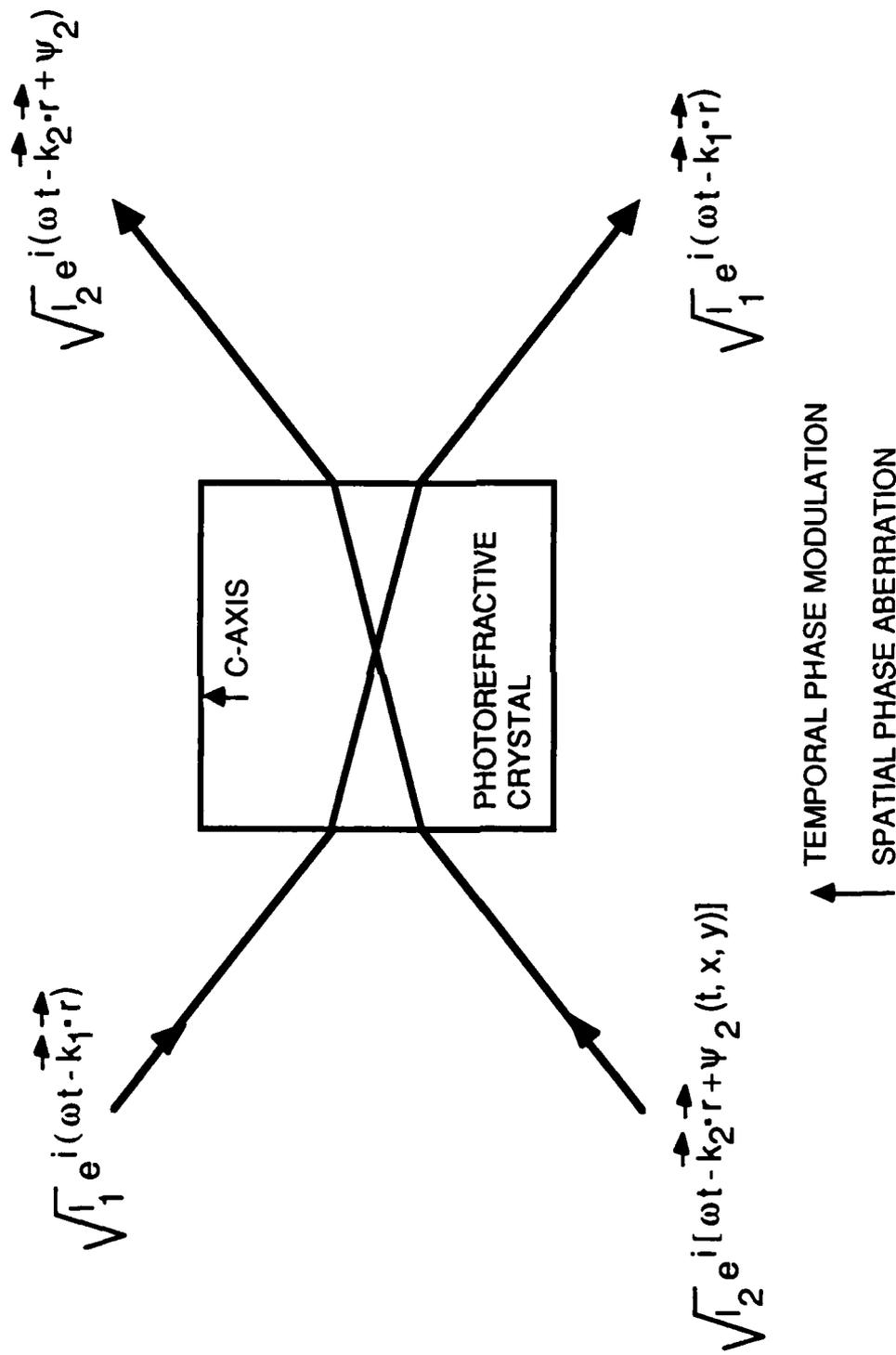
Bandwidth of pump laser

Angle between pump & injected Stokes

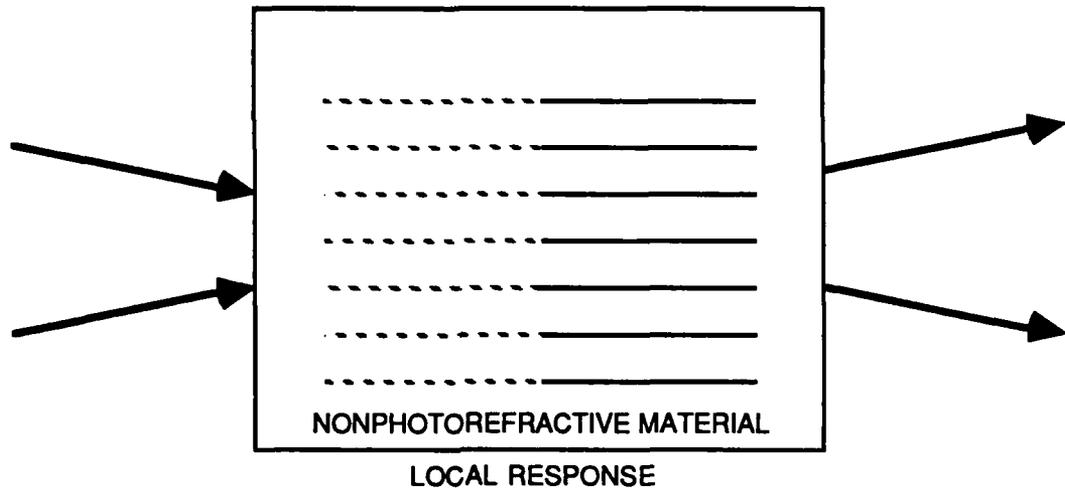
Saturation of pump

4-wave mixing & dispersion effects

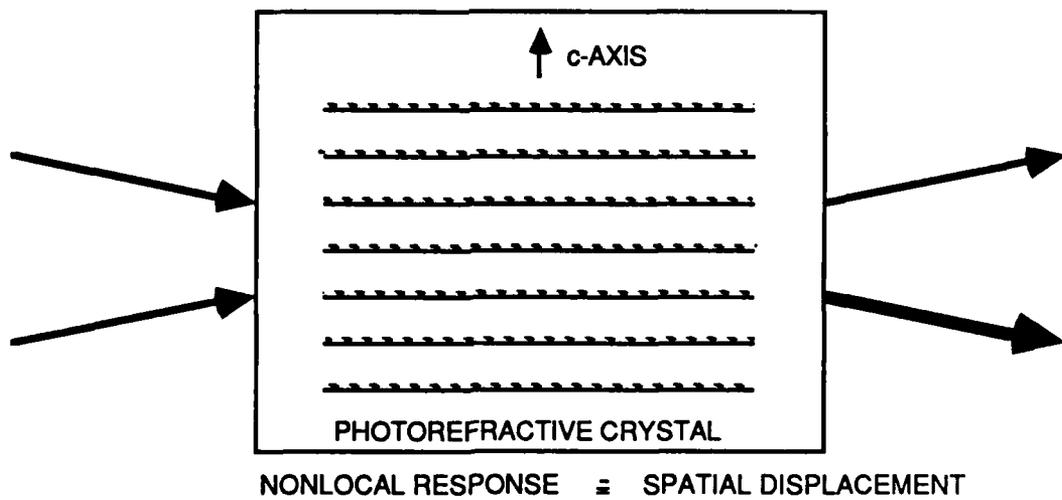
TWO WAVE MIXING



PHOTOREFRACTIVE EFFECT

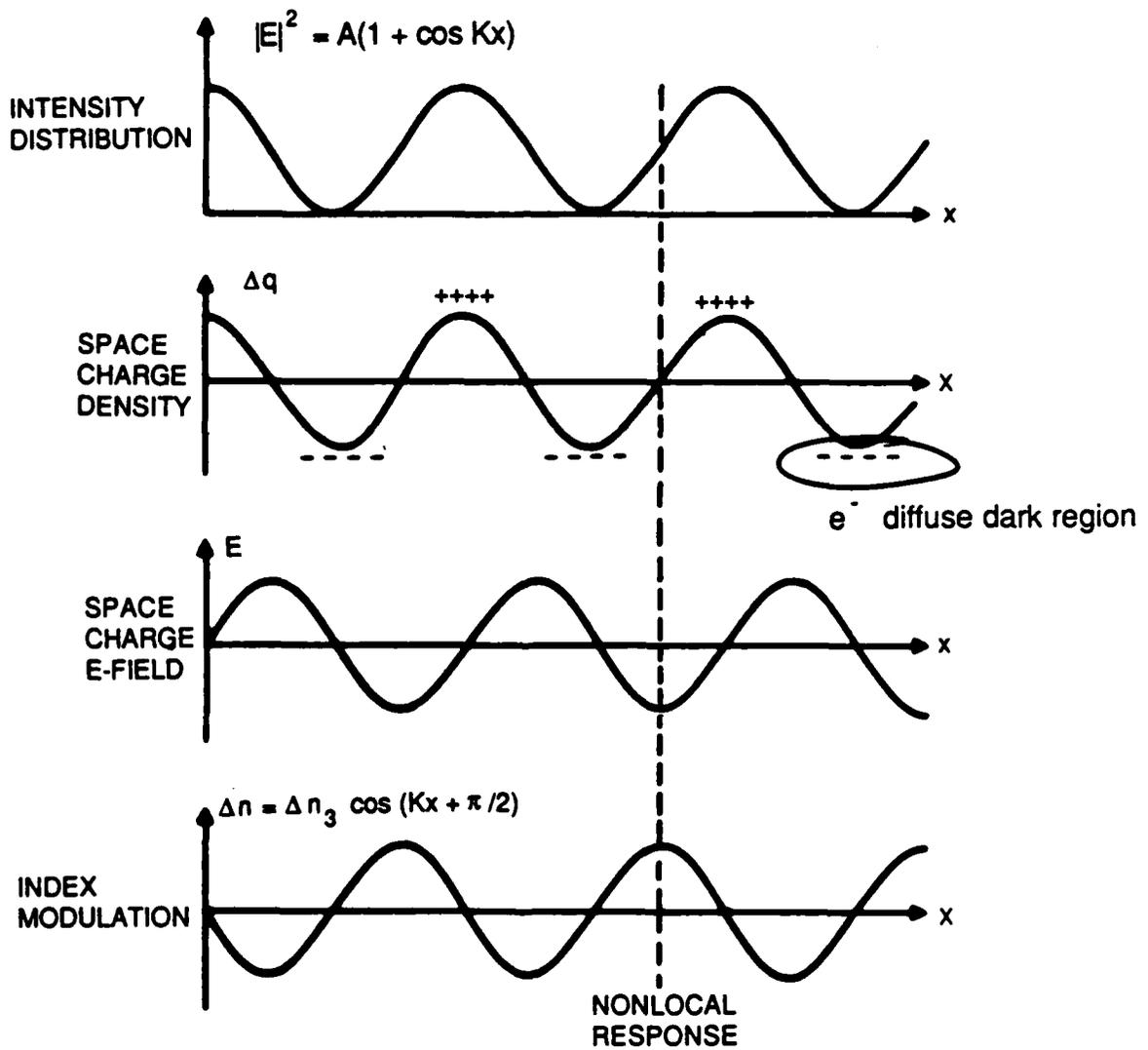


----- INTERFERENCE FRINGE
 _____ INDEX MODULATION



NONRECIPROCAL ENERGY TRANSFER
 UNEQUAL PHASE SHIFT

PHOTOREFRACTIVE EFFECT



WAVE COUPLING IN PHOTOREFRACTIVE CRYSTAL

A.
$$\left\{ \begin{array}{l} \frac{d}{dz} I_1 = -\gamma \frac{I_1 I_2}{I_1 + I_2} \\ \frac{d}{dz} I_2 = \gamma \frac{I_1 I_2}{I_1 + I_2} \end{array} \right.$$

AMPLITUDE COUPLING COEFFICIENT

$$\gamma = \frac{2\pi n_1}{\lambda} \sin\phi$$

B.
$$\left\{ \begin{array}{l} \frac{d}{dz} \psi_1 = -\beta \frac{I_2}{I_1 + I_2} \\ \frac{d}{dz} \psi_2 = -\beta \frac{I_1}{I_1 + I_2} \end{array} \right.$$

PHASE COUPLING COEFFICIENT

$$\beta = \frac{\pi n_1}{\lambda} \cos\phi$$

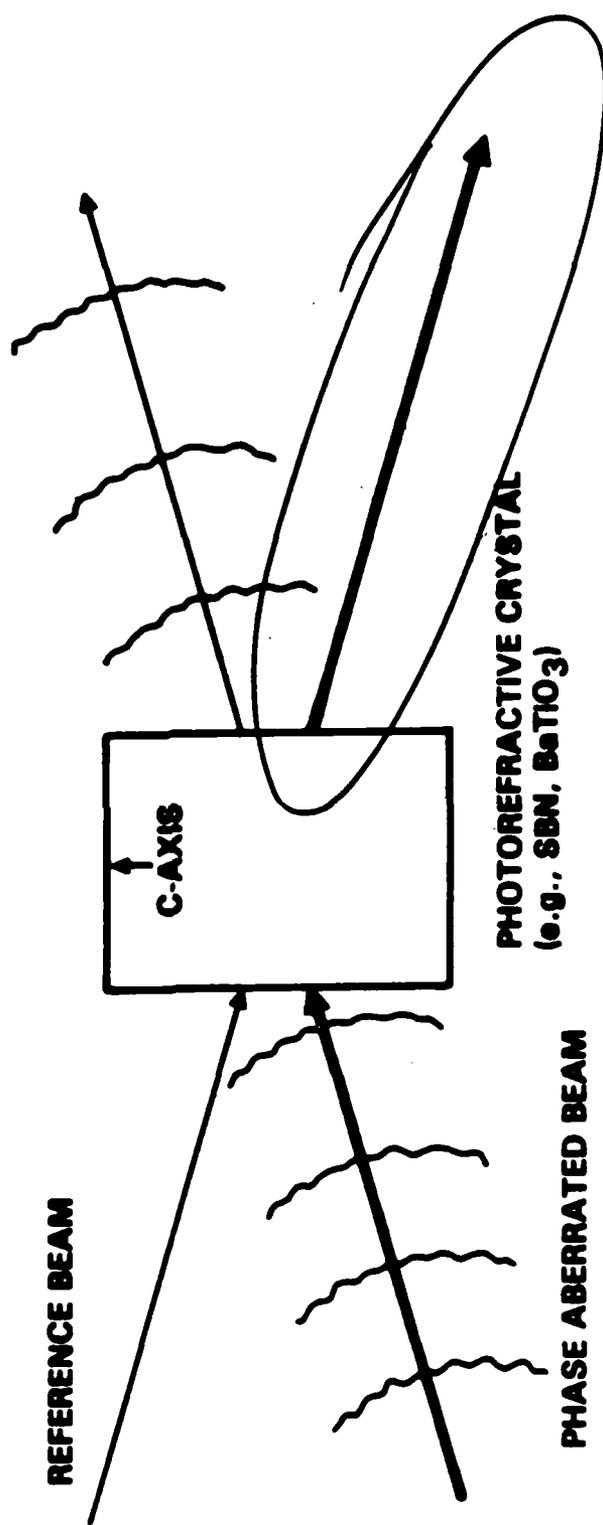
FROM A: NONRECIPROCAL ENERGY EXCHANGE

FROM B: NO PHASE CROSSTALK

ϕ FINITE PHASE SHIFT

$\phi = \frac{\pi}{2}$ FOR PURE DIFFUSION

PHOTOREFRACTIVE 2-WAVE MIXING FOR WAVEFRONT CORRECTION



ARTIFICIAL PHOTOREFRACTIVE EFFECT

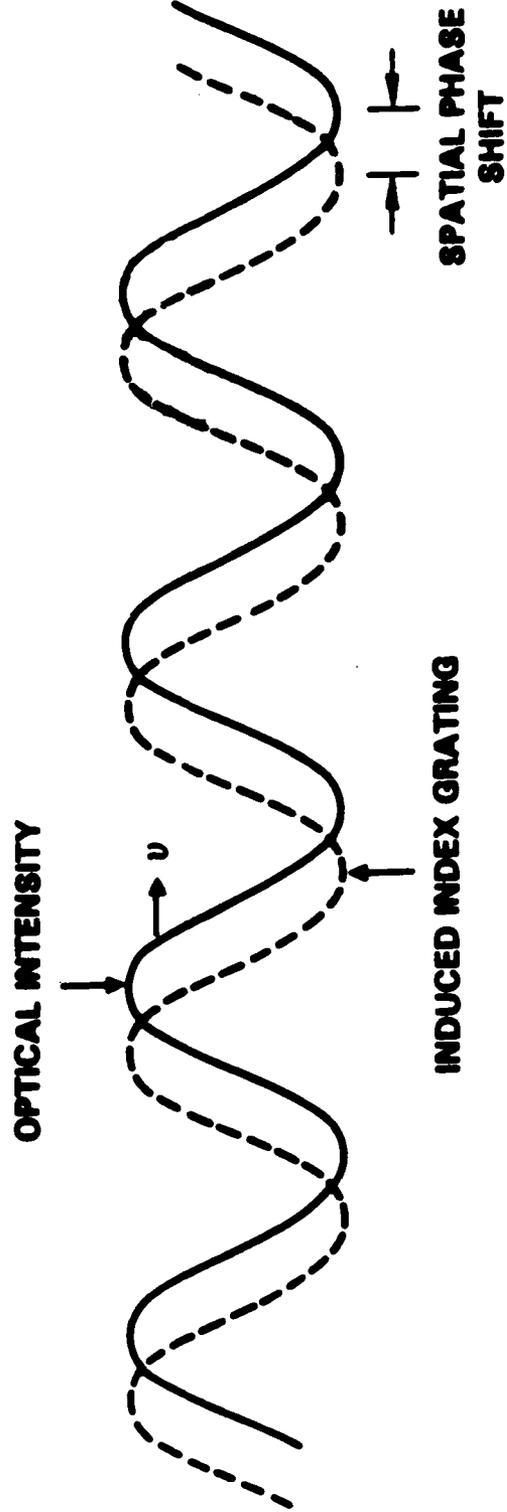
**PURPOSES: 1. HIGH EFFICIENCY
2. FAST
3. HIGH POWER**

**APPROACHES: 1. DEGENERATE TWO-WAVE MIXING IN MOVING
KERR MEDIA
2. NONDEGENERATE TWO-WAVE MIXING IN
KERR MEDIA
3. CO-DIRECTIONAL STIMULATED
BRILLOUIN SCATTERING
4. CONTRA-DIRECTIONAL STIMULATED
BRILLOUIN SCATTERING**

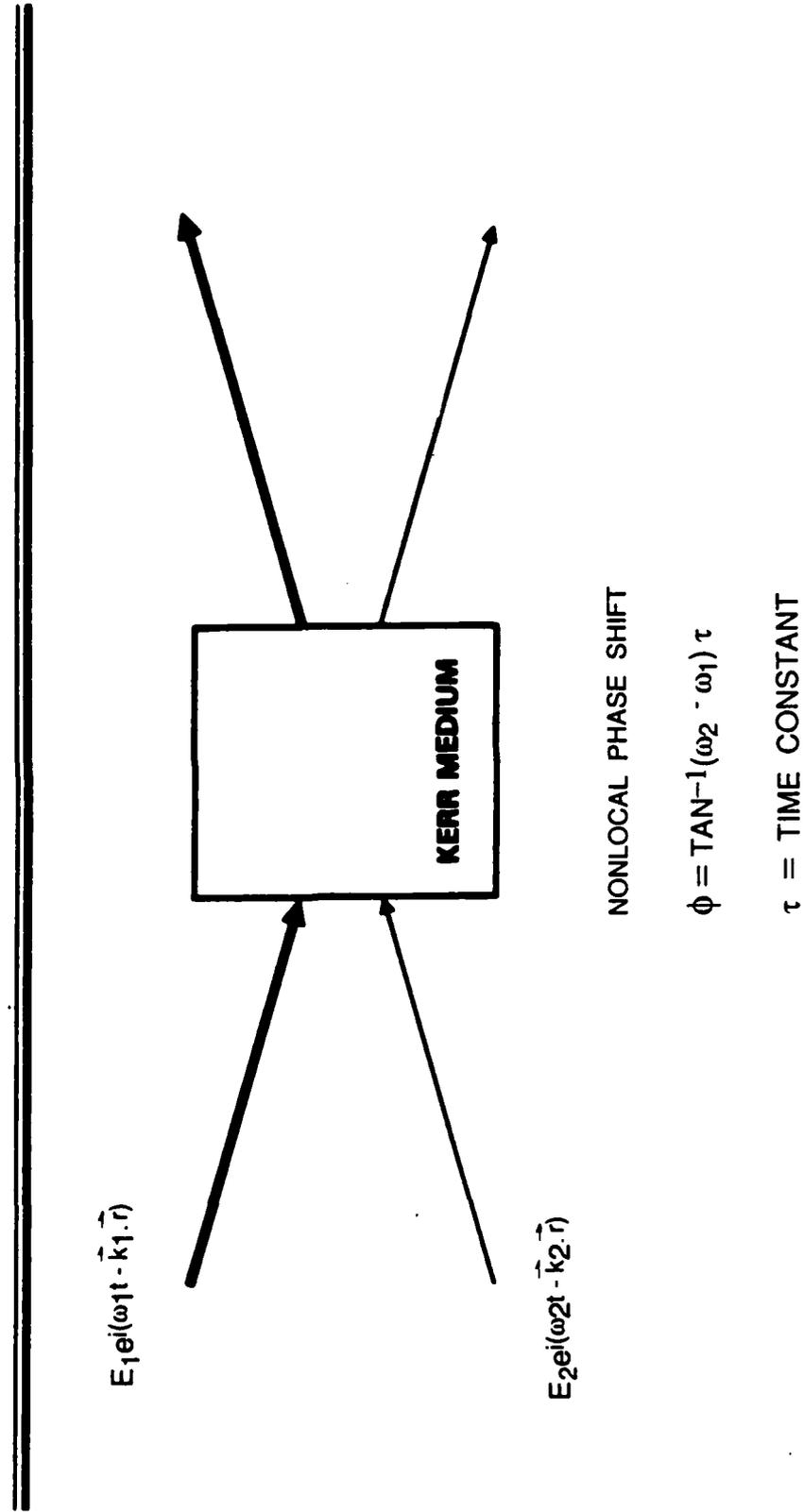
ARTIFICIAL PHOTOREFRACTIVE EFFECT

- PHOTOREFRACTIVE EFFECT
SPATIAL NONLOCAL RESPONSE
ENERGY TRANSFER WITHOUT PHASE-CROSS TALK
- KERR EFFECT
NO ENERGY TRANSFER
- KERR EFFECT IN MOVING MEDIA
TEMPORAL NONLOCAL → SPATIAL NONLOCAL

ARTIFICIAL PHOTOREFRACTIVE EFFECT



NONLOCAL RESPONSE VIA DETUNING



2-Wave Mixing

Coherent beam combining - photorefractive crystals

Artificial photorefractive effects in Kerr media

Nondegenerate 2-wave mixing in Kerr media

Ultra-Short Wavelength Lasers

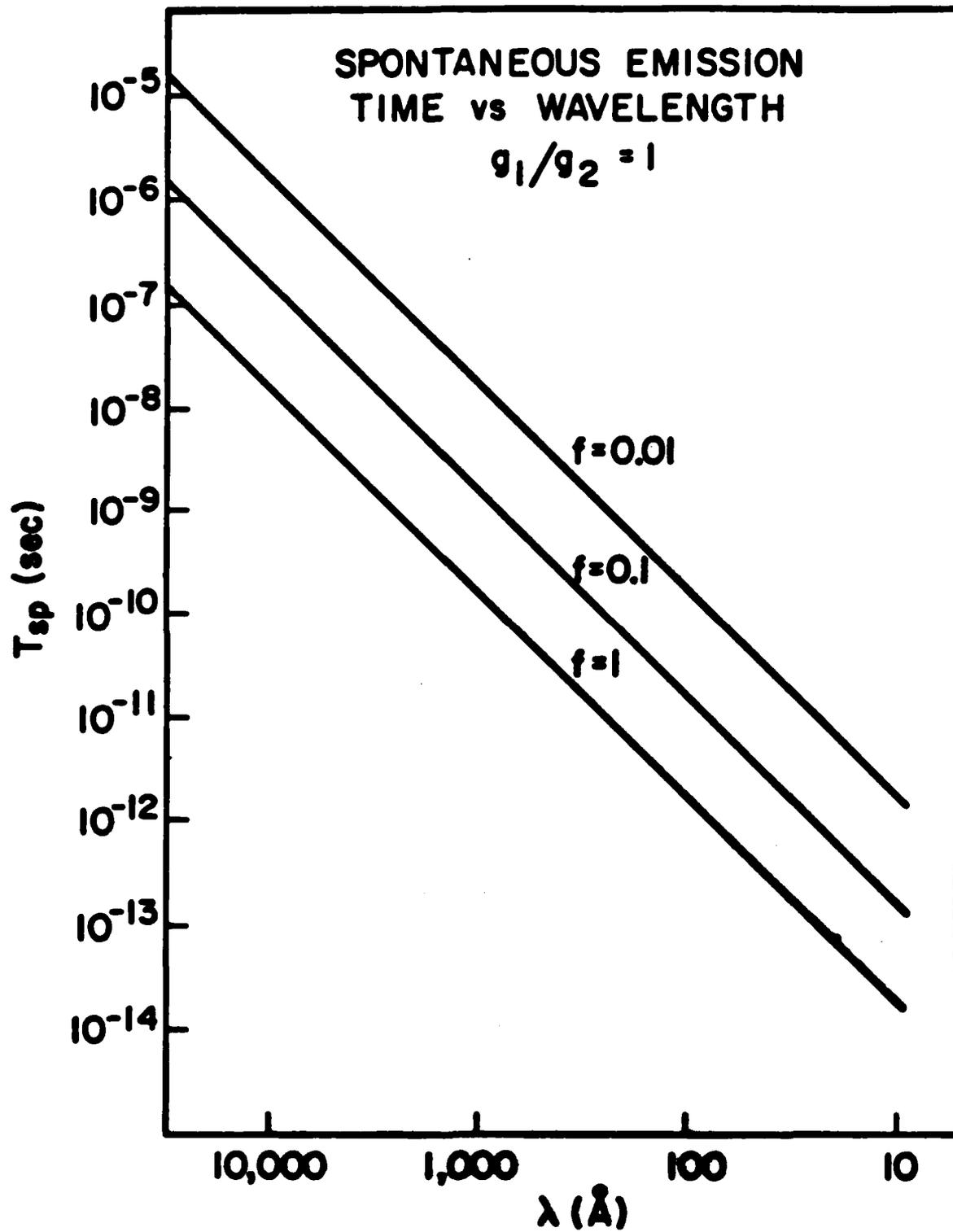
Soft X-Ray Lasers

Harris

Rhodes

Gamma-Ray Laser Concept

Collins

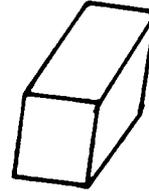


SPONTANEOUS EMISSION POWER

10^{20} atoms $\sim 1 \text{ cm}^3$

$\lambda = 100 \text{ \AA}$

$\tau = 10^{-10} \text{ sec}$



$$P = N \times \frac{1}{\tau} \times h\nu$$

$$= 10^{20} \times 10^{10} \times 2 \times 10^{-17} \text{ Joules/sec}$$

$$P = 2 \times 10^{10} \text{ kW}$$

Σ U.S. Power Plants $\lesssim 10^9 \text{ kW}$

Harris Approach

Store energy slowly in metastable state

Transfer quickly to radiating level

Production core-excited metastable atoms or ions

Picosecond laser pulse to transfer metastable state
to radiating level

Critical Issue

Produce sufficient $[N] \cdot L$ of metastables

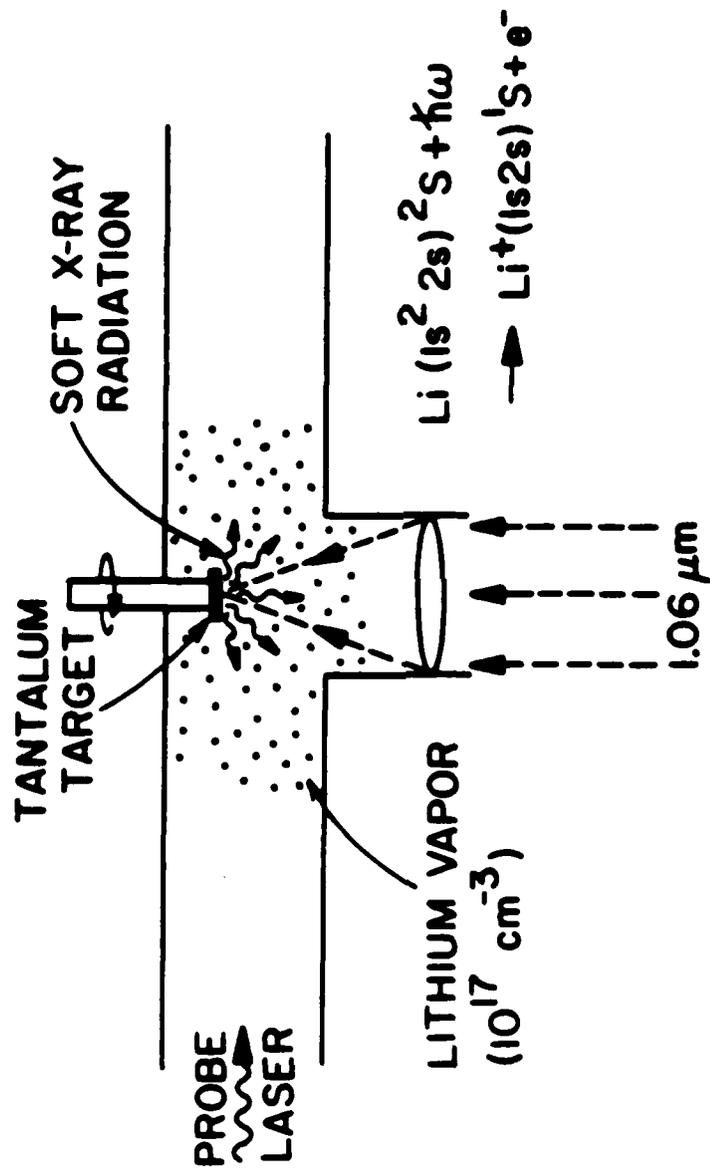
Emphasis on technology for metastable production

Quartet to Doublet Transfer System

Quartet metastable against autoionization

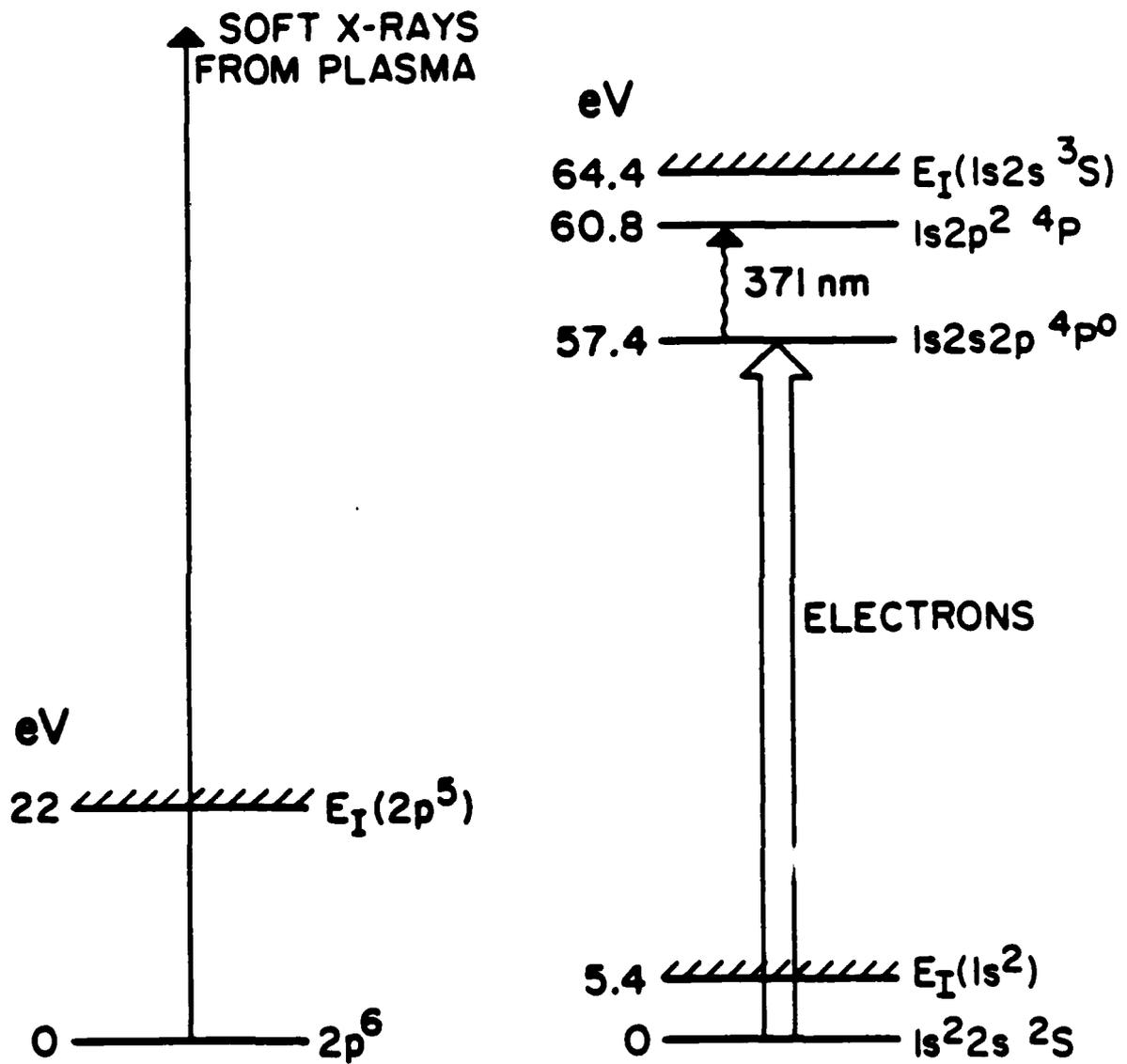
Doublet level slowly autoionizing

Doublet has 50% radiative yield

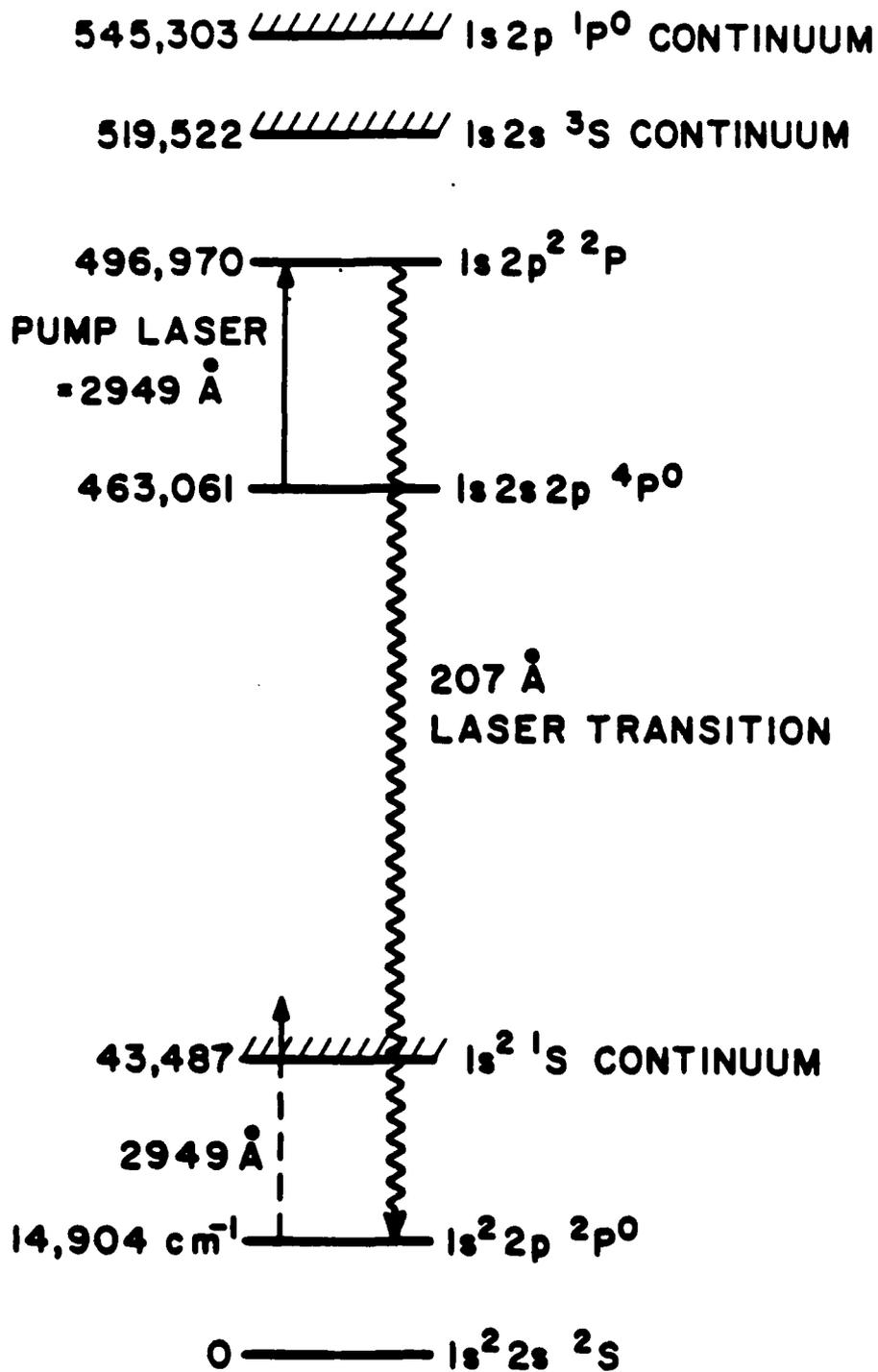


Ne

Li



QUARTET TO DOUBLET TRANSFER SCHEME



Rhodes Approach

Multiphoton excitation of inner shell transitions

Ultrahigh brightness sources

Enhancement via outer shell electrons coherently
driven by incident wave

ATOMIC INNER-SHELL EXCITATION INDUCED BY COHERENT
MOTION OF OUTER-SHELL ELECTRONS

Shell structure determines strength of interaction

Localized current density $10^{14} \leq j \leq 10^{15}$ A/cm²

All electrons in shell are in excited orbitals significant
increase in effective charge involved.

Lifetime characteristic of autoionization $10^{-14} \geq \tau \geq 10^{-15}$

Comparable to UV frequencies

Characteristic $\bar{E} = \frac{e}{a_0^2}$

Coupling Mechanism: Outer shell electrons undergoing
coherent osc. with radiation field have
inelastic collisions with core electrons
→ electronically excited core states.

$$R \sim \frac{j}{e} \sigma_e$$

σ_e exc. atomic core by inelastic coll. from j

$$R \sim \frac{10^{14} \text{ amp/cm}^2}{1.6 \times 10^{-19} \text{ coulomb}} \times 10^{-19} \text{ cm}^2$$
$$\sim 6 \times 10^{13} \text{ sec}^{-1}$$

j radiatively damped $\tau \sim 10^{-15} \text{ sec}$

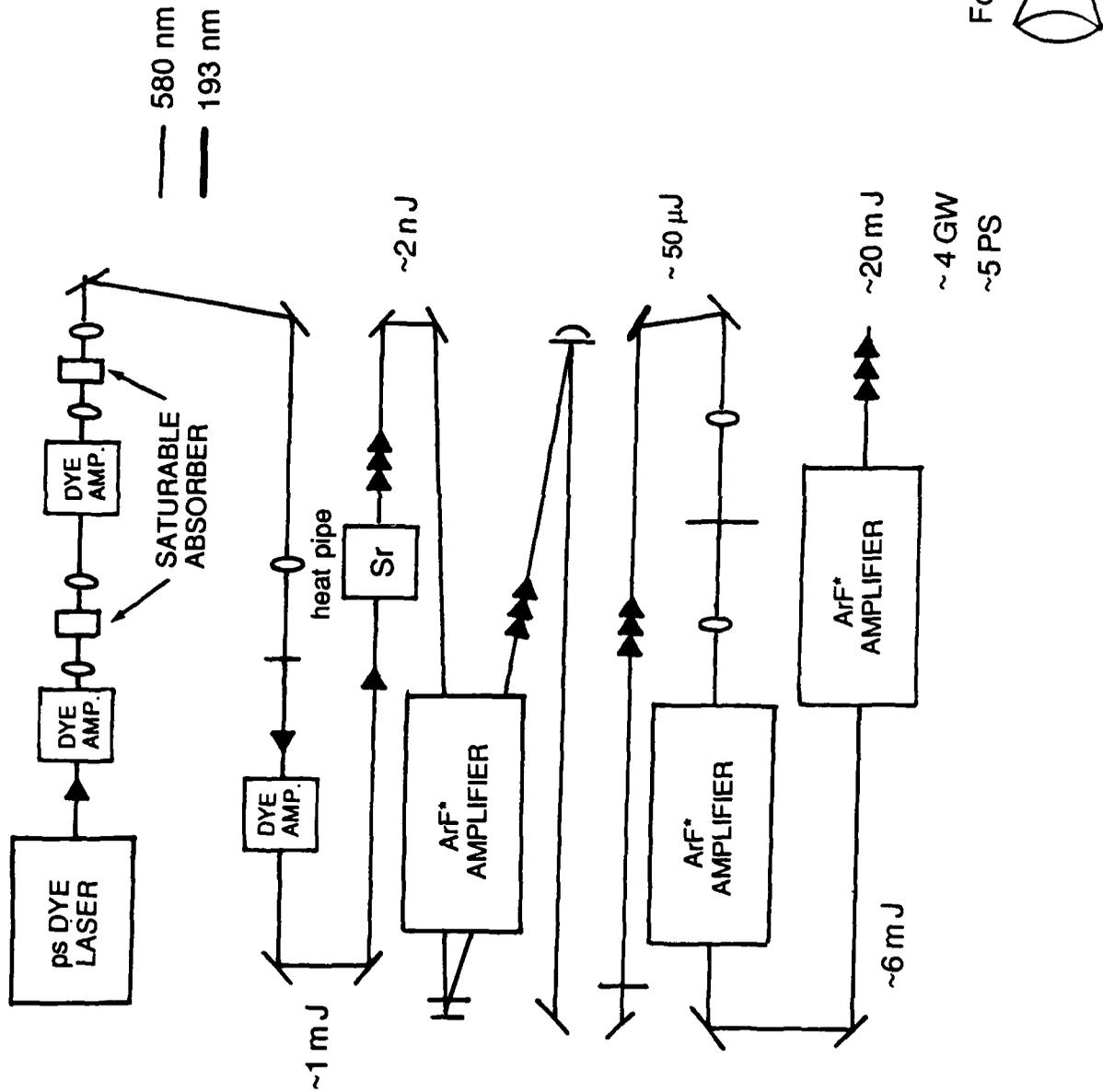
Probability of Energy Transfer

$$P \sim R \tau$$

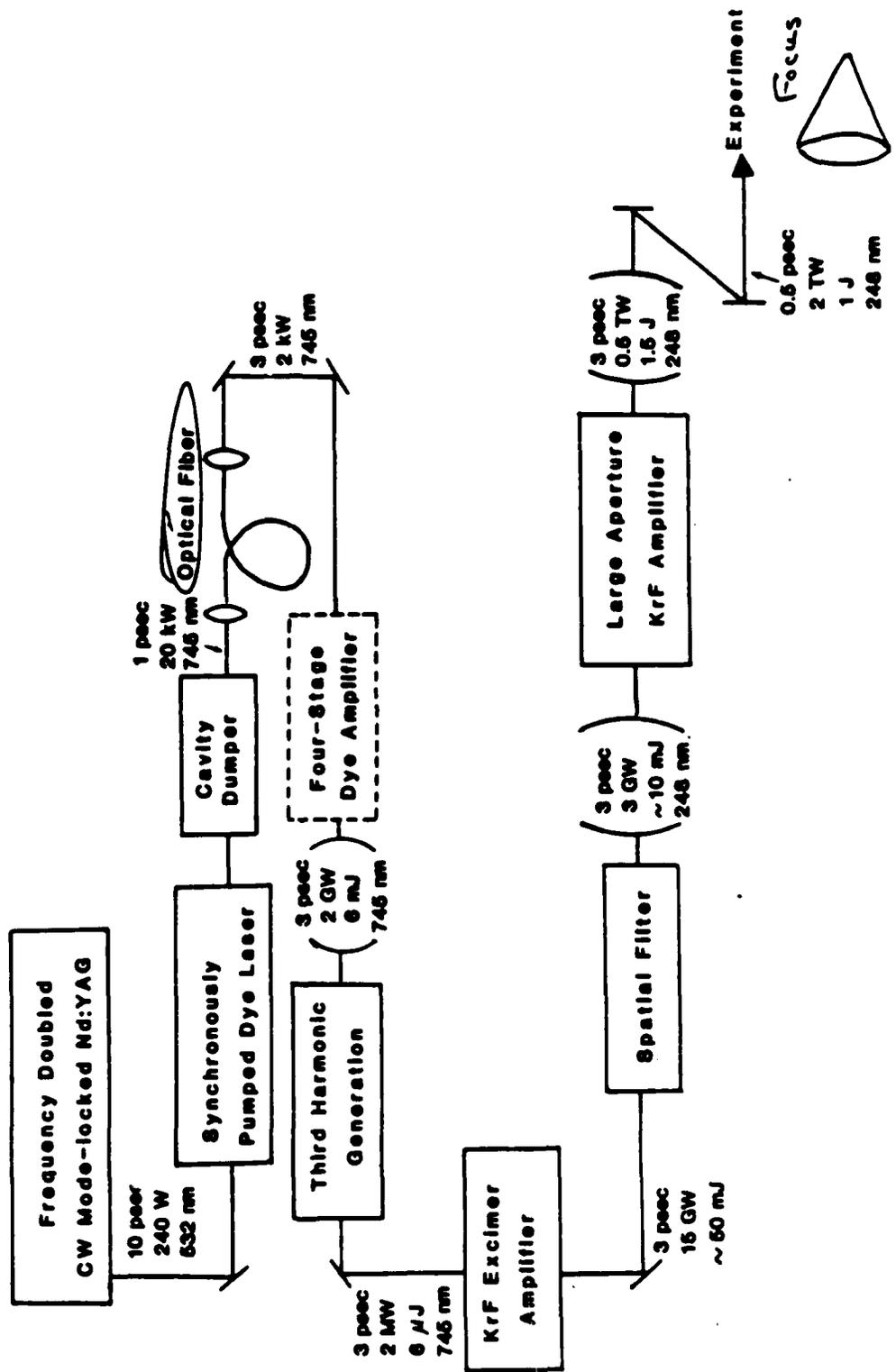
$$\sim 6 \times 10^{13} \times 10^{-15}$$

$$P \sim 6 \times 10^{-2}$$

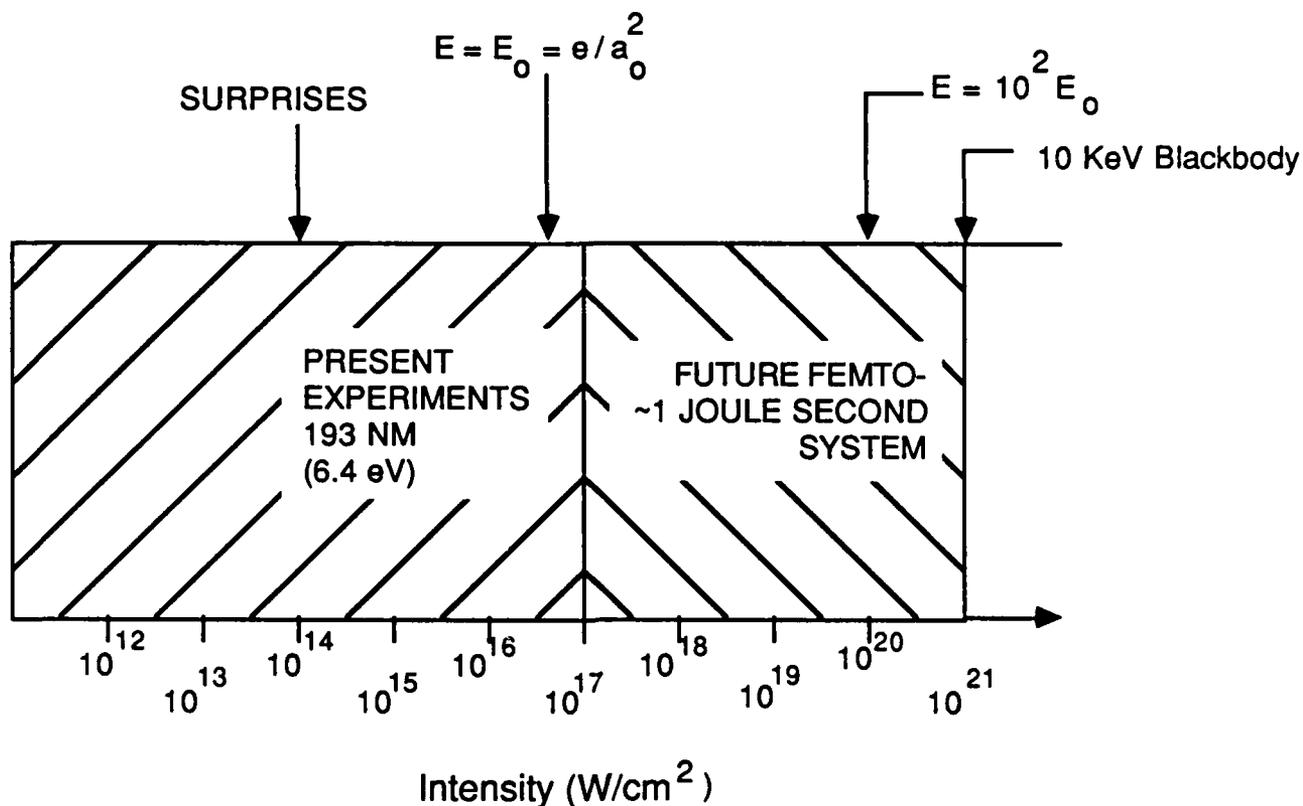
significant prob.



SUBPICOSECOND KrF - LASER SYSTEM



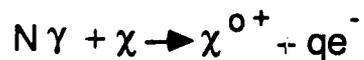
EXPERIMENTAL PARAMETERS AND MEASUREMENTS



- MEASUREMENTS

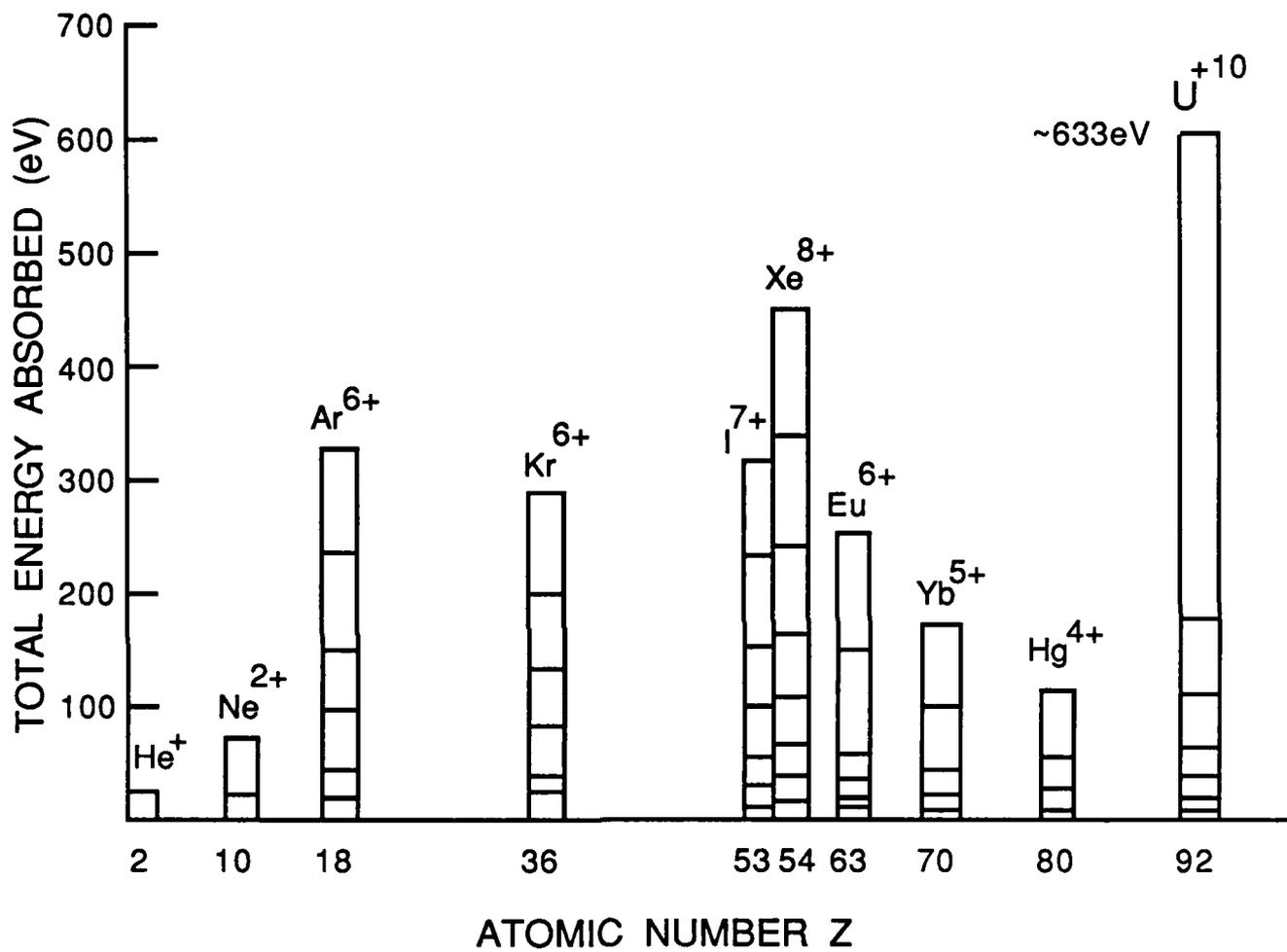
- $E \sim E_0 = e/a_0^2$ to $E \gg E_0$ (future)

- Ion Charge State Spectra

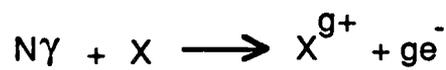


- Photoelectron Energy Spectra (qe^-)

- Scattered Radiation (γ)



$$\leq 10^{14} \text{ W/cm}^2 \quad \lambda = 193 \text{ nm}$$



$$N \leq 99$$

$$q \leq 10$$

Gamma Ray Laser Concept

Motivation:

Energy storage density – strategic potential

Unique physics associated with graser concepts

Doppler recoil broadening

Recoilless transitions – Mössbauer transitions

Comments: Tuning and Stimulation of Nuc. Rad.

Anti-Stokes Raman upconversion from exc. nuclear states

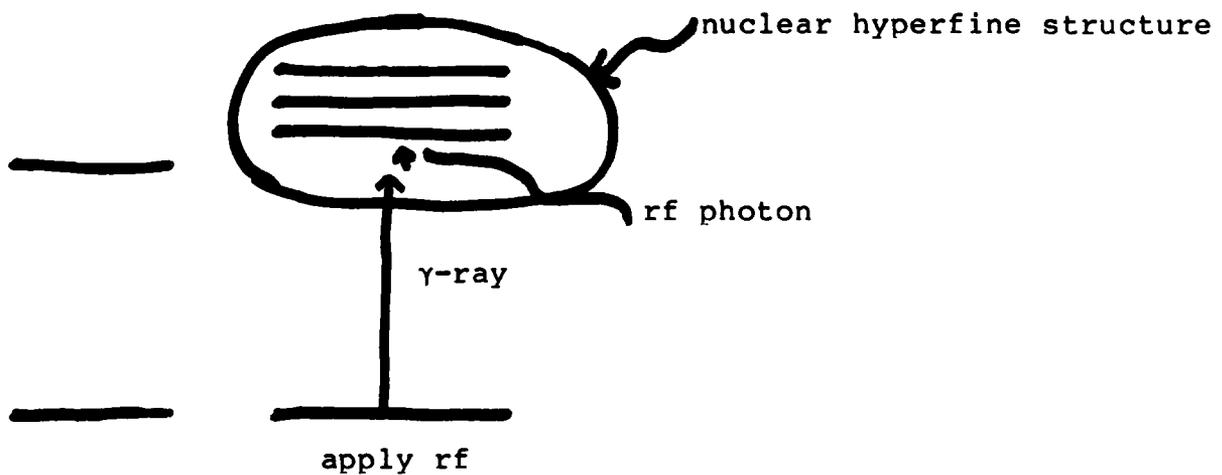
Recoil Energy $\Delta E = \frac{(h\nu)^2}{2mc^2}$

Require level width $\gg \Delta E$

True for optical photons

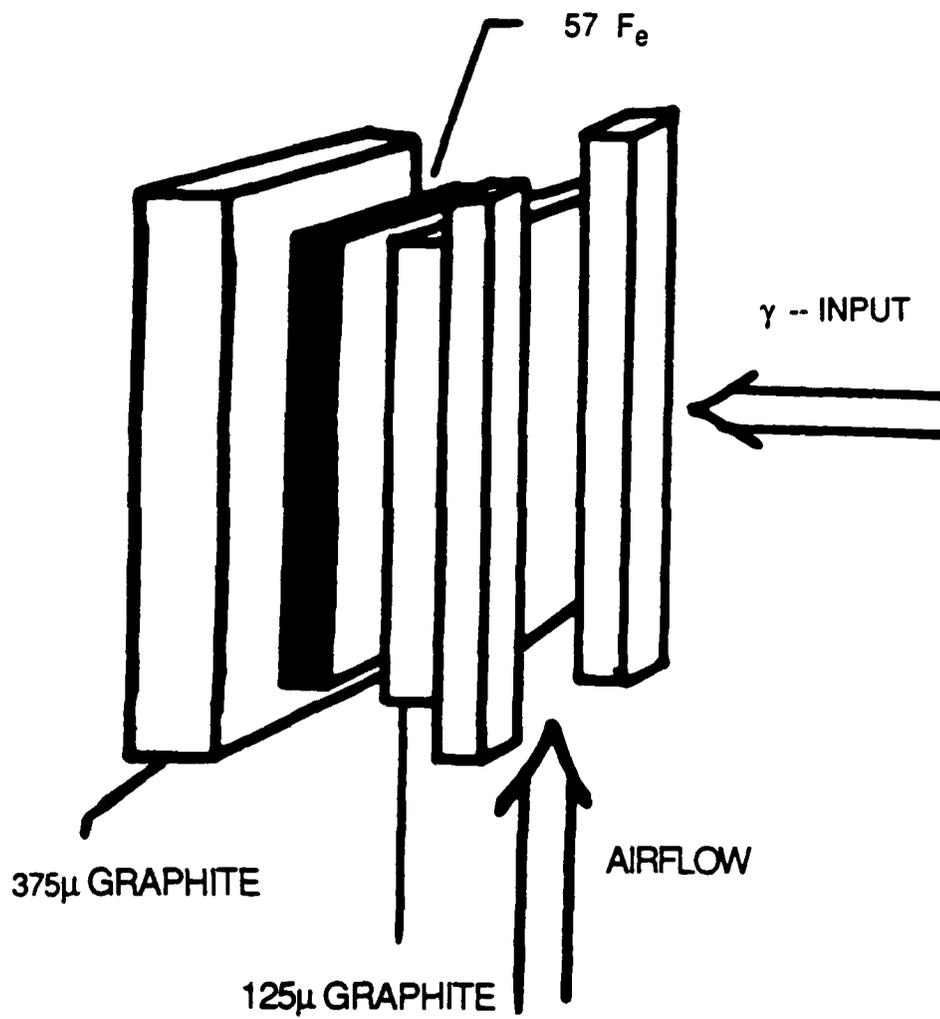
Gen. not true for γ -ray em.

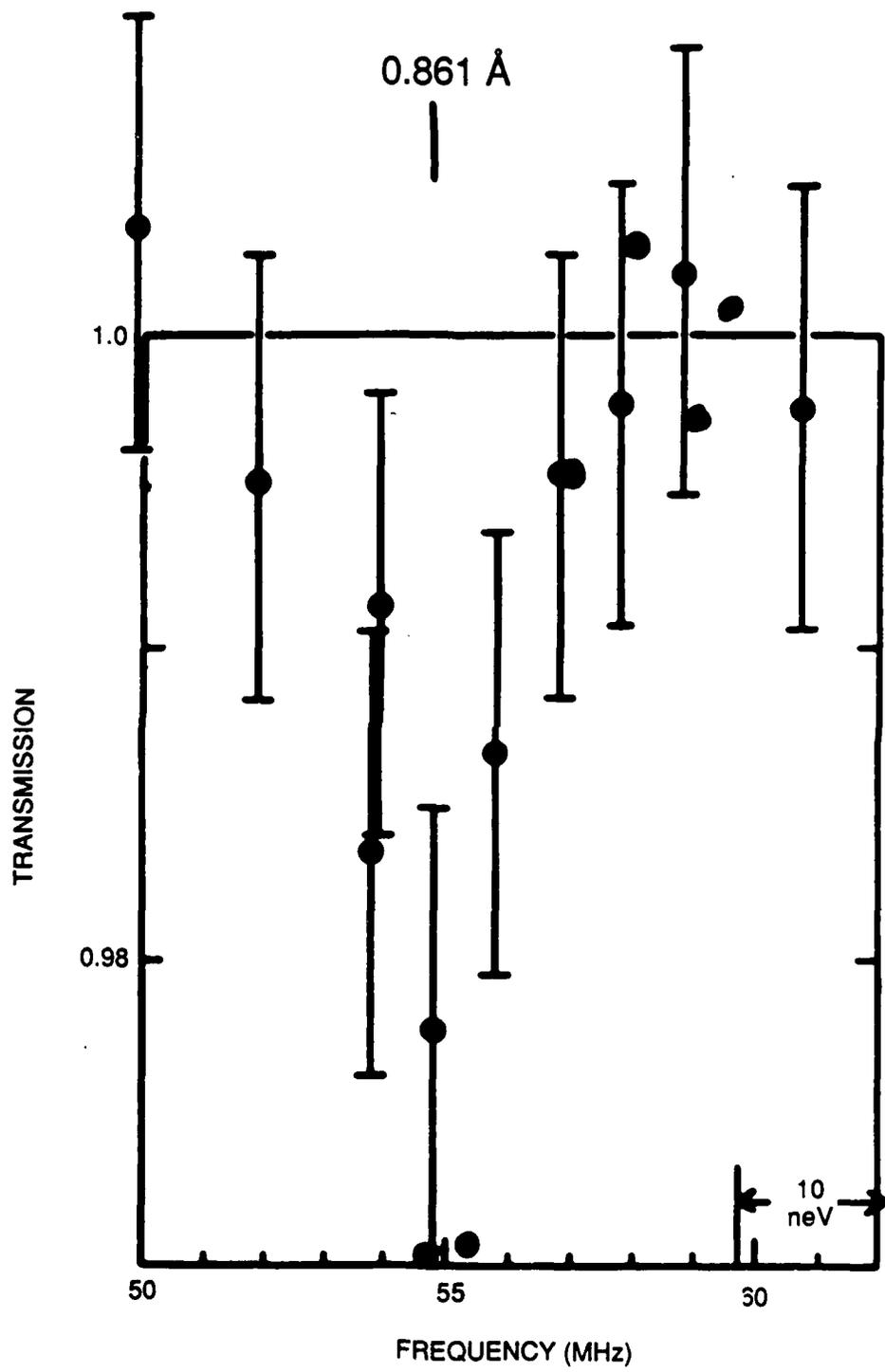
Mössbauer Effect

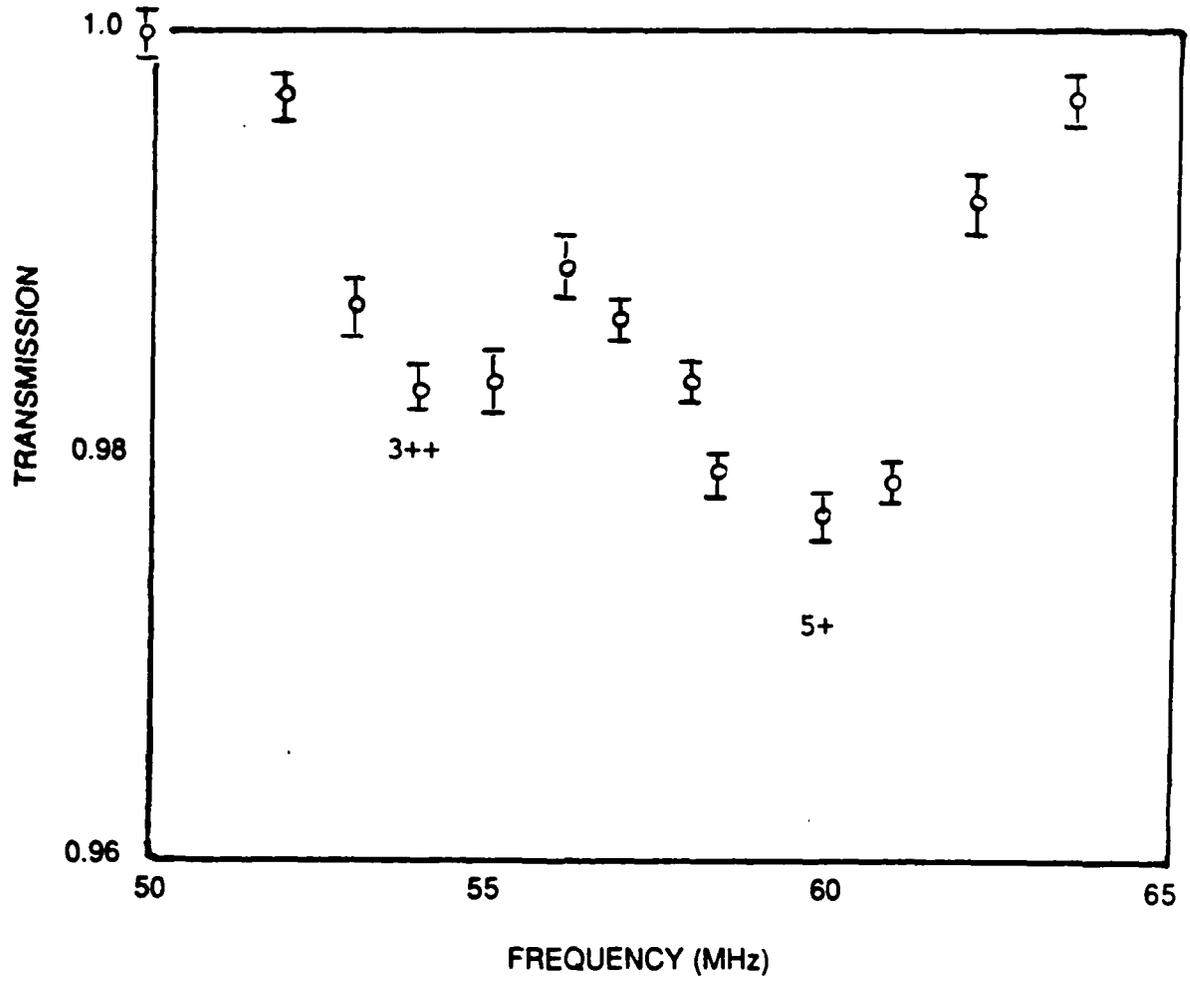


Measure Mössbauer sidebands

Non-mechanical Mössbauer spectroscopy!!!







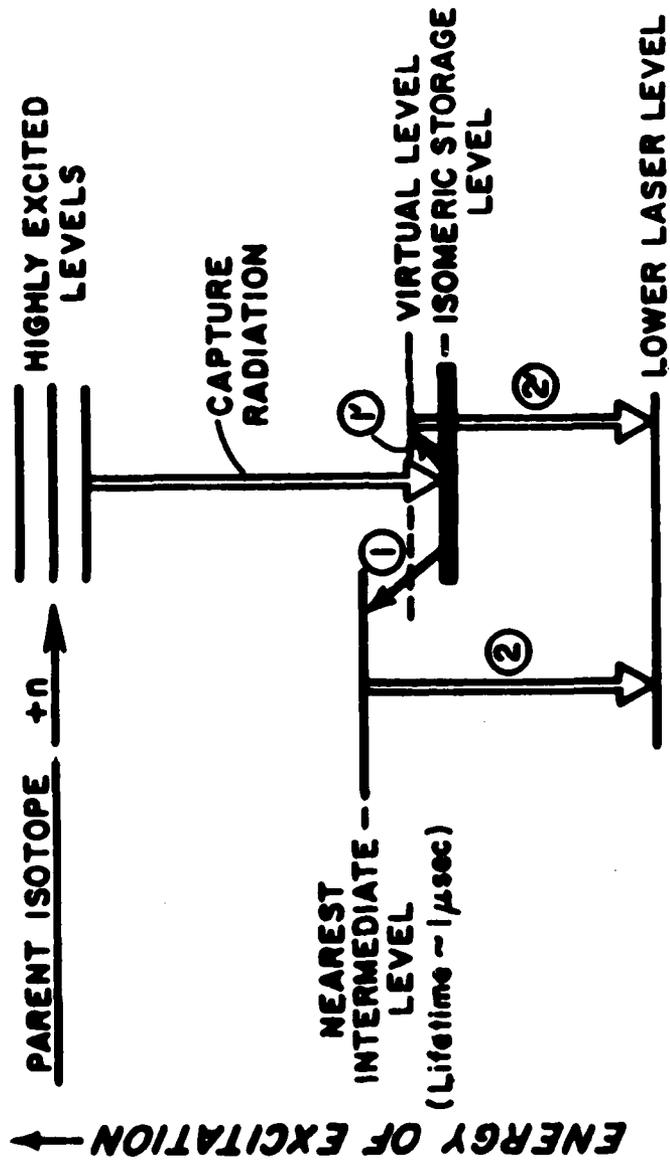
Non-mech. Mössbauer Spectroscopy

Demonstrated rf sidebands of Fe 57

Potential for extending Mössbauer spectroscopy
over much larger tuning range

Application to potential graser concepts

Nuclear Quantum Electronics



Graser Feasibility

Critical Data Needed

Non-resonant Upconversion

1. Location of nearly resonant intermediate states invisible to current nuclear spectroscopy

Resonant Upconversion

2. Energies, lifetimes and branching ratios of gamma transitions involving isomeric states too poorly characterized to screen candidate materials

APPENDIX J
SHORT-WAVELENGTH CHEMICAL LASERS

Dr. C.R. Jones, LANL

Short-Wavelength Chemical Lasers
C.R. Jones (505) 667-0402

Because of their minimal electrical power requirements, chemical lasers are very attractive space-based laser weapon candidates. However, the mid-infrared output wavelengths obtained from current devices necessitate the use of very large optics for concentrating output energy on target. The objective of this program is to obviate this disadvantage by performing the research and innovative technology development necessary for the realization of chemical lasers that emit at visible and/or near-ultraviolet wavelengths.

The program's primary emphasis is to find innovative techniques for efficient, selective, direct generation of electronically excited atomic and molecular states through chemical reactions, and to understand the kinetic processes that influence excited specie populations (e.g., intra- and inter-molecular energy transfer, collisional quenching/relaxation, and radiative decay). Innovative and potentially workable hybrid chemical approaches, in which there is an intermediate optical or electrical step, are not ruled out. Parallel, closely coordinated theoretical and experimental efforts are anticipated.

**SHORT-WAVELENGTH
CHEMICAL LASERS**

FOR

SDI

AD-A163 403

REPORT OF THE AD HOC COMMITTEE ON THE POTENTIAL
BENEFITS TO US INDUSTRY F (U) INSTITUTE FOR DEFENSE
ANALYSES ALEXANDRIA VA B BALKO NOV 85 IDA-M-110

3/3

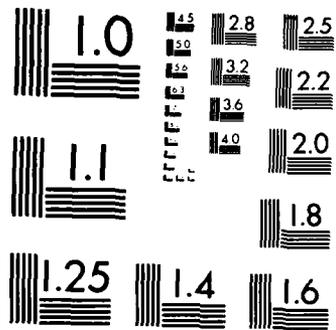
UNCLASSIFIED

IDA/HQ-85-30257 NDA903-84-C-0031

F/G 15/3 1

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Excitation Means

Phase of Medium	Excitation Means			
	Optical	Electrical	Chemical	Fluid Dynamic
Gas	<u>Atomic Iodine</u> Molecular Iodine Rotational	<u>CO₂</u> <u>Excimer</u> Helium-Neon Argon Ion Copper Vapor	<u>HF/DF</u> <u>Iodine</u>	<u>Gas-Dynamic CO₂</u>
Liquid	Dye: Alcohol Nd: Liquid	—	—	—
Solid	Nd: YAG <u>Nd: Glass</u> Cr: Crystals Color Center Transition Metal	Semiconductor	—	—
Vacuum	—	Free Electron	—	—

Code: High Pulse Energies, High Average Powers

HIGH-POWER GAS LASERS



ANTARES IS WORLD'S HIGHEST ENERGY GAS LASER



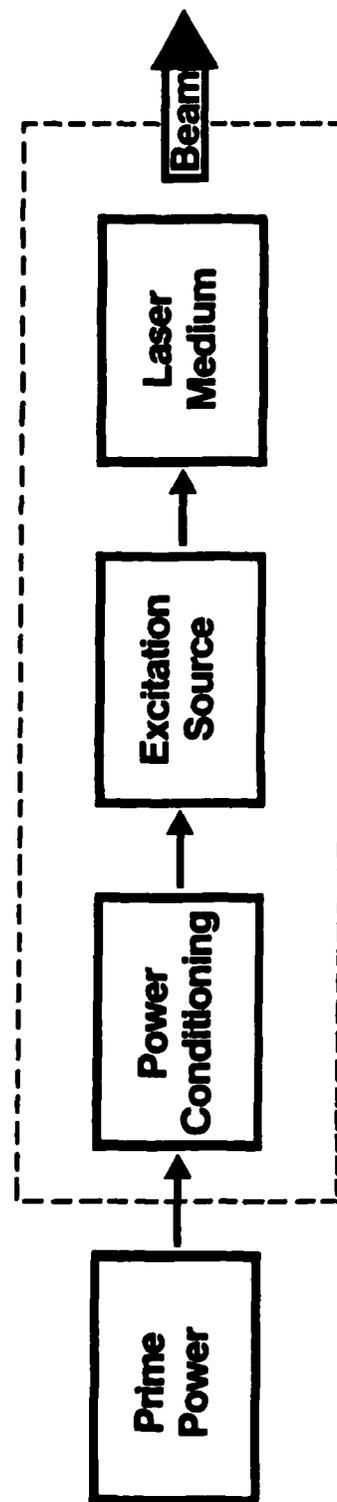
LAM IS WORLD'S HIGHEST ENERGY EXCIMER LASER



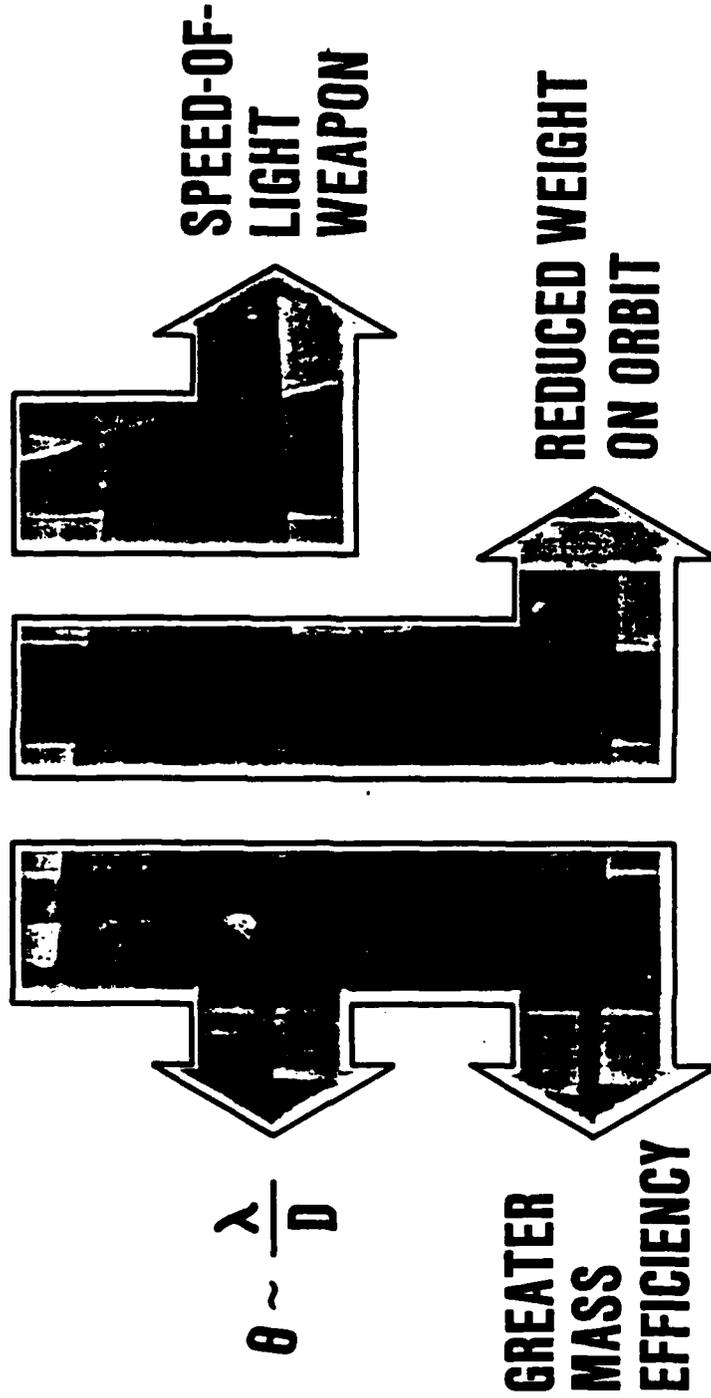
HIGH AVERAGE POWER EXCIMER LASER



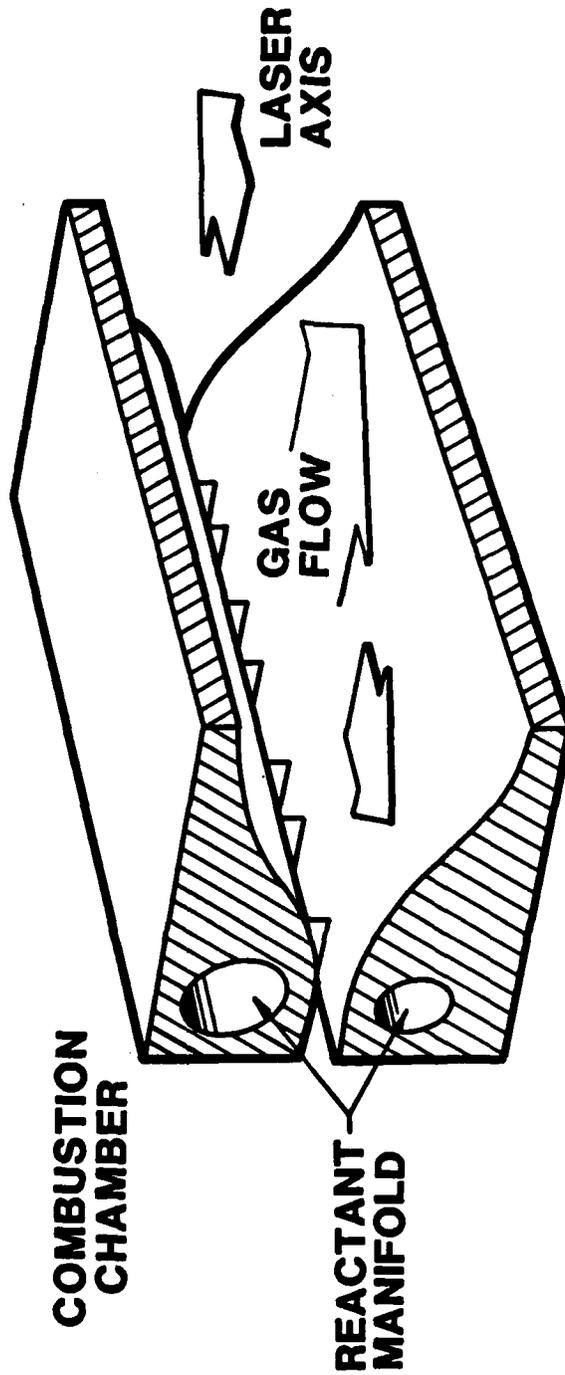
POWER FLOW DIAGRAM FOR ELECTRICALLY DRIVEN LASER SYSTEMS



WHY VISIBLE CHEMICAL LASERS?



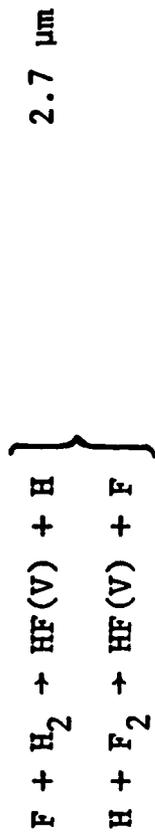
FLOW IN CHEMICAL LASER NOZZLE



PURELY CHEMICAL LASERS

BASIC REACTION

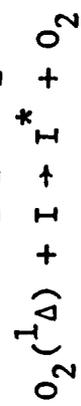
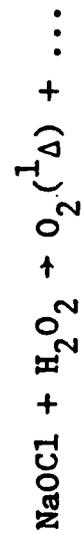
λ



3.7



5.0



1.3

CHEMILUMINESCENT REACTIONS

<u>REACTION</u>	<u>PHOTON EFFICIENCY</u>
$\text{Sm} + \text{F}_2 \rightarrow \text{SmF}^* + \text{F}$	70%
$\text{Sm} + \text{N}_2\text{O} \rightarrow \text{SmO}^* + \text{O}$	40%
$\text{Ba} + \text{N}_2\text{O} \rightarrow \text{BaO}^* + \text{N}_2$	30%
$\text{Na}_2 + \text{Cl} \rightarrow \text{Na}^* + \text{NaCl}$	100%

RULES FOR A GOOD VIS CHEM LASER

- HIGH MASS EFFICIENCY
- NEAR-UV OR VISIBLE λ
- SIMPLE REACTION SCHEMES
- MINIMAL EXTERNAL POWER
- SUITABLE REACTANTS

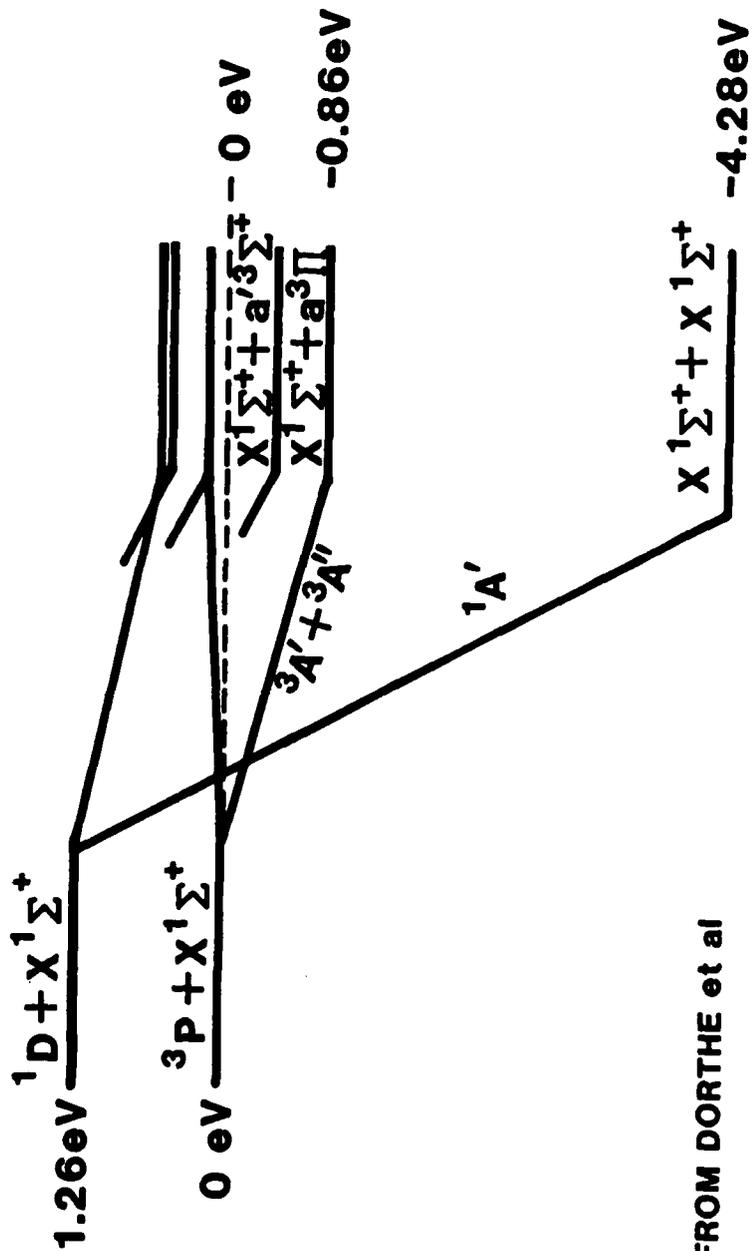
A CANDIDATE REACTION SYSTEM



o HIGH MASS EFFICIENCY

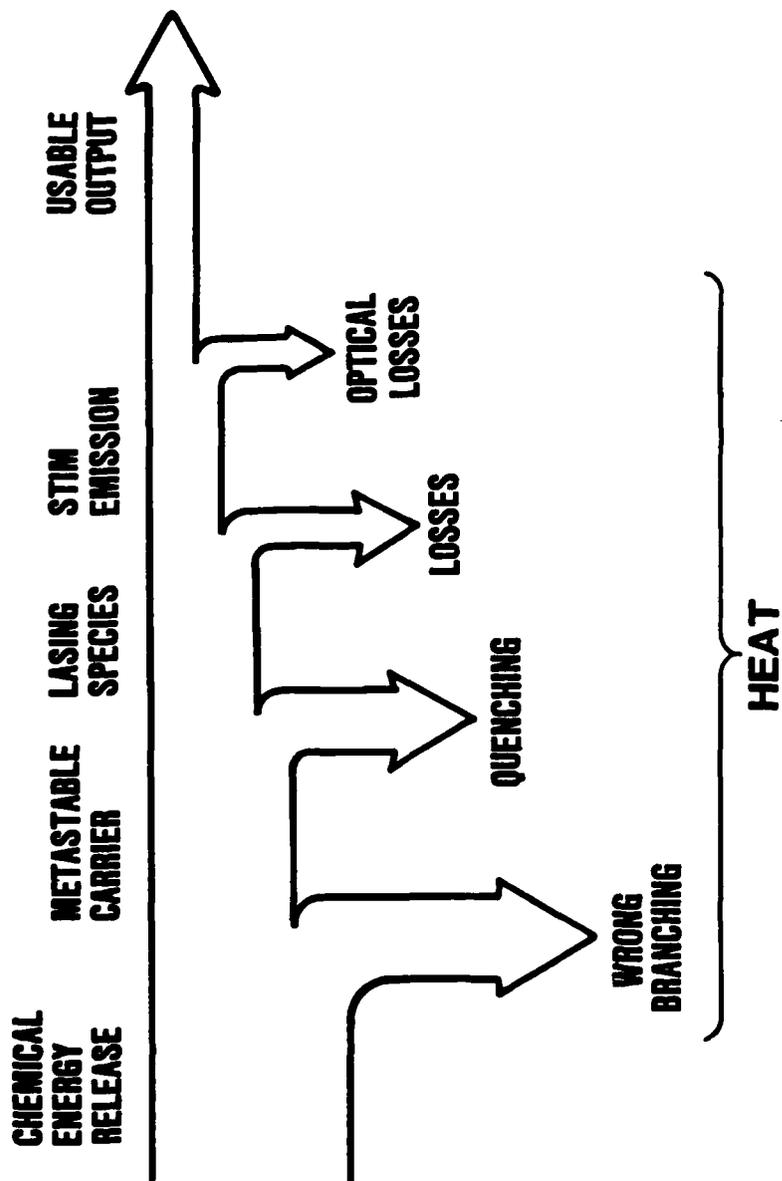
o FAIRLY SIMPLE

SYMMETRY CORRELATION DIAGRAM



FROM DORTHE et al

CHEMICAL LASER EFFICIENCIES



SWCL TASK PHILOSOPHY

- VERY DIFFICULT TECHNOLOGY
- LONG-TERM BASIC RESEARCH REQUIRED
- BROAD SCOPE, NO EARLY FOCUS
- STRESS INNOVATIVE APPROACHES
- EMPHASIZE BROAD PARTICIPATION

SWCL TASK OBJECTIVE

● CONDUCT QUALITY RESEARCH LEADING TO

SWCL DEVELOPMENT

● VIABLE SDIO BEAM WEAPON CONCEPTS

SWCL TECHNICAL APPROACHES

- DIRECT CHEMICAL PRODUCTION OF LASING SPECIES
- CHEMICAL PRODUCTION OF TRANSFER AGENT
- NEW AND INNOVATIVE SCHEMES
- HYBRID APPROACHES NOT RULED OUT

CANDIDATE TOPICS

- HIGH-EXPLOSIVE PUMPED CONCEPTS
- BASIC CHEMICAL REACTION STUDIES
- V-E PUMPING
- DIOXETANE DECOMPOSITION
- PUMPING VIA ENERGY-POOLING OF METASTABLES
- HETEROGENEOUS REACTIONS

PROCUREMENT STRATEGY

- LANL IS AGENT FOR SDIO/IST
- FIRST CONTRACTS GENERATED BY RFP PROCESS
- ALL-GOVERNMENT EVALUATION TEAM
- ANTICIPATE MOSTLY MULTI-YEAR AWARDS
- ATTEMPT SEVERAL NEW STARTS EACH YEAR
- USE PRDA PROCESS BEYOND FIRST ROUND

POSSIBLE COMMERCIAL APPLICATIONS

- VERY HIGH-POWER REQUIREMENTS
- LOCATIONS OF HIGH TRANSPORTATION COSTS

APPENDIX K

FREE ELECTRON LASERS

Dr. Dwight Duston, SDIO/IST

(Material scheduled for presentation but not presented at workshop)

Free-Electron Laser Technology
Dwight Duston (202) 653-0029

As a directed energy concept, the free-electron laser is being studied by the SDIO as both a ground-based directed energy weapon and a space-based active discrimination device. The purposes of this program are the following:

- To develop high-voltage-gradient accelerator structures for use in Free Electron Lasers (FEL) using superconducting components;
- To investigate advanced injector techniques for use with RF linear accelerators to increase electron beam quality, peak current, and overall efficiency when incorporated into FEL devices;
- To explore novel energy and electron beam recovery techniques for use in high voltage RF linear accelerators to increase FEL system efficiency;
- To investigate innovative wiggler concepts to reduce the operational energy required in the electron beam to achieve visible radiation from an FEL;
- To develop novel resonator configurations to reduce the physical size of these structures; and
- To investigate operation of an FEL using higher harmonics to reduce the electron beam energy required for operation at visible wavelengths.

SDIO/IST FREE ELECTRON LASER/MEDICAL/MATERIALS PROGRAM

The free electron laser (FEL) is a relatively new source of coherent photons which, because of the physical mechanisms involved, may be a high-brightness tunable source of light. In some ways this is an attractive research tool for biological and medical researchers who have long sought a tunable laser source in the infrared-visible region with the high intensity that the FEL promises. The SDIO/IST Office has been given the responsibility to sponsor research in FEL applications in the medical and materials sciences which spans a wide spectrum of areas.

The medical facets of the program will be divided into three main areas: (1) cellular biology, (2) surgical and other clinical applications, and (3) FEL biological hazards. The goal of the program is, first, to conduct experiments with existing laser light sources which can mimic the high-intensity, short pulse structure typical of FEL's. In this way, we hope to better predict the interaction physics which may dominate in actual FEL-matter studies. This will allow us to better design the type of FEL which will be needed in the continuing research program.

Second, the understanding gained through the early experimentation with both existing and FEL sources on the photon-cell interactions at these intensities will direct the clinical and surgical efforts. In this way, the early basic research at the cell level will hopefully lead to valuable applications with human subjects, presumably in the areas of advanced surgical techniques, novel cancer treatment, etc.

Concurrent with the other program, studies will be conducted to quantify the dangers of FEL radiation to both laboratory and field personnel. As a tool with both military and research applications, it is a necessity that guidelines for exposure and possible damage levels be determined, to adequately protect those involved with FEL's.



FREE ELECTRON LASERS

OBJECTIVE:

- INCREASED FEL EFFICIENCY & BEAM QUALITY
- THRUST TOWARD SHORTER WAVELENGTH (UV)
- REDUCTION IN SYSTEM SIZE & OPERATIONAL ENERGY

APPROACH:

- DEVELOP HIGH VOLTAGE-GRADIENT ACCELERATOR STRUCTURES
- INVESTIGATE ADVANCED INJECTOR TECHNIQUES FOR R-F LINACS
- INNOVATIVE WIGGLER CONCEPTS FOR VISIBLE OPERATION
- EXPLORE ELECTRON BEAM RECOVERY TECHNIQUES
- STUDY NOVEL RESONATOR CONFIGURATIONS



FREE ELECTRON LASERS (CON'T)

PAYOFF:

- **COMPACT FEL SYSTEM FOR SPACE-BASED ACTIVE DISCRIMINATION ROLE**
- **ORDER OF MAGNITUDE INCREASE IN EFFICIENCY**
- **ATTAINMENT OF HIGH-POWERED OPERATION IN THE VISIBLE (OR UV) FOR STRATEGIC ROLE**

END

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