UNIVERSITY OF CALIFORNIA
LOS ALAMOS SCIENTIFIC LABORATORY
(CONTRACT W-7405-ENG-36)
P. O. Box 1663
LOS ALAMOS, NEW MEXICO 87544

IN REPLY REFER TO: SPO-849
MAIL STOP: 120

February 27, 1976



Division of Research Grants
National Institutes of Health
Bethesda, Maryland 20014

Gentlemen:

Enclosed please find a proposal (original plus 6 copies, LASL #P-604) prepared by the University of California, Los Alamos Scientific Laboratory. We propose to perform theoretical, numerical calculations of the dose-distribution of highly-ionizing particle beams in human patients. The results derived will be those immediately required in on-going experimental programs of pre-clinical radiation therapy. We wish to emphasize the recognized need for the results in experimental programs. We request that the National Cancer Institute consider supporting our proposal.

The proposal is offered to the NIH/NCI at this time with the following understandings.

A. The work would be a collaborative effort performed by the U of C, Los Alamos Scientific Laboratory, the Oak Ridge National Laboratory, the University of New Mexico, and Science Applications, Inc. The Los Alamos Scientific Laboratory of the U of C would provide the principal investigator, and generally direct the work. The U of C would also make the necessary contractual and/or financial arrangements with the other participating institutions and organizations to support the work with funds provided to the U of C by the NCI.

B. The Los Alamos Scientific Laboratory and the Oak Ridge National Laboratory are U.S. government-owned facilities of the USERDA. Work in these Laboratories can be undertaken only at the discretion of ERDA, and under the terms and conditions of contracts between the facility operating contractors (e.g., the U of C at Los Alamos) and the ERDA. We have submitted the enclosed proposal to the ERDA, and reasonably anticipate that it will be favorably endorsed. Meanwhile, we hope that receipt of the proposal at this time in advance of the March 1 deadline will permit you to include it in the next review cycle.

We do not yet have endorsements signed by appropriate officials of the participating institutions other than the U of C, but we are assured that same will soon be provided, and we will forward them to your office.

Thank you very much for your consideration of our proposal. We hope you will be able to forward it to the NCI for further consideration. We have discussed this subject informally with Dr. C. Herman of the NCI.

If we can provide further information of interest in connection with the enclosed, we would be pleased to do so.

Sincerely,

A. D. McGuire

A. D. McGuire
Special Projects Officer

ADM:rb
Enc: Proposal LASL #P-604 (original and 6 copies)
cc: J. F. Dicello, LASL MP-3, w/o enc. MS 844
SPO, w/o enc.
ISD-5, w/enc.

Form Approved
O.M.B. 68-R0249

SECTION 1

DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

# GRANT APPLICATION

| LEAVE BLANK | | |
|---|---|---|
| TYPE | PROGRAM | NUMBER |
| REVIEW GROUP | | FORMERLY |
| COUNCIL *(Month, Year)* | | DATE RECEIVED |

TO BE COMPLETED BY PRINCIPAL INVESTIGATOR *(Items 1 through 7 and 15A)*

1. TITLE OF PROPOSAL *(Do not exceed 53 typewriter spaces)*
CALCULATIONS NEEDED IN PION AND HIGH LET RADIOTHERAPY

2. PRINCIPAL INVESTIGATOR

2A. NAME *(Last, First, Initial)*
Dicello, John F.

2B. TITLE OF POSITION
Staff Member, Los Alamos Scientific Lab.,
University of California

2C. MAILING ADDRESS *(Street, City, State, Zip Code)*
Group MP-3, MS 844
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

2D. DEGREE
Ph.D.

2E. [redacted] NO.
[redacted]

2F. TELEPHONE DATA — Area Code: 505 — TELEPHONE NUMBER AND EXTENSION: 667-4274

2G. DEPARTMENT, SERVICE, LABORATORY OR EQUIVALENT *(See Instructions)* Medium Energy Physics Division
(Practical Applications Group)

2H. MAJOR SUBDIVISION *(See Instructions)*
Los Alamos Scientific Laboratory

3. DATES OF ENTIRE PROPOSED PROJECT PERIOD *(This application)*
FROM: 1 Sept 1976 — THROUGH: 31 Aug 1979

4. TOTAL DIRECT COSTS REQUESTED FOR PERIOD IN ITEM 3
$739,200

5. DIRECT COSTS REQUESTED FOR FIRST 12-MONTH PERIOD
$228,400

6. PERFORMANCE SITE(S) *(See Instructions)*
a. University of California
Los Alamos Scientific Laboratory
Los Alamos, NM 87545
b. Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830
c. Science Applications, Inc.
1200 Prospect Street
La Jolla, CA 92037
d. Cancer Research and Treatment Center
University of New Mexico
100 Camino de Saud, N.E.
Albuquerque, NM 87131

00133014
FILE BARCODE

7. Research Involving Human Subjects *(See Instructions)*
A. [X] NO B. [ ] YES Approved: ______ Date
C. [ ] YES – Pending Review

8. Inventions *(Renewal Applicants Only - See Instructions)*
A. [ ] NO B. [ ] YES – Not previously reported NA
C. [ ] YES – Previously reported

TO BE COMPLETED BY RESPONSIBLE ADMINISTRATIVE AUTHORITY *(Items 8 through 13 and 15B)*

9. APPLICANT ORGANIZATION(S) *(See Instructions)*
The Regents of the University of
California
o/c Director, Los Alamos Scientific
Laboratory
Los Alamos, NM 87545

10. NAME, TITLE, AND TELEPHONE NUMBER OF OFFICIAL(S) SIGNING FOR APPLICANT ORGANIZATION(S)
Dr. Harold M. Agnew
Director
Los Alamos Scientific Laboratory
Telephone Number (s) (505) 667-5101

11. TYPE OF ORGANIZATION *(Check applicable item)*
[ ] FEDERAL [X] STATE [ ] LOCAL [ ] OTHER *(Specify)*

12. NAME, TITLE, ADDRESS, AND TELEPHONE NUMBER OF OFFICIAL IN BUSINESS OFFICE WHO SHOULD ALSO BE NOTIFIED IF AN AWARD IS MADE
A. D. McGuire
Special Projects Office
Los Alamos Scientific Laboratory
Los Alamos, NM 87545
Telephone Number (505) 667-5136

13. IDENTIFY ORGANIZATIONAL COMPONENT TO RECEIVE CREDIT FOR INSTITUTIONAL GRANT PURPOSES *(See Instructions)*
Los Alamos Scientific Laboratory

14. ENTITY NUMBER (Formerly PHS Account Number)
Vendor No. 72-1483

15. CERTIFICATION AND ACCEPTANCE. We, the undersigned, certify that the statements herein are true and complete to the best of our knowledge and accept, as to any grant awarded, the obligation to comply with Public Health Service terms and conditions in effect at the time of the award.

| SIGNATURES (Signatures required on original copy only. *Use ink, "Per" signatures not acceptable*) | | DATE |
|---|---|---|
| | A. SIGNATURE OF PERSON NAMED IN ITEM 2A | DATE |
| | B. SIGNATURE(S) OF PERSON(S) NAMED IN ITEM 10 — Harold M. Agnew | 2/26/76 |

NIH 398 (FORMERLY PHS 398)
Rev. 1/73

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LASL #P-604

1091747

SECTION 1

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

# RESEARCH OBJECTIVES

LEAVE BLANK

PROJECT NUMBER

NAME AND ADDRESS OF APPLICANT ORGANIZATION

The Regents of the University of California, Los Alamos Scientific Laboratory
Los Alamos, NM 87545

NAME, SOCIAL SECURITY NUMBER, OFFICIAL TITLE, AND DEPARTMENT OF ALL PROFESSIONAL PERSONNEL ENGAGED ON PROJECT, BEGINNING WITH PRINCIPAL INVESTIGATOR

John F. Dicello, [redacted] Staff Member, Group MP-3, Los Alamos Scientific Laboratory

TITLE OF PROJECT

CALCULATIONS NEEDED IN PION AND HIGH LET RADIOTHERAPY

USE THIS SPACE TO ABSTRACT YOUR PROPOSED RESEARCH. OUTLINE OBJECTIVES AND METHODS. UNDERSCORE THE KEY WORDS (NOT TO EXCEED 10) IN YOUR ABSTRACT.

Detailed calculations are proposed as part of a coordinated theroretical-experimenta effort associated with preclinical investigations of negative pion beams for radiotherapy It is intended that these calculations provide information which cannot be obtained experimentally without considerably more difficulty or cost. These calculations would utilize existing computer codes to contribute toward 1) the reduction of the total amount of experimental effort needed for the investigation of high LET radiations in therapy, 2) the development of broad beams appropriate for patient treatment, 3) the development of appropriate collimators, wedge filters, and boluses, 4) precise and accurate dosimetry and biology, 5) precise and accurate treatment planning, and 6) a bett understanding of the preclinical and clinical results.

LEAVE BLANK

SECTION II – PRIVILEGED COMMUNICATION

## DETAILED BUDGET FOR FIRST 12-MONTH PERIOD

| FROM | THROUGH |
|---|---|
| Sept 1, 1976 | Aug 31, 1977 |

| PERSONNEL NAME | TITLE OF POSITION | TIME OR EFFORT %/HRS. | SALARY | FRINGE BENEFITS | TOTAL |
|---|---|---|---|---|---|
| LASL-J. F. Dicello | PRINCIPAL INVESTIGATOR | 50 | | | 17,700 |
| -C. Richman | Staff Member | 0 | | | |
| ORNL* | | | SEE REMARK NO. 4, P. 4 | | |
| -B. L. Bishop | Computer Analyst | 100 | | | |
| R. H. Hamm | Staff Member | 25 | | | |
| J. E. Turner | Associate Director, ORNL | 0 | | | |
| H. A. Wright | Section Chief | 25 | | | |
| SAI**T. W. Armstrong | Staff Scientist | 50 | | | |
| B. L. Colborn | Sr. Computer Programmer | 100 | | | |
| UNM***M. M. Kligerman | Dir., Cancer Res & TreatCr | 0 | | | |
| C. A. Kelsey | Chief, Biomedical Physics | 10 | | | |
| A. Smith | Radiation Physicist | 0 | | | |

| DESCRIPTION (itemize) | TOTAL |
|---|---|
| CONSULTANT COSTS R. A. Katz, U. of Nebraska @ $150/day plus travel and consultants from other pion and high LET facilities @ $150/day plus travel | 5,000 |
| EQUIPMENT | |
| SUPPLIES | |
| TRAVEL – DOMESTIC | 2,500 |
| TRAVEL – FOREIGN | |
| PATIENT COSTS (See instructions) | |
| ALTERATIONS AND RENOVATIONS | |
| OTHER EXPENSES (itemize) Computer Use (at LASL) | 2,000 |
| *Purchase Order for Oak Ridge National Laboratory Participation | 90,000 |
| **Subcontract for Science Applications, Inc. participation | 105,000 |
| ***Purchase Order for University of New Mexico participation | 6,200 |
| NOTE: ITEMIZATION OF OTHER EXPENSES AS TO PERSONNEL, COMPUTER USE, INDIRECT, ETC. TO BE PROVIDED | |
| TOTAL DIRECT COST (Enter on Page 1, Item 5) → | |

INDIRECT COST (See Instructions)

53 % S&W*

_____ % TDC*

DATE OF DHEW AGREEMENT:

☐ WAIVED

☐ UNDER NEGOTIATION WITH:

*IF THIS IS A SPECIAL RATE (e.g. off-site), SO INDICATE.

SECTION II – PRIVILEGED COMMUNICATION

**BUDGET ESTIMATES FOR ALL YEARS OF SUPPORT REQUESTED FROM PUBLIC HEALTH SERVICE**
**DIRECT COSTS ONLY (Omit Cents)**

| DESCRIPTION | | 1ST PERIOD (SAME AS DETAILED BUDGET) | ADDITIONAL YEARS SUPPORT REQUESTED (This application only) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2ND YEAR | 3RD YEAR | 4TH YEAR | 5TH YEAR | 6TH YEAR | 7TH YEAR |
| PERSONNEL COSTS | | 17,700 | 19,100 | 21,000 | | | | |
| CONSULTANT COSTS (Include fees, travel, etc.) | | 5,000 | 5,400 | 5,800 | | | | |
| EQUIPMENT | | | | | | | | |
| SUPPLIES | | | | | | | | |
| TRAVEL | DOMESTIC | 2,500 | 2,700 | 2,900 | | | | |
| | FOREIGN | | | | | | | |
| PATIENT COSTS | | | | | | | | |
| ALTERATIONS AND RENOVATIONS | | | | | | | | |
| OTHER EXPENSES | | 203,200 | 218,600 | 235,300 | | | | |
| TOTAL DIRECT COSTS | | 228,400 | 245,800 | 265,000 | | | | |
| TOTAL FOR ENTIRE PROPOSED PROJECT PERIOD (Enter on Page 1, Item 4) → | | | | | | $ 739,200 | | |

REMARKS: *Justify all costs for the first year for which the need may not be obvious. For future years, justify equipment costs, as well as any significant increases in any other category. If a recurring annual increase in personnel costs is requested, give percentage. (Use continuation page if needed.)*

1) The work done by Scientific Applications, Inc. will be done under a subcontract and is listed under "Other Expenses".
2) The work done by the Oak Ridge National Laboratory and the University of New Mexico will be done through a purchase order and is listed under "Other Expenses".
3) Itemization of other expenses as to personnel, computer use, indirect, etc., to be provided.
4) Personnel costs, excluding LASL, are included in entry under "Other Expenses".

SECTION II – PRIVILEGED COMMUNICATION

## BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| John F. Dicello | Staff Member | [redacted] |
| **PLACE OF BIRTH (City, State, Country)** | **PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date)** | **SEX** |
| [redacted] | US | [X] Male [ ] Female |

**EDUCATION** *(Begin with baccalaureate training and include postdoctoral)*

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | B.S.<br>M.S.<br>Ph.D. | [redacted] | Physics<br>Physics<br>Physics |

**HONORS** One of "ten young physicists" funded by the American College of Radiology to partipat in 1972 Conference on Particle Accelerators in Radiation Therapy because of "past accomplis ments, recommendations of other people in the physics community and because of probable interest and potential future contributions to problems of particle accelerators in radiation therapy.

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Medical Physics | Principal Investigator |

**RESEARCH SUPPORT** *(See instructions)*

**RESEARCH AND/OR PROFESSIONAL EXPERIENCE** *(Starting with present position, list training and experience relevant to area of project. List all or most representative publications. Do not exceed 3 pages for each individual.)*

1973 to Present – UNIVERSITY OF CALIFORNIA, LOS ALAMOS SCIENTIFIC LABORATORY: Medical physics, dosimetry, microdosimetry, biology, and patient treatment associated with the application of negative pions to radiotherapy.

1967-1973 – [redacted] Department of Radiology, Research Associate

1971-1972 – [redacted] Visiting Researcher

1969-1972 – [redacted] Medical Department, Research Collaborator

[redacted] – LOS ALAMOS SCIENTIFIC LABORATORY, [redacted]

1962-1963 – [redacted] Department of Physics, Instructor

Publications – See attached listing

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## REPRESENTATIVE PUBLICATIONS

J. F. Dicello, "Review of Pion Dosimetry," review paper requested by Medical Physics, in preparation.

H. I. Amols, J. N. Bradbury, J. F. Dicello, J. A. Helland, T. F. Lane, M. A. Paciotti, D. L. Roeder, and M. E. Schillaci, "Determination of Whole Body Dose for Patients Irradiated with Pions." In preparation.

J. F. Dicello, "Dosimetry of Pion Beams," Proceedings of the International Particle Radiation Therapy Workshop. In press.

H. I. Amols, J. F. Dicello, and T. F. Lane, "Microdosimetry of Negative Pions," Proceedings of the Fifth Symposium on Microdosimetry. In press.

M. M. Kligerman, G. West, J. F. Dicello, C. J. Sternhagen, J. E. Barnes, K. Loeffler, F. Dobrowolski, H. T. Davis, J. N. Bradbury, T. F. Lane, D. F. Petersen, E. A. Knapp, "Initial Comparative Response to Peak Pions and X-Rays of Normal Skin and Underlying Tissue Surrounding Superficial Metastatic Nodules," Presented at 57th Annual Meeting of American Radium Society, San Juan, Puerto Rico, May 4-9, 1975. Amer. J. Roent. Rad. Ther. Nucl. Med., in press.

J. F. Dicello, R. D. Colvelt, W. Gross, and U. Kraljevic, "Beta Emission from Encapsulated Sources of Californium-252," Radiat. Res. 74, 401-404 (1975).

M. R. Raju, J. F. Dicello, T. T. Trujillo, and M. M. Kligerman, "Biological Effects of the Los Alamos Meson Beam on Cells in Culture." Radiology 116, 191-193 (1975).

P. Todd, C. R. Shonk, G. West, M. M. Kligerman, and J. Dicello, "Spatial Distribution of Effects of Negative Pions on Cultured Human Cells." Radiology 116, 179-180, 186 (1975).

H. I. Amols, J. F. Dicello, T. Lane, G. Pfeufer, J. A. Helland, and H. B. Knowles, "Microdosimetry of Negative Pions at LAMPF." Radiology 116, 183-185 (1975).

M. M. Kligerman, J. F. Dicello, H. T. Davis, R. A. Thomas, C. A. Sternhagen, L. Gomez and D. F. Petersen, "Initial Comparative Response of Experimental Tumors to Peak Pions and X-Rays." Radiology 116, 181-182 (1975).

R. C. Rodgers, J. F. Dicello, and W. Gross, "The Biophysical Properties of 3.9-GeV Nitrogen Ions, II. Microdosimetry." Radiation Res. 54, 12 (1973).

J. F. Dicello, W. Gross, and U. Kraljevic, "Radiation Quality of Californium-252," Phys. Med. Biol. 17, 345 (1972).

J. F. Dicello, G. Igo, W. T. Leland, and F. G. Perey, "Differential Elastic Cross Sections for Protons between 10 and 22 MeV on $^{40}$Ca," Phys. Rev. C2, 4, 1130 (1971).

J. F. Dicello and G. Igo, "Proton Total Reaction Cross Sections in the 10-20-MeV Range: Calcium-40 and Carbon-12," Phys. Rev. C2, 488 (1970).

J. F. Dicello, G. Igo, and M. L. Roush, "Proton Total Reaction Cross Sections for 22 Isotopes of Ti, Fe, Ni, Cu, Zr, and Sn at 14.5 MeV," Phys. Rev. 157, 1001 (1967).

G. J. Igo, J. F. Dicello, and M. L. Roush, "Total Reaction Cross Sections for 14.5-MeV Protons from 22 Separated Isotope Targets of Ti, Fe, Ni, Cu, Zn, Zr, and Sn," International Conference of Nuclear Physics, Gatlinburg, TN (1966).

J. Dicello, G. Igo, and M. L. Roush, "The Anomalous Dip in Total Reaction Cross Sections in the Nickel Region," Phys. Letters 23, 685 (1966).

J. Dicello, J. Geiger, Z. O'Friel, and S. Sullivan, Experiments in Physics, St. Bonaventure University, 1963.

INVITED TALKS

H. Amols, M. Awschalom, J. Bradbury, T. J. Boyd, E. Bush, L. Coulson, J. Dicello, R. Faulkner, R. A. Jameson, S. Johnsen, E. A. Knapp, J. Stovall, D. A. Swenson, and R. Theris, "Fast Neutrons: Dosimetry and Recent Developments in Ion Linear Accelerators." To be presented at the Workshop on Physical Data for Neutron Dosimetry, Rijswijk, Netherlands. May 19-21, 1976. Extended abstract to be published in the Proceedings.

H. I. Amols, J. N. Bradbury, J. F. Dicello, J. A. Helland, T. F. Lane, M. A. Paciotti, D. L. Roeder, and M. E. Schillaci, "Determination of the Shole Body Dose for Patients Irradiated with Pions." To be presented at the Workshop on Physical Data for Neutron Dosimetry, Rijswijk, Metherlands. May 19-21, 1976. Extended abstract to be published in the Proceedings.

J. F. Dicello, "Preclinical Research in Pion Radiotherapy." To be presented at the University of Nebraska, May, 1976.

J. F. Dicello, "Biomedical Pion Program at LAMPF." The University of Texas Health Science Center at Dallas. February, 1975.

J. F. Dicello, E. A. Knapp, and L. Rosen, "Application of Particle Accelerators in Medicine." Advanced Study Institute on High LET Radiations and Cancer Therapy. NATO, Modena, Italy. October, 1974.

J. F. Dicello, "Microdosimetry for Radiations with Therapeutic Applications," Los Alamos Scientific Laboratory, June, 1973.

J. F. Dicello, "Microdosimetry and Its Application to Radiobiology." Radiological Sciences Laboratory, New York Department of Health, March, 1973.

J. F. Dicello, "Proton Total Reaction Cross Sections between 10 and 22 MeV." Los Alamos Scientific Laboratory, December, 1967.

Numerous reports and abstracts not included.

SECTION II — PRIVILEGED COMMUNICATI

# BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Chaim Richman, Ph.D. | Physicist | [redacted] |
| **PLACE OF BIRTH** (City, State, Country) | **PRESENT NATIONALITY** (If non-U.S. citizen, indicate kind of visa and expiration date) | **SEX** |
| [redacted] | U.S.A. | ☒ Male ☐ Female |

**EDUCATION** (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | B.A. | [redacted] | Mathematics-Physics |
| [redacted] | M.A. | [redacted] | Mathematics-Physics |
| [redacted] | Ph.D. | [redacted] | Physics |

**HONORS**

Sigma Xi, [redacted] Fellow, American Physical Society, Ethel M. Rubelson Lecturer in Radiology, University of Minnesota Medical School

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Pion Radiobiology and Dosimetry | Physicist |

**RESEARCH SUPPORT** (See instructions)

**RESEARCH AND/OR PROFESSIONAL EXPERIENCE** (Starting with present position, list training and experience relevant to area of project. List 5 or most representative publications. Do not exceed 3 pages for each individual.)

1971-Present Los Alamos Scientific Laboratory, University of California

Organized the Biomedical Steering Committee and 8 subcommittees for LAMPF; compiled a set of recommendations from the committees into a final report.

Received two grants for pion radiotherapy work from the American Cancer Society.

Instrumented a system for analyzing pion beams using silicon and scintillation detectors which will give all the contaminations, spatial distributions of all particles, and low and high LET dose distributions

1961-1971 [redacted]

Professor of Physics; initiated and led the dosimetric and radiobiologi experiments on pion radiotherapy work at [redacted] received about 8 grants from the American Cancer Society, 5 grants from the AEC, and 2 grants from the ONR for pion radiotherapy studies; received an award from the [redacted] for pion radiotherapy studies.

Received a grant from the AEC for organizing the Biomedical Steering Committee.

Associate Professor of Radiology, [redacted]

1956-1961 [redacted]

Director of Research; investigated techniques for subsurface fracturing for increasing oil production.

1091754

1946-1956 [redacted]
Associate Professor of Physics; worked on the proton linear accelerator and the cyclotron; proton scattering work on 32-MeV protons on hydrogen; studied production of positive and negative pions by protons on carbon and hydrogen.

1942-1946 Los Alamos Scientific Laboratory, University of California
Staff Member, Theoretical Division; studies of slowing down of neutrons and critical mass calculations

## PUBLICATIONS

Deuteron Disintegration by Electrons, with B. Peters, Physical Review, 59, 804 (1941).

Angular Distribution in Deuteron Disintegration by Electrons, (A), Physical Review, 61, 203 (1942).

The Production of Slow Neutrons in a Carbon Block, with T. Snyder and R.W. Williams, U.S. Atomic Energy Commission Report MDDC-302, Sept. (1946).

Drift Tubes for Linear Proton Accelerator, (A), with F. Oppenheimer and L.H. Johnston, Physical Review, 70, 447 (1946).

Initial Performance of a 32 MeV Proton Linear Accelerator, (A), with L.V. Alvarez, H. Bradner, H. Gordon, L.C. Marshall, F. Oppenheimer, W.K.H. Panofsky, R. Serber, C. Turner, and J.R. Woodyard, Science, 106, 506 (1947).

On the Neutron-Proton Scattering Cross Section, with D. Bohm, Physical Review, 71, 567 (1947).

Resonant Cavities, Electronic Lecture Series, BP-94, September 17 (1947).

Control of the Field Distribution in the Linear Accelerator Cavity, with W.K. H. Panofsky, Physical Review, 73, 535 (1948).

Apparatus for Measuring Proton-Proton Scattering at 32 MeV Using Proportional Counters, (A), with B. Cork and L. Johnston, Bulletin of the American Physical Society, 24, 214 (1949).

Berkeley Proton Linear Accelerator, with L. Alvarez and others, UCRL-236 (1949).

An Experiment for Measuring Heavy Meson Production by High Energy Particles, (A), with H. Wilcox, presented at the December 29-30, 1949 meeting of the American Physical Society at Stanford University, Physical Review, 78, 85 (1950).

Measurement of the Production of Positive and Negative Mesons by 345 MeV Proton on Carbon, (A), with H.A. Wilcox, presented at the December 20-30, 1949 meeting of the American Physical Society at Stanford University, Physical Review, 78, 85 (1950), also Classified Document #LA-38, Lawrence Radiation Laboratory.

Production Cross-Sections for $\pi^+$ and $\pi^-$ Mesons by 345 MeV Protons on Carbon at 90° to the Beam, (L), with H.A. Wilcox, Physical Review, 78, 496 (1950).

The Production of $\pi^+$ Mesons by Protons on Protons in the Direction of the Beam, (L), with F. Cartwright, M. Whitehead, and H.A. Wilcox, Physical Review, 78, 823 (1950).

Proton-Proton Scattering at 31.8 MeV Proportional Counter Methods, with B. Cork and L. Johnston, Physical Review, 79, 71 (1950).

Production of a $\pi^+$ Meson Beam Using the Deflected Proton Beam of the 184-inch Synchrocyclotron, (L), with M. Skinner, J. Merritt, and B. Youtz, Physical Review, 80, 900 (1950).

Scattering of $\pi^+$ Mesons on Carbon, (A), with M. Skinner, Physical Review, 83, 217 (1951).

On the Angular Distribution of the $\pi^+$ Mesons from 341 MeV Protons on Protons, (L), with M. Whitehead, Physical Review, 83, 855 (1951).

On the Angular Distribution and the Polarization of the Deuteron in the Reaction $p + p + d + \pi^+$, with K. M. Watson, Physical Review, 83, 1256 (1951).

The Production of $\pi^+$ and $\pi^-$ Mesons by 340 MeV Protons at 90° to the Beam from Carbon and Lead, with M. Weissbluth and H.A. Wilcox, Physical Review, 85, 161 (1952).

The Production of Positive Pions by 341 MeV Protons on Protons, with W. F. Cartwright, M.N. Whitehead, and H.A. Wilcox, Physical Review, 91, 677 (1953).

The Berkeley Proton Linear Accelerator, with L.W. Alvarez, H. Bradner, J.F. Finch H. Gordon, J. Gow, L.C. Marshall, F. Oppenheimer, W.K.H. Panofsky, and J.R. Woodyard, Rev. Sci. Insti., 26, 2, 111 (1955).

On the Dosimetry of Negative Pions with a View Toward Their Use in Cancer Therapy with H. Aceto, M.R. Raju, B. Schwartz, and M. Weissbluth, Spring 1964, Semi-annual Report Biology and Medicine, 114, Donner Lab, University of California, Berkeley, California.

The Therapeutic Possibilities of Negative Pions, Preliminary Physical Experiments with H. Aceto, M.R. Raju, and B. Schwartz, American Jounral of Roentgenology.

Pion Studies with Silicon Detectors, with M.R. Raju and H. Aceto, Nuclear Instruments and Methods, 37, 152-158 (1965).

Lithium-Drifted Silicon Detector Used as a Pulse Dosimeter, with M.R. Raju, E.J. Lampo, S.B. Curtis, and J.M. Sperinde, UCRL-16924 (delivered at the 13th Nuclear Science Symposium on Instrumentation in Space and Laboratory, Boston, Massachusetts) (1966).

$\pi^-$ Mesons, Radiobiology, and Cancer Therapy, C. Richman, Proceedings of the First International Symposium on the Biological Interpretation of Dose from Accelerator-Produted Radiation, 346-348 (1967).

A Review of the Physical Characteristics of Pion Beams, with M.R. Raju and S.B. Curtis, Proceedings of the First International Symposium on the Biological Interpretation of Dose from Accelerator-Produced Radiation, 349-367 (1967).

Studies of Vicia Root Meristems Irradiated with $\pi^-$ Beam, with S.P. Richman, M.R. Raju, and B. Schwartz, Radiation Research, 7, 182-189 (1967).

Effect of Negative Pions on the Proliferative Capacity of Ascites Tumor Cells (lymphoma) in Vivo, with J.M. Peola, M.R. Raju, S.B. Curtis, and J.H. Lawrence, Radiation Research, 34, 70-78 (1968).

Physical and Radiobiological Aspects of Negative Pions with Reference to Radiotherapy, with M.R. Raju. Presented at the XII International Congress of Radiology, October 6-11, Tokyo, Japan. GANN Monograph on Radiology of Cancer, No. 9, 105 (1970).

The RBE of Negative Pions in 2-day-old Ascites Tumors, with J.M. Feola, M.R. Raju, and J.H. Lawrence, Radiation Research, 44, 637 (1970).

The Oxygen Effect of $\pi^-$ Mesons in Vicia faba, with M.R. Raju, N. Amer, and M. Gnanapurani, UCRL-18644, Radiation Research, 41, 135-144 (1970).

Negative $\pi$ Meson Therapy: Physical and Biological Considerations, with M.R. Raju, Chapter in Current Topics in Radiation Research, edited by M. Ebert and A. Howar to be published by North-Holland Publishing Company, Amsterdam (1970).

Recommendations for Implementing Radiotherapy with Negative Pions at LAMPF, LAMPF Biomedical Steering Committee, Chaim Richman, Los Alamos. LA Report 1972 (in

SECTION II – PRIVILEGED COMMUNICATION

# BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Bishop, Barbara L. | Computer Analyst | [redacted] |
| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
| [redacted] | US | ☐ Male ☒ Female |

EDUCATION *(Begin with baccalaureate training and include postdoctoral)*

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | B. S. | [redacted] | Statistics |

HONORS

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Medical Physics | Theoretical Calculations |

RESEARCH SUPPORT *(See instructions)*

RESEARCH AND/OR PROFESSIONAL EXPERIENCE *(Starting with present position, list training and experience relevant to area of project. List all or most representative publications. Do not exceed 3 pages for each individual.)*

Oak Ridge National Laboratory, Oak Ridge, TN., Computer Programmer, Neutron Physics Division, 1962-1971, Health Physics and Energy Divisions, 1971-1975, Computer Analyst, Computer Sciences Division, 1975-Present

[redacted], Statistical Assistant, Process Engineering Division, 1956-1962

[redacted] Clerk IBM Room, 1952-1955

Publications - See attached listing

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Barbara L. Bishop

Publications

Literature Survey of Radiochemical Cross-Section Data Below 425 MeV
(with H. W. Bertini, M. P. Guthrie, and E. H. Pickell)
ORNL-3884-UC-34-Physics (October 1966)

Representative Results in Graphical form from Computer Production Runs of the Low-Energy Intranuclear-Cascade Calculation
(with H. W. Bertini and M. P. Guthrie)
ORNL-4128-UC-34-Physics, CFSTI (August 1967)

The Absorbed Dose and Dose Equivalent from Negatively and Positively Charged Pions in the Energy Range 10 to 2000 MeV
(with R. G. Alsmiller, Jr. and T. W. Armstrong)
ORNL-4592-UC-34-Physics; Nuclear Science and Engineering 43, 257-266 (1971); ORNL-TM-3105 (September 1970)

Calculation of the Absorbed Dose and Dose Equivalent Induced by Medium-Energy Neutrons and Protons and Comparison with Experiment
(with T. W. Armstrong)
(RNL-4800; Radiation Research 47, 581-588 (1971); Proceedings of the National Symposium on Natural and Manmade Radiation in Space, 123, March 1970 (September 1971)

Monte Carlo Calculations of High-Energy Nucleon-Meson Cascades and Comparison with Experiment
(with T. W. Armstrong, R. G. Alsmiller, Jr., and K. C. Chandler)
ORNL-TM-3667; Nuclear Science and Engineering 49, 82-92 (September 1972)

The Impact of Annexation on the Growth of Adult White and Nonwhite Populations of Cities; 1960-1970
(with P. N. Ritchey and C. A. Grametbauer)
mimeograph paper to Housing and Urban Development (1974)

Components of Change for the Adult Populations of Cities by Age, Sex, and Color
(with P. N. Ritchey)
ORNL-UR-117, Volumes 1-9 (September 1974)

Documentation of Data File: Components of Change for the Adult Populations of Cities by Age, Sex, and Color
(with P. N. Ritchey)
ORNL-UR-121 (February 1975)

SECTION II – PRIVILEGED COMMUNICATION

# BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Hamm, Robert N. | Research Staff Member | [redacted] |
| **PLACE OF BIRTH** (City, State, Country) | **PRESENT NATIONALITY** (If non-U.S. citizen, indicate kind of visa and expiration date) | **SEX** |
| [redacted] | US | ☒ Male ☐ Female |

EDUCATION (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | Ph.D. | [redacted] | Physics |

HONORS

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Medical Physics | Theoretical Calculations |

RESEARCH SUPPORT (See instructions)

RESEARCH AND/OR PROFESSIONAL EXPERIENCE (Starting with present position, list training and experience relevant to area of project. List all or most representative publications. Do not exceed 3 pages for each individual.)

Oak Ridge National Laboratory, Oak Ridge, Tennessee-Physicist, Health Physics Division 1963-Present

Publications - See attached listing

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SECTION II – PRIVILEGED COMMUNICATION

# BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Turner, James E. | Associate Director, Health Physics Div., ORNL | [redacted] |
| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
| [redacted] | US | ☒ Male ☐ Female |

EDUCATION (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | Ph.D. | [redacted] | Physics |

HONORS

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Medical Physics | Theoretical Calculations |

RESEARCH SUPPORT *(See instructions)*

RESEARCH AND/OR PROFESSIONAL EXPERIENCE *(Starting with present position, list training and experience relevant to area of project. List all or most representative publications. Do not exceed 3 pages for each individual.)*

Associate Director, Health Physics Division, Oak Ridge National Laboratory
Visiting Scientist, [redacted], 1969-1970
Lecturer in Physics, [redacted], 1965-1966, 1968-1969
Visiting Assistant Professor of Physics, [redacted] 1963-1964
Physicist, Health Physics Division, Oak Ridge National Laboratory, 1962-Present
Radiological Physicist, [redacted]., 1958-1962
Instructor of Physics, [redacted], 1956-1958

Publications: See attached listing

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SECTION II – PRIVILEGED COMMUNICATION

# BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Wright, Harvel A. | Chief, Biological and Radiation Physics Section, Health Physics Division, ORNL | [redacted] |

| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
|---|---|---|
| [redacted] | USA | ☒ Male ☐ Female |

EDUCATION (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | Ph.D. | [redacted] | Mathematics |

HONORS

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Medical Physics | Theoretical Calculations |

RESEARCH SUPPORT *(See instructions)*

RESEARCH AND/OR PROFESSIONAL EXPERIENCE *(Starting with present position, list training and experience relevant to area of project. List all or most representative publications. Do not exceed 3 pages for each individual.)*

Chief, Biological and Radiation Physics Section Health Physics Division, Oak Ridge National Laboratory, 1972-Present
Visiting Scientist, [redacted] 1971-1972
Assistant Professor, [redacted] 1969-Present
Lecturer, [redacted], 1967-1969
Health Physicist, Health Physics Division, Oak Ridge National Laboratory, 1962-Present
Instructor of Mathematics, [redacted] 1958-1962
Instructor of Physics and Mathematics, [redacted], 1956-1958

Publications - See attached listing

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PIONS

1. J. E. Turner, J. Dutrannois, H. A. Wright, J. Baarli, R. N. Hamm, and A. H. Sullivan
Calculation of Pion Depth-Dose Curves and Comparison with Experiment
in PROCEEDINGS OF IVth INTERNATIONAL CONGRESS OF RADIATION RESEARCH
Evian, France, June 28-July 4, 1970 CERN DI/HP/132, December 1970

2. J. E. Turner, H. A. Wright, and R. N. Hamm
Pion Beam Dosimetry: Comparison of Experiment and Theory and Other Studies
in PROCEEDINGS OF INTERNATIONAL CONGRESS ON PROTECTION AGAINST ACCELERATOR AND SPACE RADIATION, Geneva, Switzerland, April 26-30, 1971

3. J. E. Turner, J. Dutrannois, H. A. Wright, R. N. Hamm, J. Baarli, A. H. Sullivan, M. J. Berger, and S. M. Seltzer
A Method of Calculating Pion Depth-Dose Curves in Water and Comparison with Experiment
Radiation Research 52, 229-246 (November 1972)

4. J. R. Dutrannois, R. N.Hamm, J. E. Turner, and H. A. Wright
Analysis of Energy Deposition in Water around the Site of Capture of a Negative Pion by an Oxygen or Carbon Nucleus
Phys. Medicine and Biology 17, 765-770 (1972)

5. J. R. Dutrannois, H. A. Wright, J. E. Turner, and R. N. Hamm
Estimations of Pion$^+$ and Pion$^-$ Quality Factor and RBE for Survival of T-1 Human Kidney Cells
Int. J. Rad. Biology 23, 421 (1973)

6. J. E. Turner, R. N. Hamm, and H. A. Wright
Microscopic Description of Energy Deposition in Tissue by Pion Beams
in PROCEEDINGS OF FOURTH SYMPOSIUM ON MICRODOSIMETRY, Verbania Pallanza, Italy, September 24-28, 1973

7. H. A. Wright, R. N. Hamm, and J. E. Turner
Dose, Dose Equivalent, Effective Dose and Cell Survival from Negative Pio
in PROCEEDINGS OF THIRD INTERNATIONAL CONGRESS OF INTERNATIONAL RADIATION PROTECTION ASSOCIATION, Washington, DC, September 24-28, 1973

8. H. A. Wright, R. N. Hamm, and J. E. Turner
Estimation of Dose Equivalent and Average Quality Factors for $\pi^-$ and $\pi^+$ Beams
Health Physics 27, 3-8 (July 1974)

9. R. N. Hamm, H. A. Wright, and J. E. Turner
Monte Carlo Treatment of Multiple Coulomb Scattering in Pion-Beam Dose Calculations
Journal of Applied Physics 46, 4445-4452 (October 10, 1975)

10. J. E. Turner, H. A. Wright, and R. N. Hamm
Estimated W-Values for Negative Pions in Nitrogen and Argon
Health Physics 29, 792-794 (November 1975)

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PIONS (continued)

11. R. N. Hamm, H. A. Wright, and J. E. Turner
Effects of Tissue Inhomogeneities on Dose Patterns in Cylinders Irradiated by Negative Pion Beams
Oak Ridge National Laboratory Report ORNL-TM-5038 (1975)

PARTICLE PENETRATION, HIGH-ENERGY DOSIMETRY


1. J. E. Turner, C. D. Zerby, R. L. Woodyard, H. A. Wright, W. E. Kinney, W. S. Snyder, and J. Neufeld
Calculation of Radiation Dose from Protons to 400 MeV
Health Physics 10, 783-808 (November 1964)

2. J. Neufeld, W. S. Snyder, J. E. Turner, and Harvel Wright
Calculation of Radiation Dose from Protons and Neutrons to 400 MeV
Health Physics 12, 227-237 (February 1966)

3. J. E. Turner
Theoretical Methods in the Dosimetry of High-Energy Particles
Proceedings of First AEC Symposium on Accelerator Radiation Dosimetry and Experience, Brookhaven National Laboratory, November 3-5, 1965
CONF-651109, USAEC, 1966, pp. 346-364

4. K. Katoh and J. E. Turner
A Review of Elementary Particle Interactions for High-Energy Dosimetry
Health Physics 13, 831-843 (1967).

5. J. E. Turner, V. E. Anderson, H. A. Wright, W. S. Snyder, and J. Neufeld
Dose from High-Energy Radiations at an Interface between Two Media
in PROCEEDINGS FIRST INTERNATIONAL SYMPOSIUM ON THE BIOLOGICAL INTERPRETATION OF DOSE FROM ACCELERATOR-PRODUCED RADIATION
Edited by Roger Wallace
U.S. AEC/DTI CONF-670305, pp. 306-317 (1967)

6. R. B. Vora, M. A. Prasad, and J. E. Turner
Effect of Delta-Ray Buildup in High-Energy Dose Calculations
Health Physics 15, 139-143 (1968)

7. W. S. Snyder, H. A. Wright, J. E. Turner, and J. Neufeld
Calculations of Depth Dose from Neutrons and Protons of High Energy and their Interpretation for Radiation Protection
Trans. American Nuclear Society 11, No. 1, 391 (1968)

8. J. E. TUrner, V. E. Anderson, H. A. Wright, W. S. Snyder, and J. Neufeld
Radiation Dose from High-ENergy Nucleons in Targets Containing Soft Tissue and Bone
Radiation Research 35, 596-611 (September 1968)

9. Jacob Neufeld, V. E. Anderson, Harvel Wright, W. S. Snyder, and J. E. Turne
Effects of Phantom Geometry on Dose Distribution
in PROCEEDINGS FIRST INTERNATIONAL CONGRESS OF RADIATION PROTECTION (Rcme, Italy, September 5-10, 1966)
Pergamon Press, New York (1968), pp. 1469-1472

10. Harvel Wright, E. E. Branstetter, Jacob Neufeld, J. E. Turner, and W. S. Snyder
Calculation of Radiation Dose due to High-Energy Protons
in PROCEEDINGS OF FIRST INTERNATIONAL CONGRESS OF RADIATION PROTECTION (Ro
Italy, September 5-10, 1966)
Pergamon Press, New York (1968) pp. 1487-1492

PARTICLE PENETRATION, HIGH-ENERGY DOSIMETRY (continued)


11. Harvel A. Wright, V. E. Anderson, J. E. Turner, Jacob Neufeld, and W. S. Snyder
Calculation of Radiation Dose due to Protons and Neutrons with Energies from 0.4 to 2.0 GeV
Health Physics 16, 13-31 (January 1969)

12. W. S. Snyder, H. A. Wright, J. E. Turner, and J. Neufeld
Calculations of Depth-Dose Curves for High-Energy Neutrons and Protons and their Interpretation for Radiation Protection
Nuclear Applications 6, 336-343 (April 1969)

13. J. Neufeld, W. S. SNyder, J. E. Turner, Harvel Wright, B. M. Wheatley, and H. Wyckoff
Radiation Dose from Neutrons and Protons in the Energy Range from 400 MeV to 2 GeV
ICRP Report (Task Group on High Energy Radiations)
Health Physics 17, 449-457 (September 1969)

14. J. E. Turner, R. V. Vora, M. A. Prasad, V. N. Neelavathi, and T. S. Subramanian
Contributions of Spin, Anomalous Magnetic Moment, and Form Factors to the Stopping Power of Matter for Protons and Muons at Extreme Relativistic Energies
Physical Review 183, 453-457 (July 10, 1969)

15. J. E. Turner, Patricia Dalton Roecklein, and R. B. Vora
Mean Excitation Energies for Chemical Elements
Health Physics (Note) 18, 159-160 (February 1970)

16. R. B. Vora and J. E. Turner
Stopping Power of Matter for Deuterons at Extreme Relativistic Energies
Physical Review B1, 2011-2014 (March 1970)

17. H. A. Wright and J.E. Turner
Free-Nucleon Target Model Applied to Penetration and Dose Calculations for 200 and 400 MeV Protons and Neutrons
Health Physics 18, 711-720 (June 1970)

18. J. E. Turner and H. A. Wright
Calculation of Dose from High Energy Nucleons
in PROCEEDINGS 2nd INTERNATIONAL CONFERENCE ON ACCELERATOR DOSIMETRY AND EXPERIENCE (Stanford, CA, November 5-7, 1969)
U.S. AEC/DTI CONF-691101, pp. 146-158 (1970)

19. H. A. Wright and J. E. Turner
Free-Nucleon Target Model Applied to Nuclear Penetration through Matter
Trans. American Nuclear Society 12, 968-969 (1969)

20. J. E. Turner
Calculations of the Penetration of Charged Particles through Matter at Very High Energies
in PENETRATION OF CHARGED PARTICLES IN MATTER: A SYMPOSIUM
National Academy of Sciences, Washington, DC, 1970) pp. 48-58

PARTICLE PENETRATION, HIGH-ENERGY DOSIMETRY (continued)

21. H. A. Wright, R. N. Hamm, and J. E. Turner
Effect of Lateral Scattering on Absorbed Dose from 400 MeV Neutrons and Prot
in PROCEEDINGS INTERNATIONAL CONGRESS ON PROTECTION AGAINST ACCELERATOR AND SPACE RADIATION
Geneva, Switzerland, April 26-30, 1971

22. J. E. Turner, V. N. Neelavathi, R. B. Vora, and J. S. Bisht
Generalized Formulation of Stopping-Power Theory for Nucleons in the First Born Approximation
Physical Review B8, No. 9, 4053-4056 (November 1, 1973)

23. J. E. Turner, H. A. Wright, R. N. Hamm
Radioprotection 9, 131 (1974)

24. H. A. Wright, G. S. Hurst, and E. B. Wagner
An Application of the Generalized Concept of Dosimetry to Space Radiations
PROCEEDINGS OF SECOND SYMPOSIUM ON PROTECTION AGAINST RADIATIONS IN SPACE
(Gatlinburg, TN, October 12-14, 1964) NASA SP-71 (June 1965)

25. W. S. Snyder, J. Neufeld, and J. E. Turner
Calculation of Dose Due to High Energy Particles
Health Physics 8, 458 (1962)

26. J. S. McIntish, S. C. Park, and J. E. Turner
On the Elastic Scattering of Heavy Ions
Physical Review 117, 1284 (1960)

27. J. E. Turner
Calculations of the Penetration of Charged Particles through Matter at Very High Energies
in PENETRATION OF CHARGED PARTICLES IN MATTER: A SYMPOSIUM
National Academy of Sciences, Washington, DC, 1970, pp. 48-58

GENERAL DOSIM ΣY

1. J. E. Turner and Hal Hollister
The Possible Role of Momentum in Radiation Dosimetry
Health Physics 8, 523-531 (1962)

2. J. E. Turner
The Possible Role of Momentum in Radiation Dosimetry - II. Extension to Charged or Uncharged Particles and Implications

3. J. E. Turner and Hal Hollister
On the Relationship of the Velocity of a Charged Particle to Its Relati Biological Effectiveness (RBE)
Nature 208, 36 (1965)

4. H.Hollister and J. E. Turner
The Possible Role of Momentum in Radiation Dosimetry - III. Remarks on the 1962 ICRP/ICRU Report
Health Physics 12, 949-953 (1966)

5. W. J. McConnell, H. H. Hubbell, Jr., R. N. Hamm, R. H. Ritchie, and R. D. Birkhoff
Electron Slowing-Down Spectrum in Cu of Beta Rays from $^{64}$Cu
Physical Review 138, A1377 (1965)

6. W. J. McConnell, R. N. Hamm, R. H. Ritchie, and R. D. Birkhoff
Electron Flux Spectra in Aluminum; Analysis for LET Spectra and Excitation and Ionization Yields
Radiation Research 33, 216-228 (February 1968)

7. D. R. Nelson, J. G. Carter, R. D. Birkhoff, R. N. Hamm, and L. G. Augenstein
Yield of Luminescence from X-Irradiated Biochemicals
Radiation Research 32, 723-743 (December 1967)

8. R. D. Birkhoff, J. E. Turner, V. E. Anderson, J. M. Feola and R. N. Hamm
The Determination of LET Spectra from Energy-Proportional Pulse-Height Measurements. I. Track-Length Distributions in Cavities
Health Physics 18, 1-14 (1970)

9. J. E. Turner
Calculation of Stopping Power of a Heavy Charged Particle in Matter
Health Physics 13, 1255-1263 (December 1967)

10. K. Z. Morgan and J. E. Turner, Editors
PRINCIPLES OF RADIATION PROTECTION - A TEXTBOOK OF HEALTH PHYSICS
John Wiley and Sons, Inc., New York, 1967

11. J. Neufeld, L. C. Emerson, F. J. Davis, and J. E. Turner
The Passage of Heavy Charged Particles, Gamma Rays, and X-Rays through Matter
in PRINCIPLES OF RADIATION PROTECTION - A TEXTBOOK OF HEALTH PHYSICS
K. Z. Morgan and J. E. Turner, Editors
John Wiley and Sons, Inc., New York, 1967, pp. 76-113

GENERAL DOSIMETRY (continued)

12. E. T. Arakawa, R. N. Hamm, and M. W. Williams
Optical Properties and Electron Attenuation Lengths from Photoelectric Yield Measurements
Journal of the Optical Society of America 63, No. 9, 1131-1134 (Sept. 1973)

13. Patricia Dalton and J. E. Turner
New Evaluation of Mean Excitation Energies for Use in Radiation Dosimetry
Health Physics 15, 257-262 (1968)

14. J. E. Turner, R. D. Birkhoff, V. E. Anderson, E. B. Wagner, and H. A. Wrigh
Monte Carlo Method of Determining LET Spectra from Pulse-Height Measurement
in PROCEEDINGS 2nd SYMPOSIUM ON MICRODOSIMETRY (Ispra, Italy, October 20-24 1969) Commission of the European Communities (EURATOM), Brussels, Belgi
January 1970, p. 373

15. Cornelius E. Klots and Harvel Wright
Aspects of Degradation Spectra
International Journal of Radiation Physics and Chemistry 2, 191-200 (1971)

16. Jacob Neufeld and Harvel Wright
Radiation Levels and Fluence Conversion Factors
Health Physics 23, 183-186 (August 1972)

17. Jacob Neufeld, H. A. Wright, and R. N. Hamm
A Comparison of Two-Component Models of Cellular Survival
in PROCEEDINGS OF FOURTH SYMPOSIUM ON MICRODOSIMETRY
Verbania Pallanza, Italy, September 24-28, 1973

18. J. E. Turner
Effects of Shell Corrections to Stopping Power in Theoretical Dose Studies
in PROCEEDINGS SYMPOSIUM ON THE DOSIMETRY OF IRRADIATIONS FROM EXTERNAL SOURCES. Paris, France, November 23-27, 1964
Service Central de Protection Contre les Rayonnements Ionisants, Le Vesinet, 1968, pp. 53-59

19. J. E. Turner and Hal Hollister
RBE, LET, z, v; Some Further Thoughts
Health Physics 17, 356 (August 1969)

20. G. S. Hurst and J. E. Turner
ELEMENTARY RADIATION PHYSICS
John Wiley and Sons, New York, 1969

21. J. E. Turner, V. E. Anderson, R. D. Birkhoff, and D. R. Johnson
The Determination of LET Spectra from Energy-Proportional Pulse-Height Measurements - II. A Monte Carlo Unfolding Procedure
Health Physics 18, 15-24 (1970)

22. R. B. Vora, V. N. Neelavathi, J. E. Turner, T. S. Subramanian, and N. A. Prasad
Semiclassical Estimation of Neutron Stopping Power
Physical Review B3, 2929-2933 (May 1, 1971)

GENERAL DOSIMETRY (continued)

23. J. E. Turner
Meaning and Assessment of Radiation Quality for Radiation Protection in PROCEEDINGS OF SYMPOSIUM ON BIOPHYSICAL ASPECTS OF RADIATION QUALITY (Lucas Heights, N.S.W., Australia - March 8-12, 1971) (International Atomic Energy Agency IAEA-SM-145/3, Vienna, 1971) p. 55

24. J. E. Turner and C. E. Klots
Status of the Theory of Delta-Ray Production
in PROCEEDINGS THIRD SYMPOSIUM ON MICRODOSIMETRY (Stresa, Italy) October 18-22, 1971
EUR 4810 d-f-e (1972), pp. 31-69

25. J. E. Turner, V. N. Neelavathi, R. B. Vora, and J. S. Bisht
Generalized Formulation of Stopping-Power Theory for Nucleons in the First Born Approximation
Physical Review B8, No. 9, 4053-4056 (November 1, 1973)

26. J. E. Turner, R. K. Kher, D. Arora, J. S. Bisht, V. N. Neelavathi, and R. B. Vora
Quantum-Mechanical Calculation of Neutron Stopping Power
Physical Review B8, No. 9, 4057-4062 (November 1, 1973)

BIOGRAPHICAL SKETCH

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Tony W. Armstrong | Staff Scientist | [redacted] |
| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
| [redacted] | U.S.A. | [X] Male [ ] Female |

EDUCATION (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | B.S.<br>M.S.<br>Ph.D. | [redacted] | Nuclear Engineering<br>Nuclear Engineering<br>Nuclear Engineering |

HONORS

[redacted]

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Theoretical Radiation Physics | Radiation Transport Calculations |

RESEARCH SUPPORT (See instructions)

RESEARCH AND/OR PROFESSIONAL EXPERIENCE (Starting with present position, list training and experience relevant to area of project. List, or most representative publications. Do not exceed 3 pages for each individual.)

PROFESSIONAL EXPERIENCE:

1974-present: Staff Scientist, Scientific Applications, Inc.

1974-present: Consultant, Univ. of New Mexico, Cancer Research and Treatment Center, Albuquerque, New Mexico

1974-present: Consultant, Los Alamos Scientific Laboratory, Los Alamos, New Mexico

1974-present: Staff Scientist, JRB Associates, La Jolla, California

1967-1974: Research Staff Member, [redacted]

1965-1967: Faculty, Nuclear Engineering Department, [redacted]

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PUBLICATIONS:

Over thirty five journal publications on the development and application of calculational methods for radiation transport, with applications in the areas of high-energy accelerator shielding, space physics, dose and biological effects by nucleons and charged pions, high-LET radiation for radiotherapy, and radiation dosimetry. Recent relevant publications include:

Tony W. Armstrong and K.C. Chandler, "Calculations Related to the Application of Silicon Detectors in Pion Radiobiology," (to be published in Nucl. Instr. Meth.).

T.W. Armstrong and K.C. Chandler, "Calculations on Tissue Equivalence for Stopping $\pi^-$ Mesons," (to be published in Nucl. Instr. Meth.).

R.G. Alsmiller, Jr., R.T. Santoro, T.W. Armstrong, J. Barish, K.C. Chandler, and G.T. Chapman, "Calculations Related to the Use of Photons, Neutrons, Negatively-Charged Pions, Protons, and Alpha Particles in Cancer Radiotherapy," (to be published).

Tony W. Armstrong and Kay C. Chandler, "Calculation of Residual Nuclei Production by a Beam of Negatively-Charged Pions Incident on a Tissue Phantom," (to be published in Nucl. Instr. Meth.).

T.W. Armstrong and K.C. Chandler, "Calculated Particle-Production Spectra From $\pi^-$ Captures in Tissue, Tissue Equivalent Plastic, Silicon, and Germanium," Nucl. Instr. Meth. 118 (1974) 515.

T.W. Armstrong and K.C. Chandler, "Calculations Related to the Application of Negatively Charged Pions in Radiotherapy: Absorbed Dose, LET Spectra, and Cell Survival," Radiat. Res. 58 (1974) 293.

T.W. Armstrong and K.C. Chandler, "SPAR, A Fortran Program for Computing Stopping Powers and Ranges for Muons, Pions, Protons, and Heavy Ions," Nucl. Instr. Meth. 113 (1973) 313.

T.W. Armstrong, R.G. Alsmiller, Jr., and K.C. Chandler, "Calculations of the Dose Induced in Tissue by Negatively Charged Pion Beams," Phys. Med. Biol. 18 (1973) 830.

T.W. Armstrong and K.C. Chandler, "Monte Carlo Calculations of the Dose Induced by Charged Pions and Comparisons with Experiment," Radiat. Res. 52 (1972) 247.

T.W. Armstrong and K.C. Chandler, "HETC, A High Energy Transport Code," Nucl. Sci. Eng. 49 (1972) 110.

T.W. Armstrong and B.L. Bishop, "Calculation of the Absorbed Dose and Dose Equivalent Induced by Medium-Energy Protons and Comparison with Experiment," Radiat. Res. 47 (1971) 581.

SECTION II – PRIVILEGED COMMUNIC ON

## BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Princi al Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| M. M. Kligerman, M. D. | Dir, Cancer Res & Treat Ctr UNM School of Medicine/Asst Dir for Radiation Therapy/LASL | [redacted] |

| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
|---|---|---|
| [redacted] | U.S. | ☒ Male ☐ Female |

**EDUCATION** *(Begin with baccalaureate training and include postdoctoral)*

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] (Honorary) | BS<br>MD<br>M.Sc.<br>M.A. | [redacted] | Medical Rad. |

**HONORS**

See attached pages

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Radiotherapy Techniques | Medical/Clinical Aspects |

**RESEARCH SUPPORT** *(See instructions)*

NCI 5-P01-CA-14052-03: Preclinical Studies of Pion Radiotherapy - $767,249 (Year 3) Renewal application submitted, $2,223,425 requested Year 1; $8,200,125 requested 5 Years.

NCI 5-P01-CA-16127-02: Clinical Studies of Pion Radiotherapy - $870,173 (Year 2), $1,344,657 (recommended for Year 3).

**RESEARCH AND/OR PROFESSIONAL EXPERIENCE** *(Starting with present position, list training and experience relevant to area of project. List or most representative publications. Do not exceed 3 pages for each individual.)*

See attached pages

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**Home Address:**
[redacted]

**Office:**
Cancer Research and Treatment Center, University of New Mexico, Albuquerque, New Mexico 87106

**Telephones:**
Office: 505/277-3631 Home: [redacted]

**Place and Date of Birth:**
[redacted]

**Education:**

[redacted] B.S. [redacted]
M.D.
M.Sc. (Rad.)
M.A. (Honorary

**Medical Career:**

| | |
|---|---|
| Intern, [redacted] | [redacted] |
| Resident, Radiology, [redacted] | |
| [redacted] Medical Corps, [redacted] | 1944-1947 |
| Instructor, Radiology, [redacted] | 1947-1948 |
| Instructor, Radiology, [redacted] | 1948-1950 |
| Asst. Prof., Radiology, [redacted] | 1950-1953 |
| Assoc. Prof., Radiology, [redacted] | 1953-1958 |
| Asst. Radiologist, [redacted] | 1948-1953 |
| Asst. Attending Radiologist, [redacted] | 1956-1958 |
| Assoc. Attending Radiologist, [redacted] | 1956-1958 |
| [redacted] Prof. of Radiology, and Chairman, Dept. of Radiology, [redacted] | 1958-1972 |
| Radiologist-in-Chief, [redacted] | 1958-1972 |
| Consultant, [redacted] | 1958-1972 |
| Consultant, [redacted] | 1970-1972 |
| Consultant, [redacted] | 1969-1972 |

**Present Positions:**

| | |
|---|---|
| Director, Cancer Research and Treatment Center, University of New Mexico School of Medicine, Albuquerque, New Mexico | 1972- |
| Professor and Chief, Division of Radiotherapy, Department of Radiology, University of New Mexico School of Medicine | 1972- |
| Medical Staff of the Bernalillo County Medical Center | 1972- |
| Assistant Director for Radiation Therapy, Los Alamos Scientific Laboratory, Los Alamos, New Mexico | 1972- |
| Consulting Staff, Lovelace-Bataan Medical Center; St. Joseph's Hospital; Presbyterian Hospital Center; & VA Hospital | 1972- |
| Active Staff, Bernalillo County Medical Center | 1972- |
| Admitting privileges, Los Alamos Medical Ctr. | 1974- |

**Medical and Scientific Society Membership:**

American Association for Cancer Research
American College of Radiology
American Radium Society
American Society of Therapeutic Radiologists
American Thoracic Society, Eastern Section
Association of American Medical Colleges
Association of University Radiologists
New England Roentgen-Ray Society
New York Roentgen-Ray Society
Radiation Research Society
Radiological Society of North America
Royal Society of Medicine (London)
Society of Head and Neck Surgeons
Albuquerque and Bernalillo County Medical Association
Rocky Mountain Radiological Society
American Federation of Clinical Oncologic Societies

**Licenses:**

Medical Licenses - Connecticut, New York, Pennsylvania, New Mexico
Diplomate, American Board of Radiology, 1945

**Special Honors:**

| | |
|---|---|
| American Cancer Society, Past Trustee, [redacted] | |
| Co-editor, Year Book of Radiology | 195[illegible]-196[illegible] |
| Member Radiation Study Section, N.I.H. | 196[illegible] |
| Committee for Radiation Therapy Studies | 196[illegible] [illegible]970 |
| Distinguished Alumnus Award, [redacted] | 196[illegible] |
| Silver Medallion Award, 200th Anniversary of Founding of College of Physicians & Surgeons | 1967 |
| President, Association of University Radiologists | 1967-1968 |
| Associate Editor, "Radiation Research" | 1967-1969 |
| Member, Clinical Cancer Training Committee, N.I.H. | 1967-1970 |
| President, American Soc. of Therapeutic Rad. | 1968-1969 |
| Degree of Fellowship of the American College of Radiology | 1968 |
| Chairman, Cancer Research Training Committee of N.I.H. | 1970 |
| Member, Board of Directors of the Bernalillo County Chapter of the American Cancer Society | 1972- |
| President, Bernalillo County Chapter of the American Cancer Society | 1973-1974 |
| Member, Board of Directors of the New Mexico Division of the American Cancer Society | 1973- |
| 10th Annual Ethel N. Ruvelson Memorial Lecturer, University of Minnesota hospitals, Minneapolis. "Considerations Leading to the Use of Negative Pi Mesons in Cancer Therapy." | 1973 |
| Robert M. Geyer Memorial Lecture, Baptist Medical Center of Oklahoma | 1974 |
| Member; American Cancer Society, Inc., Council for Research & Clinical Investigation Awards | 1[illegible] |

... Division American Cancer

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Kligerman, M.M.: Where Do We Go From Here? Proceedings of the Conference of Particle Accelerators in Radiation Therapy, Los Alamos, October 2-5, 1972. Oak Ridge, Tenn.: U.S. Atomic Energy Commission, Technical Information Center, 1973.

Kligerman, M.M.: The Cancer Center, The Community and Research, University of New Mexico/Los Alamos Plan. Frontiers in Radiation Therapy Oncology, Vol. 8, Basel, Switzerland: S. Karger, and Baltimore: University Park Press, pp. 94-99, 1973.

Kligerman, M.M.: Principles of Radiation Therapy. Cancer Medicine, ed. J. F. Holland and E. Frei, III. Philadelphia: Lea and Febiger, pp. 541-65, 1973.

Kligerman, M.M.: Irradiation of the Primary Lesion of the Rectum. JAMA, Current Concepts in Cancer Series, Gastrointestinal Tract Cancer, in press.

Kligerman, M.M., Urdaneta-Lafee, N.: Observations on Fifteen Selected Inoperable/Non-Resectable Cases of Rectal Cancer Given Preoprative Irradiation. Am. J. of Roent. 120:624-626, 1974.

Freedman, G.S., Lofgren, S.B., Kligerman, M.M.: Radiation Induced Changes in Pulmonary Perfusion. Radiology. 112: 435-437, 1974.

Kligerman, M.M.; Knapp, E.A.; and Petersen, D.F.: Biomedical Program Leading to Therapeutic Trials at Los Alamos. Cancer, in press.

Kligerman, M.M.; Dicello, J.F.; Davis, H.T.; Thomas, R.A.; Sternhagen, C.J.; Gomez, L.; and Petersen, D.F. Initial Comparative Response of Experimental Tumors to Peak Pions and X-rays. (Paper presented at the Radiological Society of North America, Chicago, December 1974.) Submitted to Radiology.

Todd, P.; Dicello, J.; West, G.; Shonk, C.; Kligerman, M.M.; and Raju, M.R.: Preliminary Progress Report: Survival of Cultured Human (T-1) Cells Irradiated at Various Depths in the LAMPF Negative Pion Therapy Beam. (Paper presented at the Radiological Society of North America, Chicago, 1974.) Submitted to Radiology.

Raju, M.R.; Dicello, J.F.; Trujillo, T.T.; and Kligerman, M.M. Effect of Mesons on Cells in Culture. (Paper presented at the Radiological Society of North America, Chicago, 1974.) Submitted to Radiology.

Kligerman, M.M.; Preoperative Radiation in Cancer Therapy. (Paper presented at the National Conferences on Advances in Cancer Management, New York, 1974.) Cancer, in press.

Kligerman, M.M.: "Chemotherapy Enhancement of Radio-sensitivity and Clinical Radiocurability." In: The Biological and Clinical Basis of Radiosensitivity. Springfield, Ill.: Charles C. Thomas. 1974. pp. 528-534.

MOST RECENT PUBLICATIC (Continued)

.. Kligerman, Morton M.; West, G.; Dicello, John F.; Sternhagen, C.J.; Barnes, J.E.; Loeffler, Kenneth; Dobrowolski, Frances; Davis, H.T.; Bradbury, James N.; Lane, Thomas F.; Petersen, Donald F.; and Knapp, Edward A. "Initial Comparative Response to Peak Pions and X-rays of Normal Skin and Underlying Tissue Surrounding Superficial Metastatic Nodules," presented at the 57th Annual Meeting of the American Radium Society, San Juan, Puerto Rico, May 1975. Submitted for publication.

. Kligerman, Morton M. Radiation Oncology in Physiopathology of Cancer, ed. F. Homburger, 1975. In press.

.. Kligerman, Morton M. "Irradiation of the Primary Lesion of the Rectum and Rectosigmoid," JAMA 231: 1381-1384, 1975.

.. Todd, Paul; Shonk, Carl R.; West, Gary; Kligerman, Morton M.; and Dicello, John. "Spatial Distribution of Effects of Negative Pions on Cultured Human Cells," Radiology 116: 179-180, 1975.

. Kligerman, Morton M.; Dicello, John F.; Davis, Herbert T.; Thomas, Robert A.; Sternhagen, Charles J.; Gomez, Leo; and Petersen, Donald F. "Initial Comparative Response of Experimental Tumors to Peak Pions and X-rays," Radiology 116: 181-182, 1975..

SECTION II – PRIVILEGED COMMUNI    .ION

## BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Charles Andrew Kelsey | Professor of Radiology, Chief, Biomedical Div., Cancer Res. Treat. Ctr., UNM | [redacted] |

| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
|---|---|---|
| [redacted] | U.S. | ☒ Male ☐ Female |

EDUCATION (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | B.S.<br>Ph.D. | [redacted] | Physics<br>Physics |

HONORS

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Medical Physics | Medical/Clinical Aspects |

RESEARCH SUPPORT *(See instructions)*

Renewal application submitted, $2,223,425 requested Year 1, $8,200,125 requested 5 years.

RESEARCH AND/OR PROFESSIONAL EXPERIENCE *(Starting with present position, list training and experience relevant to area of project. List or most representative publications. Do not exceed 3 pages for each individual.)*

1975 - Present Professor of Radiology/Chief, Biomedical Div., Cancer Research & Treatment Center, U. of New Mexico
1971-1975 Professor of Radiology-Medical Physics-[redacted]
1968-1971 Assoc. Professor of Radiology-Medical Physics [redacted]
1965-1968 Asst. Professor of Radiology-Medical Physics [redacted]
1964-1965 Asst. Professor of Physics- [redacted]
1963-1964 Instructor & Research Assoc.-Physics Department-[redacted]
[redacted] Postdoctoral Research Assoc.-Physics Department [redacted]

REPRESENTATIVE PUBLICATIONS: See attachments

Kelsey, C.A., Minific, F.D. and Hixon, T.J.; Applications of Ultrasound in Speech Research. J. Speech and Hearing Research 12:3, 564-575, 1969.

Kelsey, C.A., Hixon, T.J. and Minific, F.D.; Ultrasound Measurement of Lateral Pharyngeal Wall Displacement. Transactions on Biomedical Engineering 16: 143-147, April 1969

Kelsey, C.A.; A Time Motion Display Method for "A Scope" Ultrasonic Units. J. Assoc. for Advancement of Medical Instrumentation 4: 165-166, August 1970.

Beach, J.L. and Kelsey, C.A.; Doppler Monitoring of Vocal Fold Motion. J.A.S.A. 46: 1045-1047, 1969.

Kelsey, C.A., Crummy, A.B. and Schullman, E.; A Comparison of Ultrasonic and Cineradiographic Measurement of Lateral Pharyngeal Wall Motion. Investigative Radiology 4: 241-245, July-August 1969.

Kelsey, C.A., Woodhouse, R.J. and Minifie, F.D.; Coarticulation Effects in the Pharynx. J.A.S.A. 46: 1016-1019, 1969.

Minifie, F.D., Hixon, T.J., Kelsey, C.A. and Woodhouse, R.J.; Motion of the Lateral Pharyngeal Wall Motion in Cleft Palate Patients. Submitted to Cleft Palate Journal.

Kelsey, C.A. and Ewanowski, S.J.; Lateral Pharyngeal Wall Movement During Esophageal Voice Production. Arch. Otolaryng. 92: 167-172, August 1970.

Kelsey, C.A.; Chapter III-Radiation Detection Instruments. In: Handbook of Nuclear Medicine, Ed., Y. Wang, Chemical Rubber Publishers, 1969.

Swingle, J. and Kelsey, C.A.; Chapter IV-Radiation Dosimetry. In: Body Section Radiography, Ed., M. Valvasori, Charles C. Thomas Publishers, 1969.

Kelsey, C.A., Boone, M.L.M., Hevezi, J.M., Wiley, A.L. and Spalek, G.C.; Gas Target Source for Neutron Radiation Therapy. Radiology 98: 686-688, 1971.

Kelsey, C.A., Boone, M.L.M., Hevezi, J.M., Wiley, A.L., Spalek, G.C., Forsen, H.K. and Winter, W.; Gas Target Source for Fast Neutron Cancer Therapy. Proc. of Am. Nuclear Society National Topical Meeting on Neutron Sources and Applications. Report CONF 710402, Vol. II, available from NTIS, Springfield, Virginia 22151.

Minifie, F.D., Kelsey, C.A., Zagzebski, J.A. and King, T.W.; Ultrasonic Scans of the Dorsal Surface of the Tongue. J.A.S.A. 49: 1857-1869, 1971.

Kelsey, C.A., Curet, L.B., Crummy, A.B. and Cytacki, E.P.; Clinical Experiences in Ultrasonic Scanning of Obstetrical Patients. Wisconsin Medical Journal, Vol. 71, June 1972.

Kelsey, C.A., Ewanowski, S.J., Bless, D.L. and Crummy, A.B.; Lateral Pharyngeal Wall Motion As A Predictor of Surgical Success in Velopharyngeal Insufficiency. New England Journal of Medicine 287: 64-68 (July 1972).

PUBLICATIONS (cont.)

Cytacki, E.P. and Kelsey, C.A.; A contour Monitor for Radiation Therapy Patients. IEEE Transactions on Biomedical Engineering, BME-19, No. 2: 160-162, March 1972.

Parnell, C.J. and Kelsey, C.A.; Shielding of Fast Neutron Sources for Cancer Therapy. Health Physics, 23, 576-578, October 1972.

Kelsey, C.A., Lane, R.G. and Connor, W.G.; Measurement of Patient Movement During Radiation Therapy. Radiology 103: No. 3, pp. 697-698 (June 1972).

Crummy, A.B., Ewanowski, S.J., Bless, D.M. and Kelsey, C.A.; Evaluation of Lateral Pharyngeal Wall Motion in Velopharyngeal Insufficiency. Revista Interamericana de Radiologica (Lima, Peru) 6: 56-58, 1971.

Kelsey, C.A., Spalek, G.C., DeLuca, P.M., Chenevert, G.M., McCullough E.C. and Nickles, R.J., A Recirculating Gas Target Neutron Source for Radiation Therapy, Proceedings of the Symposium on Neutron Dosimetry in Biology and Medicine, Vol. 11, 811-19 EUR4896 (May 1972)

Beach, J.L. and Kelsey, C.A., Geometric Penumbra Calculations for a Gas Target Neutron Source, Radiology 111 199-201 (1974)

Beach, J.L. and Kelsey, C.A., Evaulation of a Continuously Variable Collimator for 14 MeV Neutrons. Physics in Medicine and Biology, 20: 47-54 (1975)

Kelsey, C.A., and Bjarngard, B.E., Training Programs in Medical Physics, AAPM Quarterly Bulletin 7 146-148 (1973)

Jones, K.M. and Kelsey, C.A., Experimental Determination of the Need for a Multitaper Collimator for Neutron Radiotherapy, Medical Physics, 1 215-219 (1974)

Jones, K.M., Cytaki, E.P., and Kelsey, C.A., An Associated Particle System for Evaluation of 15 MeV Neutron Beam Sheilding and Collimator Design, Physics in Medicine and Biology, 20 131-136, (1975)

SECTION II – PRIVILEGED COMMUNICATION

# BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Smith, Alfred R. | Radiation Physicist | [redacted] |

| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
|---|---|---|
| [redacted] | US | ☒ Male ☐ Female |

EDUCATION (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | B. A.<br>M. S.<br>Ph.D. | [redacted] | Mathematics<br>Physics<br>Physics |

HONORS

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Medical Physics | Radiation Physicist |

RESEARCH SUPPORT (See instructions)

RESEARCH AND/OR PROFESSIONAL EXPERIENCE (Starting with present position, list training and experience relevant to area of project. List all or most representative publications. Do not exceed 3 pages for each individual.)

1975-Present: Cancer Research and Treatment Center, University of New Mexico Radiation Physicist

1971-1974 : Assistant Physicist and Assistant Professor of Biophysics, [redacted]

1972- : Associate to the Faculty, [redacted]

1974- : Associate Physicist and Assistant Professor of Biophysics, [redacted]

[redacted] : Advanced Senior Fellow in Medical Physics, [redacted]

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PUBLICATIONS

ALFRED R. SMITH

1. A. R. Smith and R. W. Mires: Low-Temperature Magnetic Anisotropy in $Al_2O_3:V^{3+}$. The Physical Review 172:265-268, August 1968.

2. D. J. Arnold, A. R. Smith, and R. W. Mires: Low-Temperature Magnetic Susceptibilities of $Al_2O_3:V^{3+}$. The Physical Review B 1: 2355-2356, March 1970.

3. A. R. Smith, D. J. Arnold, and R. W. Mires: Magnetic Susceptibility of $Al_2O_3:Ti^3$. The Physics Review B 2:2323-2334, October 1970.

4. M. Greenwood, R. W. Mires, and A. R. Smith: Magnetic Anisotropy of $V_2O_3$ Single Crystals. The Journal of Chemical Physics 54 (3): 1417-1418, February 1971.

5. C. A. Kahlig, A. R. Smith, and P. R. Almond: Film Calibration of a Strontium 90 Ophthalmic Applicator. The American Journal of Roentgenology, Radium Therapy and Nuclear Medicine 118:909-912, August 1973.

6. J. B. Smathers, V. Otte, P. R. Almond, and A. R. Smith: The Fast Neutron Beam Radiotherapy Installation at the TAMVEC Cyclotron. European Journal of Cancer 10:264-265, October 1973.

7. P. R. Almond, A. R. Smith, J. B. Smathers: The Fast Neutron Beams from the TAMVEC Cyclotron. European Journal of Cancer 10:313-314, October 1973.

8. A. R. Smith, P. R. Almond, and L. Delclos: Evaluation of $^{252}Cf$ Neutron Emitter for Interstitial and Intracavitary Radiation Therapy. European Journal of Cancer 10:369-370, October 1973.

9. A. R. Smith, P. R. Almond, J. B. Smathers, and V. A. Otte: Dosimetric Properties of the Fast Neutron Therapy Beam at TAMVEC. Radiology, 113 (1):187-193, October 1974.

10. P. R. Almond, A. R. Smith, J. B. Smathers, and V. A. Otte: Dosimetric Properties of the Fast Neutron Therapy Beams at TAMVEC. Proceedings: Second Symposium on Neutron Dosimetry in Biology and Medicine, pp. 359-372, September 30 - October 4, 1974.

11. P. R. Almond, A. R. Smith, J. B. Smathers, and V. A. Otte: Dosimetry Intercomparisons between Fast Neutron Radiotherapy Facilities. Proceedings: Second Symposium on Neutron Dosimetry in Biology and Medicine, pp. 663-676, September 30 - October 4, 1974.

# BIOGRAPHICAL SKETCH

*(Give the following information for all professional personnel listed on page 3, beginning with the Principal Investigator. Use continuation pages and follow the same general format for each person.)*

| NAME | TITLE | BIRTHDATE (Mo., Day, Yr.) |
|---|---|---|
| Robert Katz | Professor | [redacted] |

| PLACE OF BIRTH (City, State, Country) | PRESENT NATIONALITY (If non-U.S. citizen, indicate kind of visa and expiration date) | SEX |
|---|---|---|
| [redacted] | USA | ☒ Male ☐ Female |

EDUCATION (Begin with baccalaureate training and include postdoctoral)

| INSTITUTION AND LOCATION | DEGREE | YEAR CONFERRED | SCIENTIFIC FIELD |
|---|---|---|---|
| [redacted] | BA<br>MA<br>PhD | [redacted] | Physics<br>Physics<br>Physics |

HONORS

[redacted]
Faculty Lectureship Award, [redacted] 1962
Alexander von Humboldt Senior US Scientist Award 1974

| MAJOR RESEARCH INTEREST | ROLE IN PROPOSED PROJECT |
|---|---|
| Structure of Particle Tracks | Central to the theory of RBE of high LET radiations. |

RESEARCH SUPPORT (See instructions)

AEC Contract AT(11-1)-1671, Theory of RBE 1 Jan to 31 Dec 1975 $50,000. This contract has provided a cumulative support of $216,000 from 1 Jan 1967 to 31 Dec 1975, for the study of fundamental aspects of the theory of RBE.

NSF(RANN) Grant GI-351356, Application of the Theory of Track Effects to Radiotherapy, $50,000, 1 January to 31 December 1975. This is to initiate development of a new photographic rem dosimeter. It is for the proof of the concept that this can be done, rather than to accomplish the device.

RESEARCH AND/OR PROFESSIONAL EXPERIENCE (Starting with present position, list training and experience relevant to area of project. List all or most representative publications. Do not exceed 3 pages for each individual.)

Professor of Physics, University of Nebraska, 1966-present
Professor of Physics (associate, assistant) [redacted] 1949-66
Physicist, [redacted] 1943-46
Radiologist, [redacted] 1939-43

Research: Structure of particle tracks, RBE-LET effects, nuclear physics, instrumentation for cereal science (detection of internal insect infestation by soft x-ray radiography), precipitation static devices, radiography of structural members in aircraft.

Author or coauthor of 2 books, 1 chapter, 3 patents, 56 journal articles, and some 62 papers in abstracts or proceedings

A partial list of recent publications is attached.

## I. Refereed Journals

1. E. J. Kobetich and R. Katz, WIDTH OF HEAVY ION TRACKS IN EMULSION. Phys. Rev. 170, p. 405-411 (1968).

2. E. J. Kobetich and R. Katz, ELECTRON ENERGY DISSIPATION. Nuclear Instr. and Meth. 71, p. 226-230 (1969).

3. R. Katz and E. J. Kobetich, FORMATION OF PARTICLE TRACKS. Radiation Effects 3, p.169-174 (1970).

4. R. Katz and E. J. Kobetich, PARTICLE TRACKS IN EMULSION. Phys. Rev. 186, p. 344-351 (1969).

5. L. T. Chadderton, F. G. Krajenbrink, R. Katz, and A. Poveda, STANDING WAVES ON THE MOON. Nature 223, p. 259-263 (1969).

46. R. Katz and E. J. Kobetich, RESPONSE OF NUCLEAR EMULSION TO ELECTRON BEAMS. Nuclear Instr. and Meth. 79, p. 320-324 (1970).

47. B. Ackerson, C. M. Sorensen, and R. Katz, ANALYSIS OF A BREAK-UP USING MEAN TRACK WIDTH AND BLOB MEASUREMENTS. Nuclear Instr. and Meth. 92, p. 81-83 (1971).

4 R. Katz, B. Ackerson, M. Homayoonfar and S. C. Sharma, INACTIVATION OF CELLS BY HEAVY ION BOMBARDMENT. Radiation Research 47, p. 402-425 (1971).

49. T. E. Furtak and R. Katz, SIMULATION OF PARTICLE TRACKS IN EMULSION. Radiation Effects 11, p. 195-199 (1971).

50. R. Katz, S. C. Sharma, and M. Homayoonfar, IRRADIATION EQUIVALENCE. Health Physics 23, p. 740-742 (1972).

51. R. Katz, S. C. Sharma, and M. Homayoonfar, DETECTION OF ENERGETIC HEAVY IONS. Nuclear Instr. and Meth. 100, p. 13-22 (1972).

52. R. Katz and S. C. Sharma, RESPONSE OF CELLS TO FAST NEUTRONS, STOPPED PIONS AND HEAVY ION BEAMS, Nuclear Instr. and Meth. 110, p. 93-116 (1973).

53. R. Katz and S. C. Sharma, HEAVY PARTICLES IN THERAPY, AN APPLICATION OF TRACK THEORY, Physics in Medicine and Biology 19, 413- 435 (1974).

54. R. Katz and S. C. Sharma, CELLULAR SURVIVAL IN A MIXED RADIATION ENVIRONMENT, International Journal of Radiation Biology 26, 143-146 (1974).

55. R. Katz and S. C. Sharma, RBE-DOSE RELATIONS FOR NEUTRONS AND PIONS in press Physics in Medicine and Biology

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## A. Introduction

### 1. Objective:

Radiation herapy is a major method for the treatment of cancer. The potential advantages of the use of high LET radiations such as negatively-charged pions in order to improve the capabilities of radiation therapy have been recognized for some time. Physical and biological measurements with high intensity pion beams are presently being conducted at the Los Alamos Scientific Laboratory in Los Alamos, NM, TRIUMPF in Vancouver, B.C., SIN in Zurich, Switzerland, Stanford University in Stanford, CA, and NIMROD at the Rutherford High Energy Laboratory in England. In addition, the Soviet Union is building a pion generator which will include the capability of biomedical research. The first preclinical human radiobiological experiments with negative pions were initiated at the biomedical channel of the Clinton P. Anderson Meson Physics Facility (LAMPF) in October, 1974 (Kligerman, et al., 1975).

The physical and biological effects of pions in radiotherapy are expected to be quite different from those produced by radiations conventionally employed. In order to utilize these unique advantages, one must thoroughly understand the mechanics of producing therapeutically useful beams, the spatial distribution in dose and distribution of energy deposition in tissues, and the biological effects of pions. It is therefore necessary to develop accurate methods for beam development, collimation, dosimetry, and treatment planning in order to achieve meaningful radiobiological experiments and effective radiotherapy. Preclinical development with this new modality for treating cancer will be expensive and, necessarily, limited in scope. These studies will be enhanced, and the total cost reduced, by taking full advantage of computational and analytical methods.

Under this proposed program, theoretical work related to pion therapy will be carried out. The overall objective is to provide, by means of calculations, quantitative information that cannot be obtained, or would be more difficult or expensive to obtain, experimentally, but which is necessary for patient treatments. These calculations will contribute toward

a. The development of broad beams appropriate for the treatment of a variety of tumors.

b. The development of collimators, wedge filters, and boluses necessary for the maximum utilization of the unique properties of pions.

c. Precise and accurate dosimetry necessary for radiobiology and radiotherapy.

d. Precise and accurate treatment planning.

e. Understanding the preclinical and clinical results and comparing the results of various institutions with conventional and high LET radiations.

Although it is the specific intent of this proposal that the calculational results be directed toward pions, it should be noted that these methods will be directly applicable to other types of high LET radiations. In some cases, no modifications of existing techniques will be necessary (e.g. proton and neutron beams). Even in those cases where additional work is required to adapt the procedures to specific particles, it will be possible at considerably less manpower and expense, because the basic techniques will have already been established.

## 2. Background

The radiation field in the vicinity of a stopping negatively-charge pion beam is complex because of the numerous types and wide energy ranges of the charged and uncharged particles that result when a negatively-charged pion is captured by a nucleus (see, for example, Armstrong and Chandler, 1974A). This radiation field is composed of a mixture of high and low LET (linear energy transfer) particles, the biological effectiveness of which is dependent upon numerous factors, such as beam momentum, contribution of beam contaminants (muons and electrons), phantom composition, and spatial position. Calculations indicate that for $\pi^-$ beams specified so that the absorbed dose is relatively constant over the π- stopping region, the LET spectrum and cell survival can vary substantially over the stopping region (Armstrong and Chandler, 1974B; Dutrannors, et al., 1973). For pion dosimetry and radiobiology directed toward radiotherapy, it is important to know not only the spatial distribution of the total absorbed dose but also the spatial variation of the biological effects.

The complex nature of the radiation field must be taken into consideration in every aspect of the development of a pion therapy program, from channel design, through radiological physics and biology, to patient treatment. Calculational methods offer a way of reducing the total minimum effort needed, and, at the same time, increasing the reliability of the results. In 1972, the Neutron Physics and Health Physics Divisions of the Oak Ridge National Laboratory were funded for two years by the National Science Foundation under its RANN (Research Applied to National Needs) program to develop calculational methods applicable to pion therapy. As a result of this grant, two computer codes were developed. The first of these, the result of the work performed by the Neutron Physics Division, is a versatile, multi-purpose computer code capable of handling a number of particle types over a large range in energy in a variety of target materials and geometries. The second code, developed by the Health Physics Division, is a simpler, faster code aimed specifically at the problems of the interaction of pion beams in tissue or the elements in tissue.

Armstrong and Chandler (1974A) developed a high-energy transport code (HETC) which can be used to calculate the spatial distribution of absorbed dose (isodose contours), LET spectra, spatially dependent cell survival probabilities, and the corresponding RBE's (relative biological effect) and OER's (oxygen enhancement ratios). Detailed discussions of the code are presented by Armstrong, et al. (1972) and Armstrong and Chandler (1948B). A summary of these references is presented here.

This code uses Monte Carlo techniques based on theoretical models for nuclear interaction to determine the energy, angle, and multiplicity of the particles produced in nucleon-nucleus and pion-nucleus interactions. The code also takes into account pion captures. The Monte Carlo method selects energy, direction, and spatial coordinates of the primary particles from input data and computes the trajectory of each primary and secondary particle. Charged-particle energy loss resulting from atomic excitation and ionization is taken into account along with multiple Coulomb scattering, elastic and nonelastic nucleon and pion collisions with hydrogen and other nuclei, negative pion capture at rest, pion and muon decay in flight and at rest, and elastic and inelastic neutron collisions.

For nonelastic collisions with nuclei other than hydrogen the intranuclear-cascade-evaporation model of Bertini and Guthrie (1971) is used for pion collisions at all energies and for nuclei at energies greater than 15 MeV. Above 15 MeV, neutron elastic collisions with nuclei other than hydrogen are taken into account by using experimental data and data from optical-model calculations. Proton and pion elastic collisions with nuclei othen than hydrogen are neglected.

Nucleon collisions with hydrogen for energies greater than 15 MeV are treated by use of the intranuclear-cascade calculations.

Neutron collisions for energies from thermal to 15 MeV are treated by the use of experimental cross section data. Protons with energies less than 15 MeV and heavy ions are assumed to slow down without undergoing nuclear interaction and the slowing down distance is neglected.

Positively charged pions coming to rest are assumed to decay. Negatively charged pions coming to rest are assumed to undergo nuclear capture. The type of nucleus capturing a pion is determined by the Fermi-Teller Z law (Fermi and Teller, 1947).

Armstrong and Chandler also have developed a preliminary version of a computer code to calculate the response of ion chambers and proportional counters placed in the radiation field of stopping $\pi-$ mesons, and one calculation has been made using this code. Since the detailed and extensive data on particle-production from $\pi-$ captures needed for such studies are not presently available from measurements, this code uses the theoretical nuclear model described previously to determine the energy, direction, and particle type of each particle produced by the $\pi-$ capture. A Monte Carlo calculation is performed for each capture, and the event spectrum (i.e., the number of events per unit y, where y is the lineal energy density) and the energy deposition (dose as a function of y) by each charged-particle trajectory is determined using a sub-routine version of a code developed by Armstrong and Chandler (1973) for stopping powers and ranges. The code also computes the composite LET spectra and the contributions to these spectra by various types of charged particles. By using Monte Carlo methods, fluctuations in particle production and correlations caused by more than one particle per capture contributing to the energy deposition (i.e., the so-called "V - effect" (Kellerer, 1971) are properly included. Another advantage of this calculational approach is that arbitrary material compositions for the phantom and detector can be taken into account. At present the code is programmed for spherical counters, although the spatial distribution of the $\pi-$ is arbitrary.

Turner, et al. (1972) developed a computer code, PION-1, also capable of calculating isodose contours and cell survival as a function of position. PION-1 was designed to treat all processes which pions undergo in a manner sufficiently realistic to accurately simulate real pion transport for radiotherapy applications. Experimental values of the cross sections have been used, when available, to determine pion-nucleon interactions. These values can be revised or supplemented in the code should later data become available. All relevant pion nuclear reactions are programmed into PION-1: pion absorption, one- and two-nucleon knockout, and charge exchange. When an incident pion enters a target, the Monte Carlo technique is used to determine its history, based on these cross sections. As the pion penetrates the target, it undergoes multiple Coulomb scattering and slows down in accordance with the stopping-power formula for charged particles. Range straggling is included. When a nuclear reaction occurs, the code selects the type of reaction and the energies and initial directions of travel of any secondary particles produced. The secondary particles are followed individually in the calculations. The use of numerical data, rather than nuclear models, allows the program to process particles rapidly.

For analysis, the target is divided into a number of subvolumes. A record is kept in the program of each particle that traverses or stops or starts in every subvolume. The energy deposited, the LET of the radiation, and other physical quantities of interest are tabulated, along with data needed for cell survival models.

The different characteristics of the two codes may be summarized as follows. The HETC code is a full-scale, pure Monte Carlo method capable of treating the interactions of a variety of particles over a large energy range in essentially any material. The accuracy of the results is essentially limited only by the availability and accuracy of the input data. The versatility of this code necessitates that it require a relatively large amount of computer time.

PION-1 is a simplified program which limits itself specifically to pion beams (including the associated muon and electron contamination) in tissue-like materials. Certain types of interactions and results are not available from this method. Conversely, however, PION-1 runs rapidly. In a typical calculation $10^4$ incident pions, as well as all the secondary particles they produce, are processed completely. The statistical data are then excellent for plotting depth-dose and isodose contours and for compiling LET distributions and data for cell survival. The complete run requires about 10 minutes on the IBM 360/91. The processing of neutrons requires by far the most time. If neutrons are not processed, the running time for $10^4$ pions and the other secondary particles is less than three minutes.

3. Rationale:

Only by the availability of a well-coordinated experimental-calculational effort will maximum benefit be obtained from the results of preclinical experiments and human trials at minimum cost. The proposed calculations can perform an important role in providing guidance to beam design experimental work, in interpreting the physical and biological data, and in providing data needed for treatment planning.

An important feature of the calculational method that will be used is that the physics of nuclear interactions (e.g., correlations in particle production from $\pi^-$ captures) and energy deposition will be treated in detail. By combining detailed treatment of the physics and Monte Carlo techniques, the calculations will provide not only the above results but also much useful ancillary information (e.g., contribution of multiparticle events, the "tissue-equivalence" of the counter wall, the effect of the finite size of the detectors, etc.). This calculational approach can also provide the physics input needed for applying any of the available biological models (e.g., Kellerer and Rossi, 1972; Katz, et al., 1972; Chatterjee and Tobias, 1974) to make RBE and OER predictions. In addition, it offers a method for the investigation of new models for relating physical data to biological data.

## B. Specific Aims

### 1. Treatment Planning:

Both codes, as they presently exist, are capable of generating isodose contours for various beam configurations incident on complex systems. The necessary data are available at this time from the results of these codes to calculate contours of constant effective dose and dose equivalent for certain biological systems. Some results are illustrated in Figs. 1 to 6. It is presently possible to do these calculations for various beam configurations with provisions for treating inhomogeneities in the patient.

It is proposed that this work be continued in order (1) to compare the two methods with each other so that one can determine the validity of the simplifications utilized in PION-1, (2) to compare the calculations with experiments in order to establish the reliability of the input data and methods used, (3) to modify the existing codes, if necessary, in order to improve the accuracy of the results to a level adequate for routine calculations and to supply the clinical physicist and therapist with appropriate information in a desirable format.

It is the intention of this proposal that HETC be utilized only in the initial stages of development for treatment planning. Once the accuracy of PION-1 has been established, its speed and lower operating cost would dictate its utilization for this application.

Calculations would be performed with PION-1 for specific treatment configurations including the appropriate regions of different density and composition (bone, air, etc.) through which the beam must pass. A portion of PION-1 has already been run on the LASL computer and it runs sufficiently fast that it is a possible candidate for inclusion in the first generation treatment planning code being developed at Los Alamos and elsewhere. We would assist in the development of a treatment planning code at Los Alamos, incorporating part or all of PION-1 as appropriate. Treatment planning for pions is complex and PION-1 will be a valuable tool at least during the preclinical and early clinical trials. PION-1 will be used also to check various schemes which might be used in developing a simplified treatment planning code.

### 2. Beam Tuning and Shaping:

This particular aim is, in fact, a part of treatment planning. However, some of those characteristics that make negative pions unique for radiotherapy also make beam tuning and shaping unusually difficult. The large number of complex reactions that take place as pion beams are shaped and collimated, along with the fact the dose alone is inadequate to define the expected biological effect, will require relatively elegant calculations for designing collimators, wedge filters, and boluses. Studies must include investigation of systems which produce sharp beam edges, uniform radiation quality, and biological effect at depth. Because pions are secondary particles (i.e., produced by the accelerator beam impinging on an appropriate target), it is unlikely that sufficient dose will ever be available to indiscriminately throw away large portions of the flux for beam shaping. Extreme care must be taken to produce the necessary beams at maximum intensity.

It is proposed that the present codes be used, as necessary, to supplement existing methods to achieve the above goals. In this respect, preliminary calculations have already begun to compare the calculations with existing experimental data for collimated pion beams and to develop broad beams necessary for typical treatment plans. For these calculations, the code most appropriate for the specific objecti[ve will] be utilized.

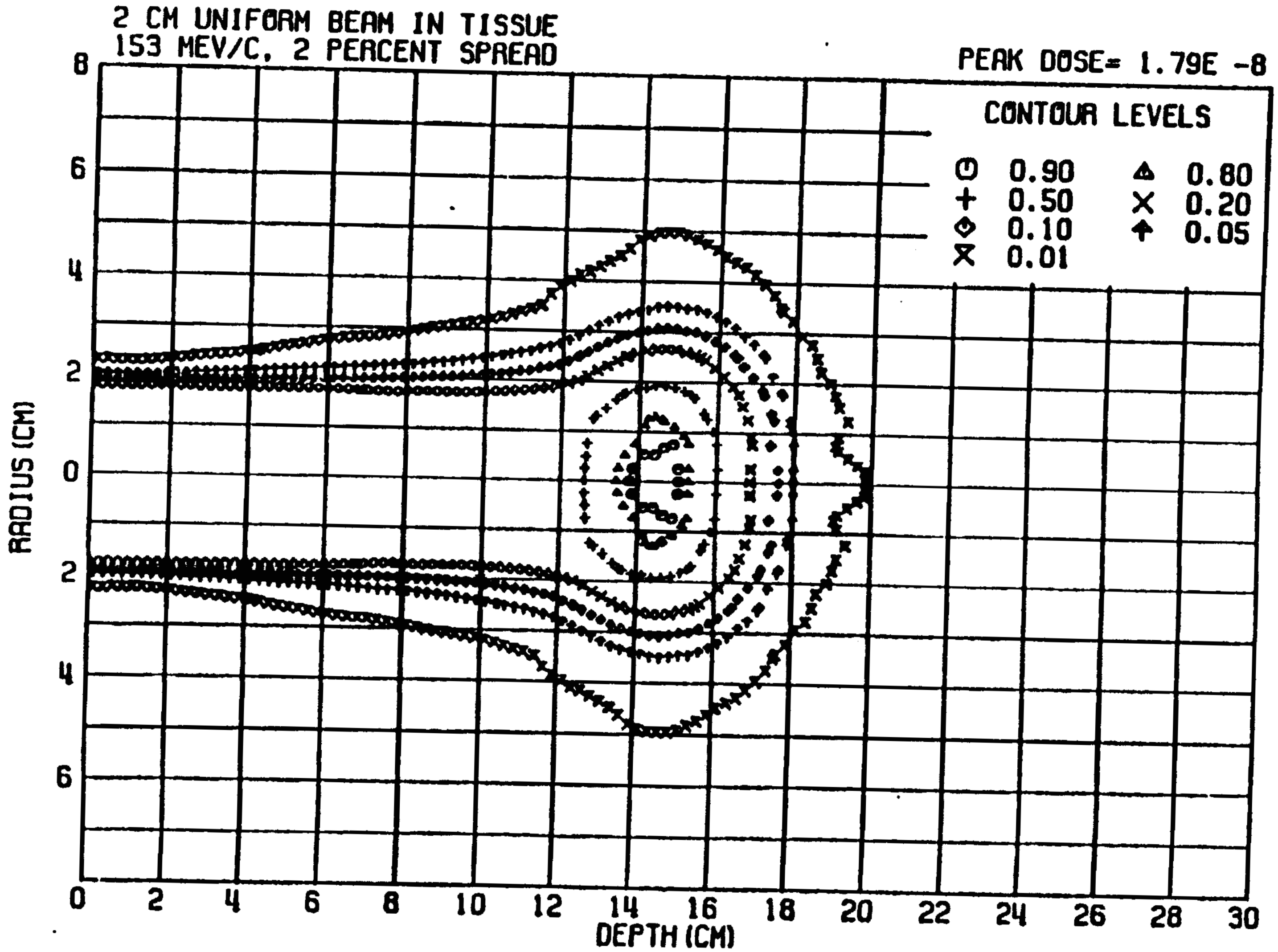


Fig. 1 - Isodose contours for parallel beam incident on homogeneous soft-tissue target. Distances are in cm (Hamm, et al, 1975)

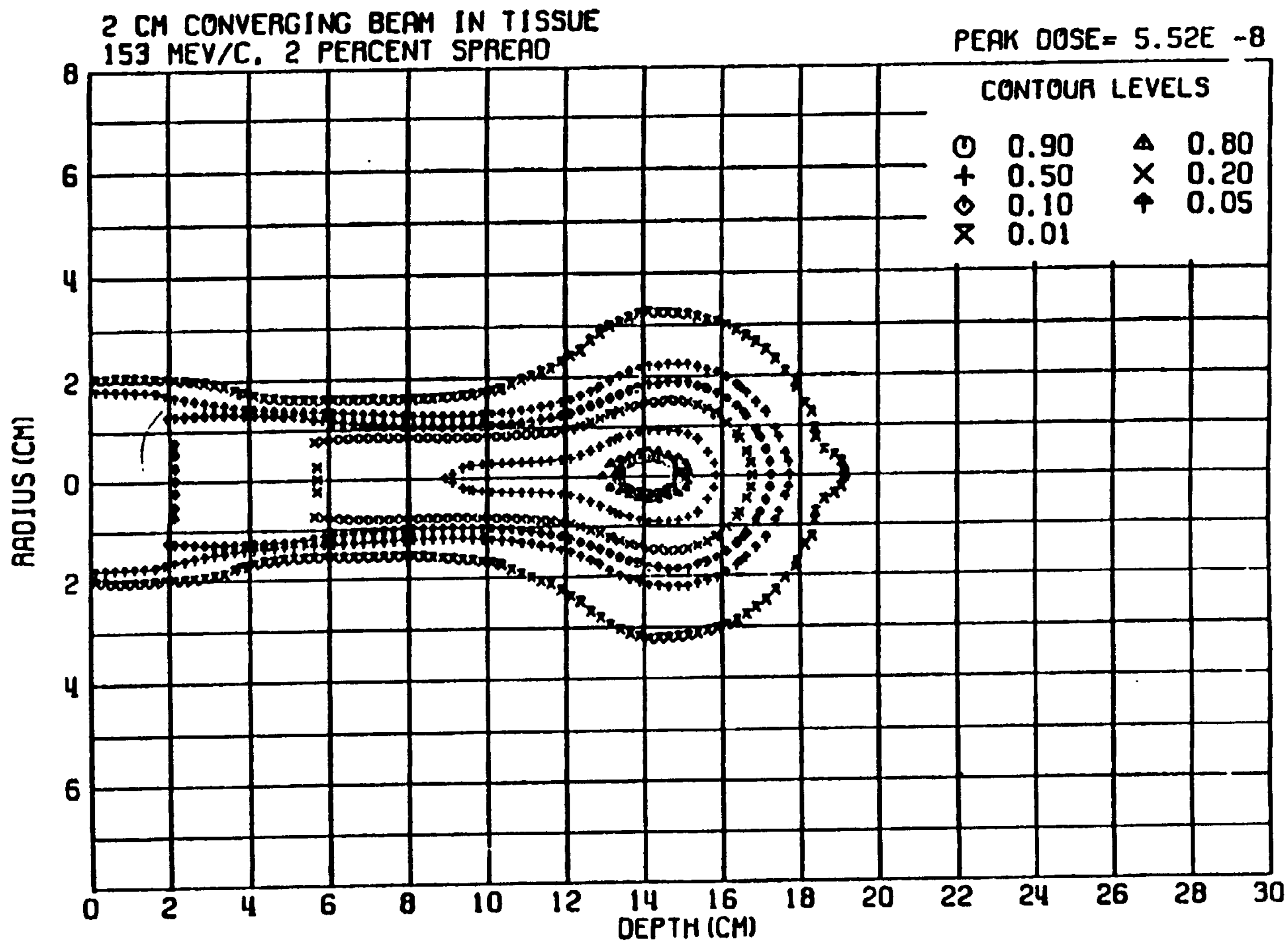


Fig. 2 - Isodose contours for convergent beam indicent on homogeneous soft-tissue target (Hamm, et al, 1975)

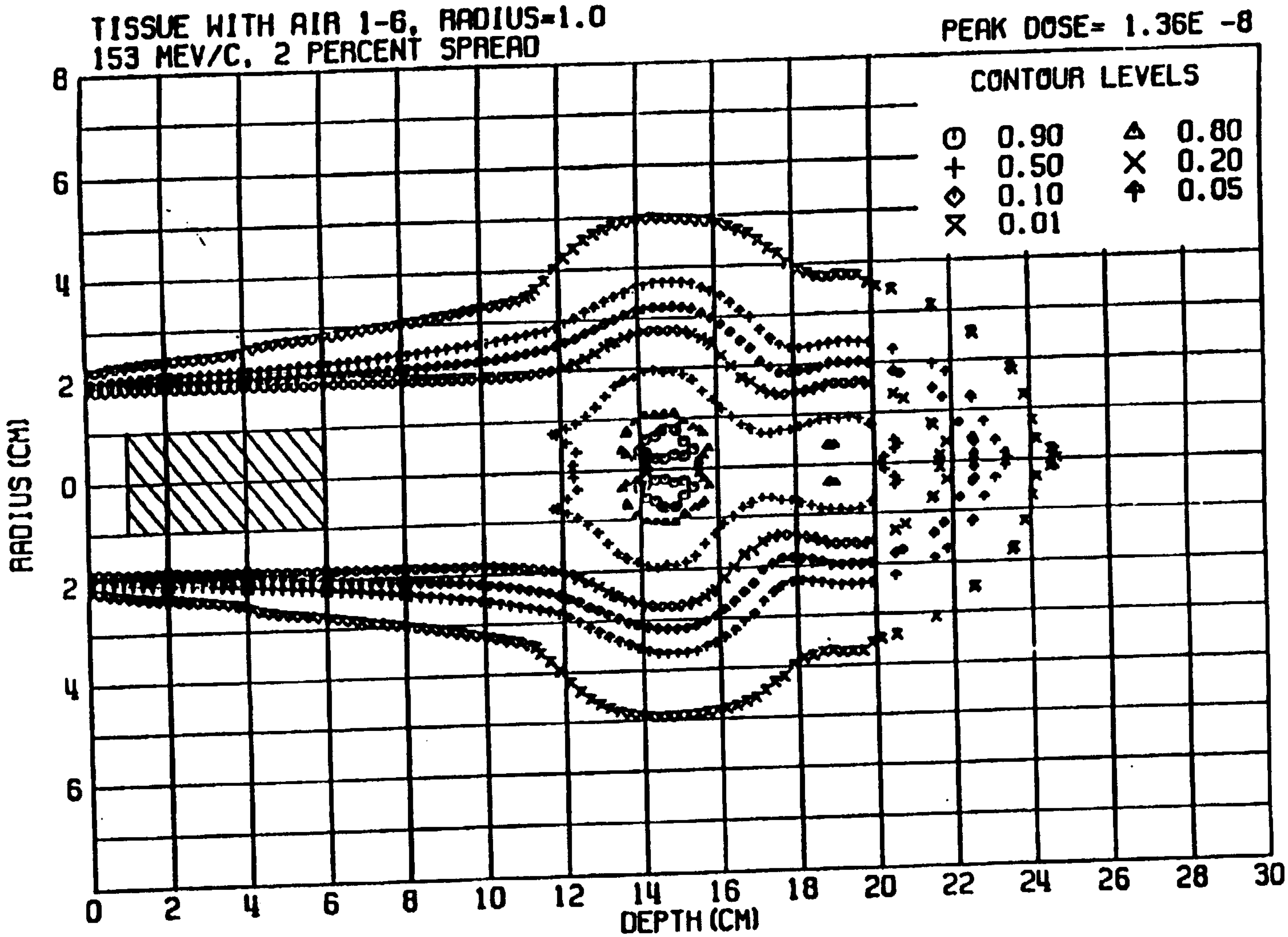


Fig. 3 - Isodose contours with air cylinder of radius 1.0 cm between 1 and 6 cm (Hamm, et al, 1975)

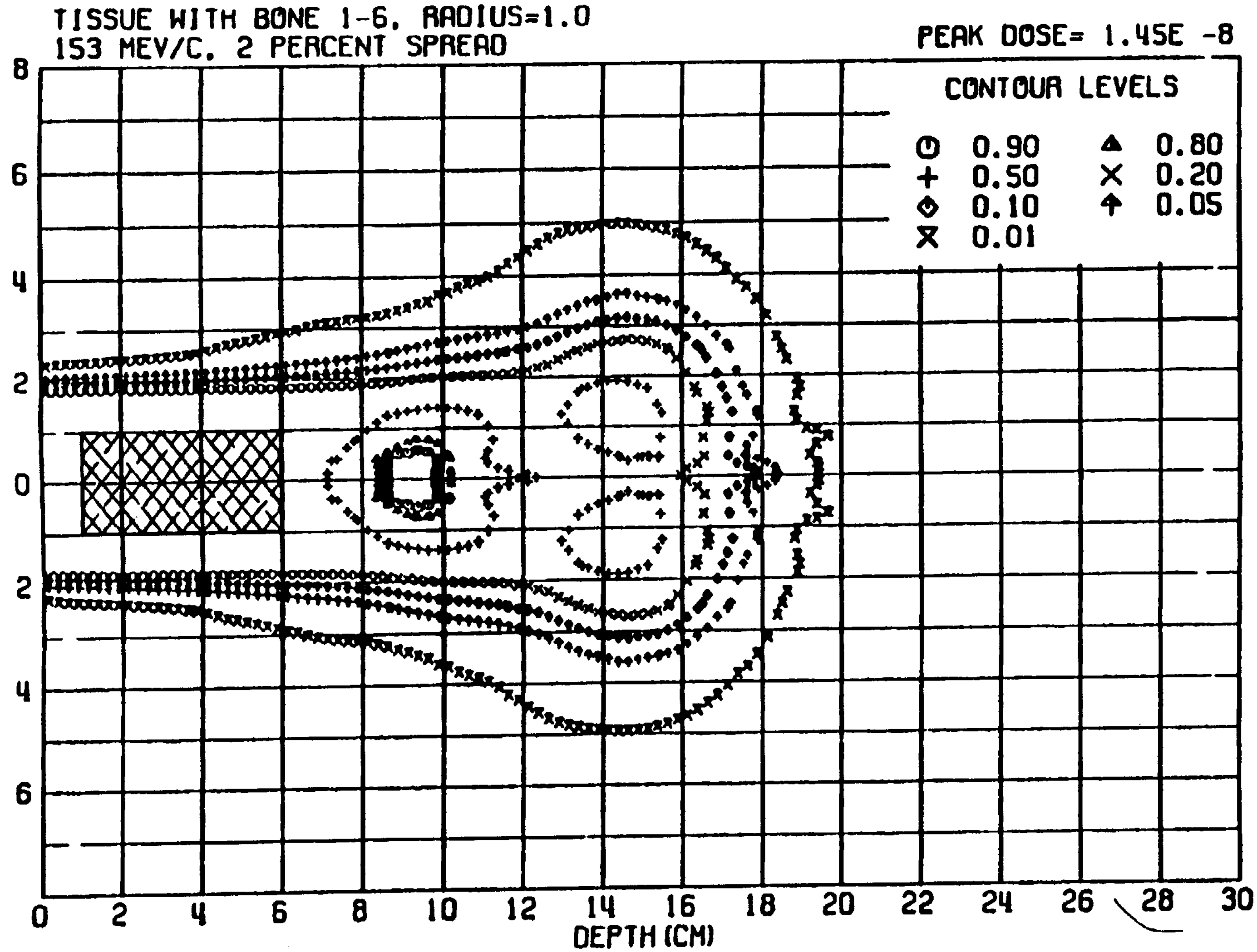


Fig. 4 - Isodose contours with bone cylinder of radius 1.0 cm between 1 and 6 cm (Hamm, et al, 1975)

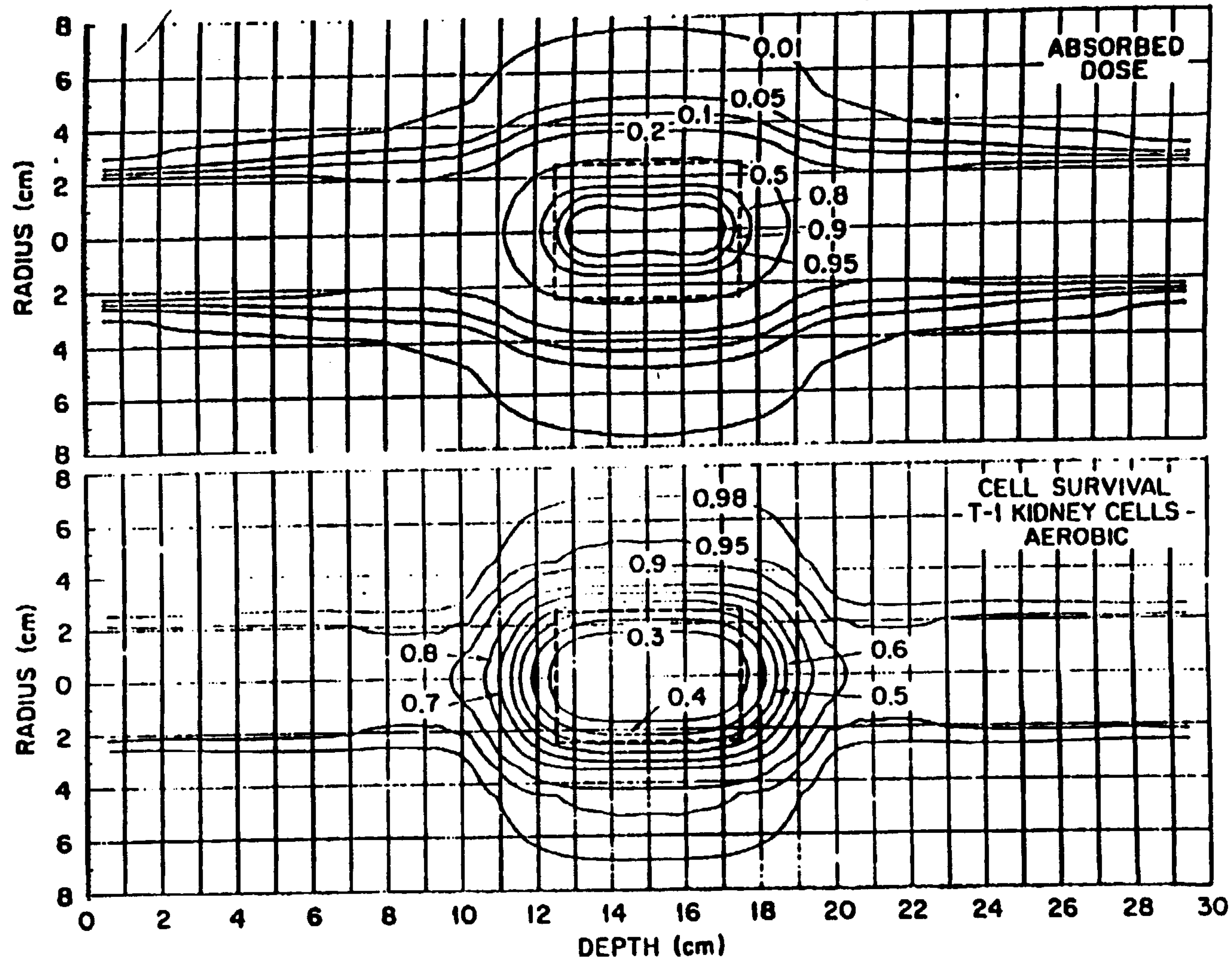


Fig. 5 Isodose and aerobic isosurvival contours for two-port entry. The isodose contours are labeled as fractions of the maximum dose, and the dose in rads per incident pion can be obtained by multiplying the contour values by $6.5 \times 10^{-9}$. The isosurvival contours are labeled as aerobic survival probability for $3.39 \times 10^{10}$ incident pions (Armstrong and Chandler, 1974B)

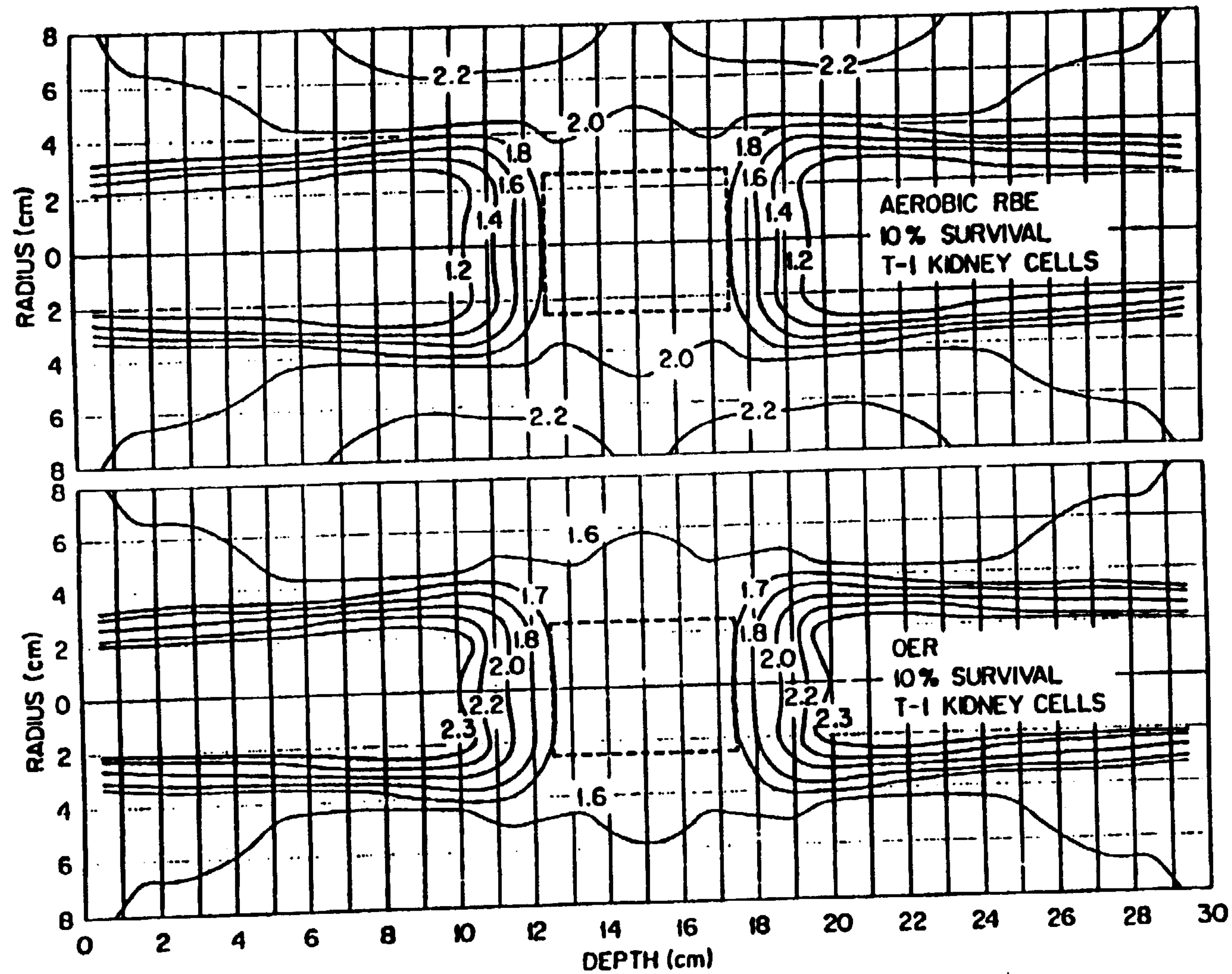


Fig. 6 Contours of constant aerobic RBE and OER at 10% survival for two-port entry (Armstrong and Chandler, 1974B)

3. Dosimetry and Radiological Physics

a. Determination of Absorbed Dose

Because of the high LET component of the dose delivered by pions, it is necessary to apply appropriate correction factors to the data obtained by conventional techniques in order to determine the actual absorbed dose. In addition, because the amount of high LET radiation varies as a function of depth and position, such corrections are necessary in order to determine relative doses as a function of position as well as absolute doses.

Calculated results will be obtained to aid in arriving at correction factors that can be applied so that the absolute absorbed dose in tissue can be estimated. The effect of the detector wall will be determined by computing the energy deposition spectra both for the wall composition actually used in the detector (e.g., "tissue-equivalent" plastic) and for a wall that has the composition of tissue. Although the difference in particle attenuation between "tissue-equivalent" plastic and tissue is small ($\lesssim$ 1%) (Armstrong and Chandler, 1974C), the difference in the $\pi^-$ capture products is significant, particularly for $\alpha$-particle production (e.g., see Armstrong and Chandler, 1974A), and corrections for wall compositions are expected to be important in estimating the absolute dose. {As discussed in Section 3.b. for the particular $\pi^-$ beam considered in the preliminary calculations (Armstrong and Chandler, 1976), the absorbed dose was $\sim$ 8% higher for a "tissue-equivalent" plastic wall (1/8" thick) than for a wall having a composition of "whole-body" tissue.}

The calculations will also be used to estimate the effects of (a) the perturbation of the radiation field caused by the finite size of the detector, (b) stopping power differences between "tissue equivalent" gas and tissue, and (c) the variation of W-values with particle type and energy.

It should be noted that while some measurements of the absolute absorbed dose using calorimeters are expected to be made, such measurements require rather large dose rates ($\gtrsim$ 10 rad/min) and will probably be made for only a few beam configurations. In addition, it is not clear that a tissue-equivalent calorimeter which minimally perturbs the pion dose distributions can be developed. Regardless, the corrections to be made to calorimetric measurements are not negligible. They are, in fact, comparable to those for other techniques (Dicello, 1976). Therefore, for low dose rates, as well as for the majority of the high dose-rate beams that will be used, calculated corrections to ion-chamber data, with occasional checks by calorimetric measurements, appear to be the most practical method for estimating the absolute dose. The calculations should be useful also in evaluating any differences in doses obtained by different measurement techniques, particularly for measurements of absolute and relative doses that are expected to be made at different pion facilities for intercomparison purposes.



b. Microdosimetry and LET Distributions

As mentioned previously, a code to calculate microdosimetric and LET spectra is operable, but to date a calculation for only one beam configuration has been made. Since this work is presently unpublished, a few of the results from this calculation will be discussed here. The case considered was that of a one-inch spherical cavity of "tissue-equivalent" (TE) gas located in the middle of a large, cylindrical (5 cm long) volume of stopping $\pi^-$ mesons in tissue. A simplified 4-element (H, C, N, O) representation of "whole-body" tissue was used. The TE gas (55.0% propane, 39.6% carbon dioxide, and 5.4% nitrogen by volume) was chosen to have a density such that the diameter of the cavity was 1.0 μm for unit density material. The cavity was surrounded by a 1/8-inch layer of TE plastic (Shonka type A-150, Shonka, 1959). It should be emphasized that in this calculation a pure $\pi^-$ beam was assumed, and the effects of incident muons and electrons were not included.

Figure 7 shows the computed event spectra, n(y) vs y, where n(y) is the relative number of events per unit y interval and y, the lineal energy density, is the energy deposited in the gas by the event divided by the mean chord length of the volume (2.3 the simulated diameter). The data in Fig. 7 labeled "total correlated" were computed using the sum of the energy depositions from all particles resulting from the same $\pi^-$ capture. Thus, correlations in the energy depositions which occur when more than one particle from the same capture deposit energy in the detector are included so that the total correlated spectrum is analogous to the spectrum that would be measured. Figure 7 also shows the event spectrum due to various particle types in which the energy deposition by particles of different types are considered separately in determining the y interval in which the contribution occurs. The curve labeled "total uncorrelated" in Figure 7 was obtained by summing the contributions from each particle type and does not, in general, correspond to the spectrum that would be measured. Thus, the difference between the total correlated spectrum and the total uncorrelated spectrum represents the contribution of multiparticle events.

Figure 8 shows the dose distributions in y corresponding to the event spectra of Fig. 7. The ordinate is the produce of y and the dose per unit y interval. Thus, yd(y) is the dose per unit logarithmic interval of y, so that the areas under the curves are proportional to the fraction of the dose in the corresponding range of y. A relatively small number of $\pi^-$ captures were used in computing these results; consequently, the statistical fluctuations are rather large as evidenced by the scatter in the points at large values of y.

One interesting result from Figs. 7 and 8 is that the contributions to the event spectrum and to the dose by multiparticle events is rather small ($\lesssim$ 5% in terms of dose). This is an important finding because the contributions of muleiparticle events is an important consideration in determining the particular type of detector (walled or wall-less) that is needed for pion dosimetry. Also, although conventional algorithms (e.g., Rossi and Rosenweig, 1955; Kellerer, 1972) for inferring LET spectra from experimental gas proportional data neglect the contribution of multiparticle events, it is important to know this contribution because it is one factor that determines the applicability of these standard algorithms to pion dosimetry.

It seems that the major correction to the data will be in converting to real tissue, regardless of the type of detector. In this case, along with the fact that walled chambers tend to be more accurate and reliable indicates that the proper approach would be to use conventional detectors, calculate the corrections, and, perhaps, check a few of the corrections experimentally to be certain they are correct.

It should be noted that the characterization of the radiation field in terms of mean LET is not applicable where the particles exhibit small energy losses and large fluctuations in energy losses and path lengths result. Furthermore, there are restrictions on the use of LET as a universal parameter for expressing biological effects. An investigation of energy losses in biologically significant sites, as also proposed here

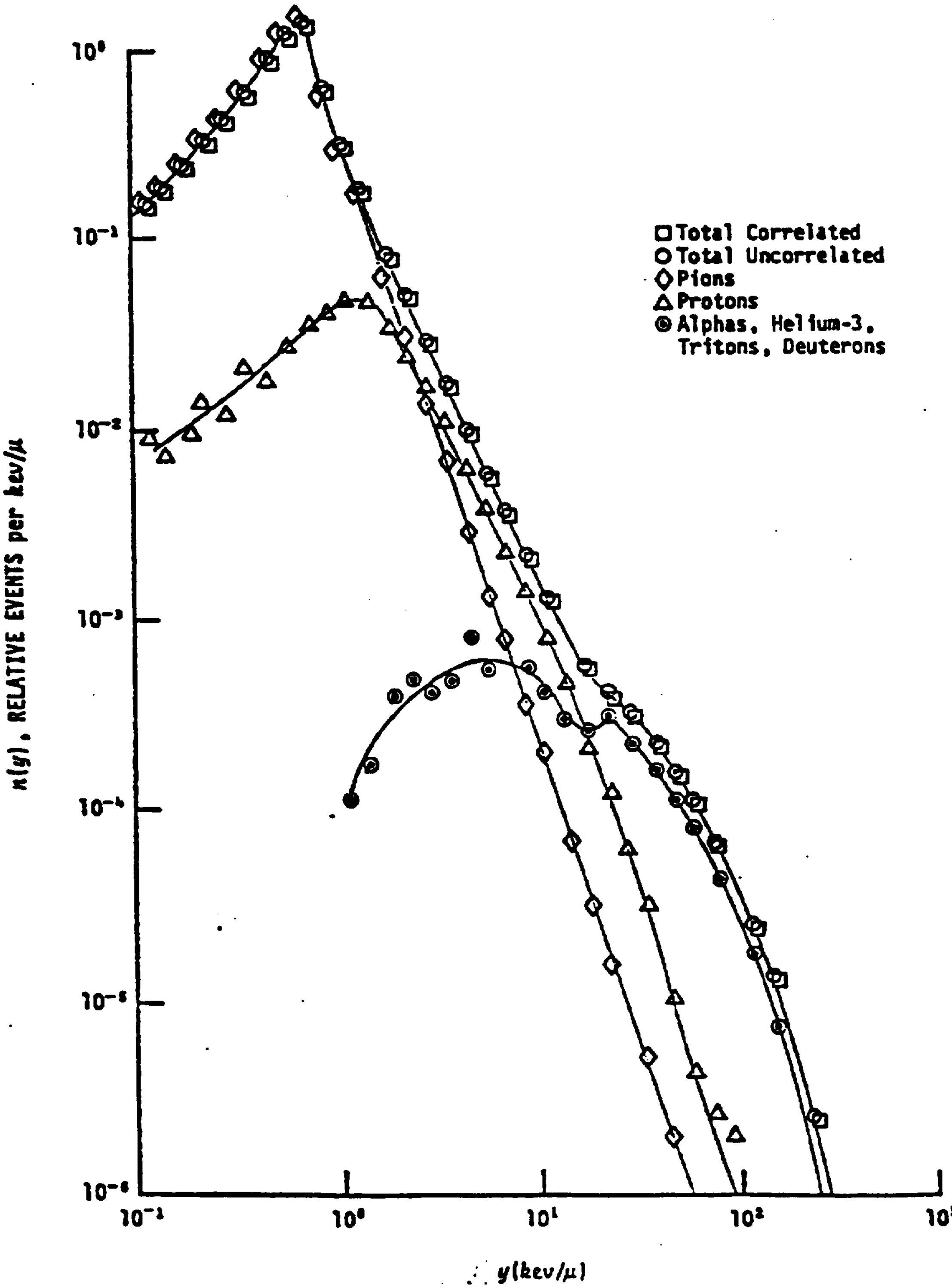


Figure 7. Computed Event Spectra for a Gas Proportional Counter Located in the Stopping Region of a π⁻ Beam (Armstrong and Chandler, 1976)

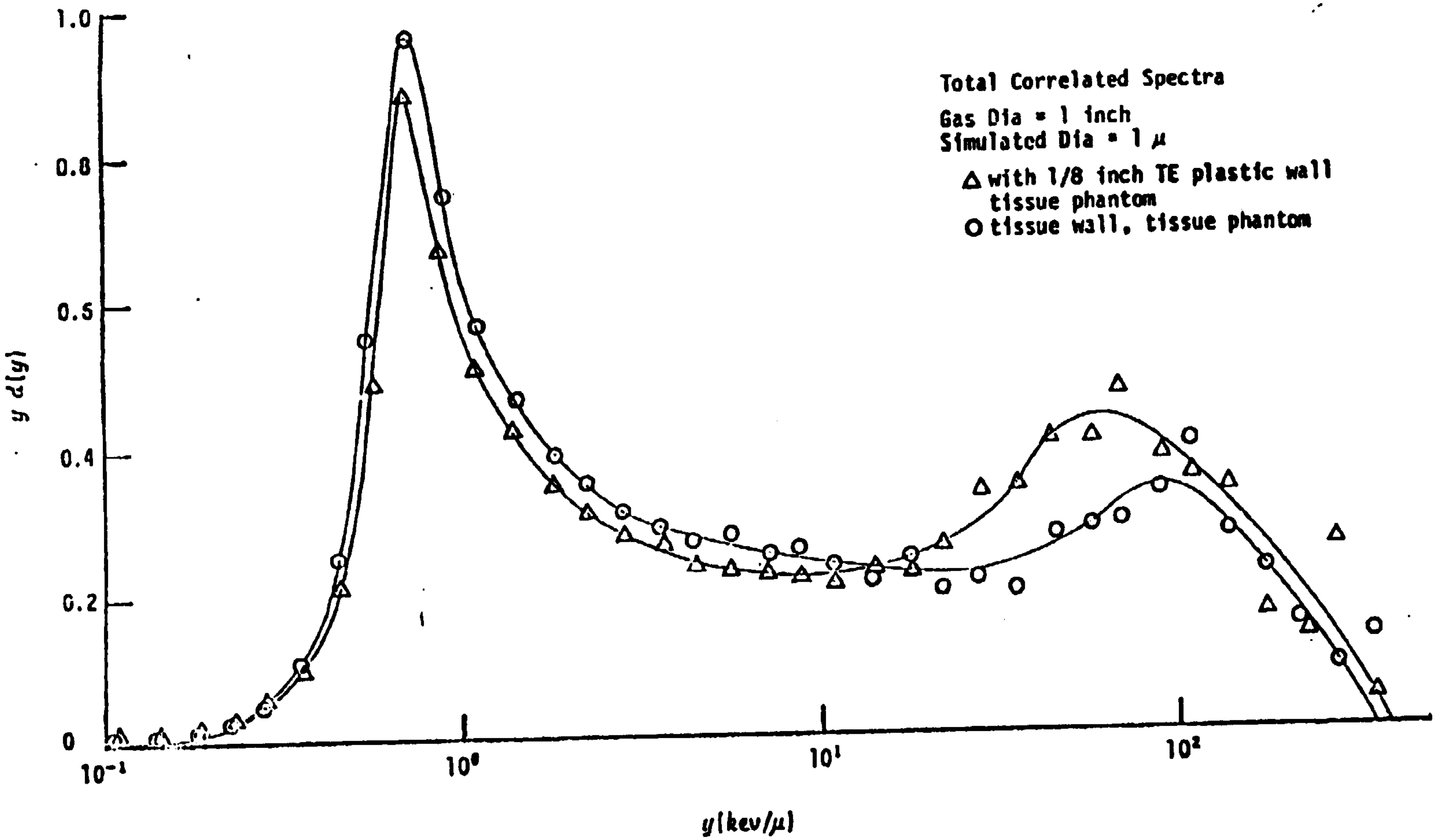


Figure 8. Comparison of Computed Dose Distributions for a Counter Having a Tissue-Equivalent (TE) Wall vs. a Tissue Wall (Armstrong and Chandler, 1976)

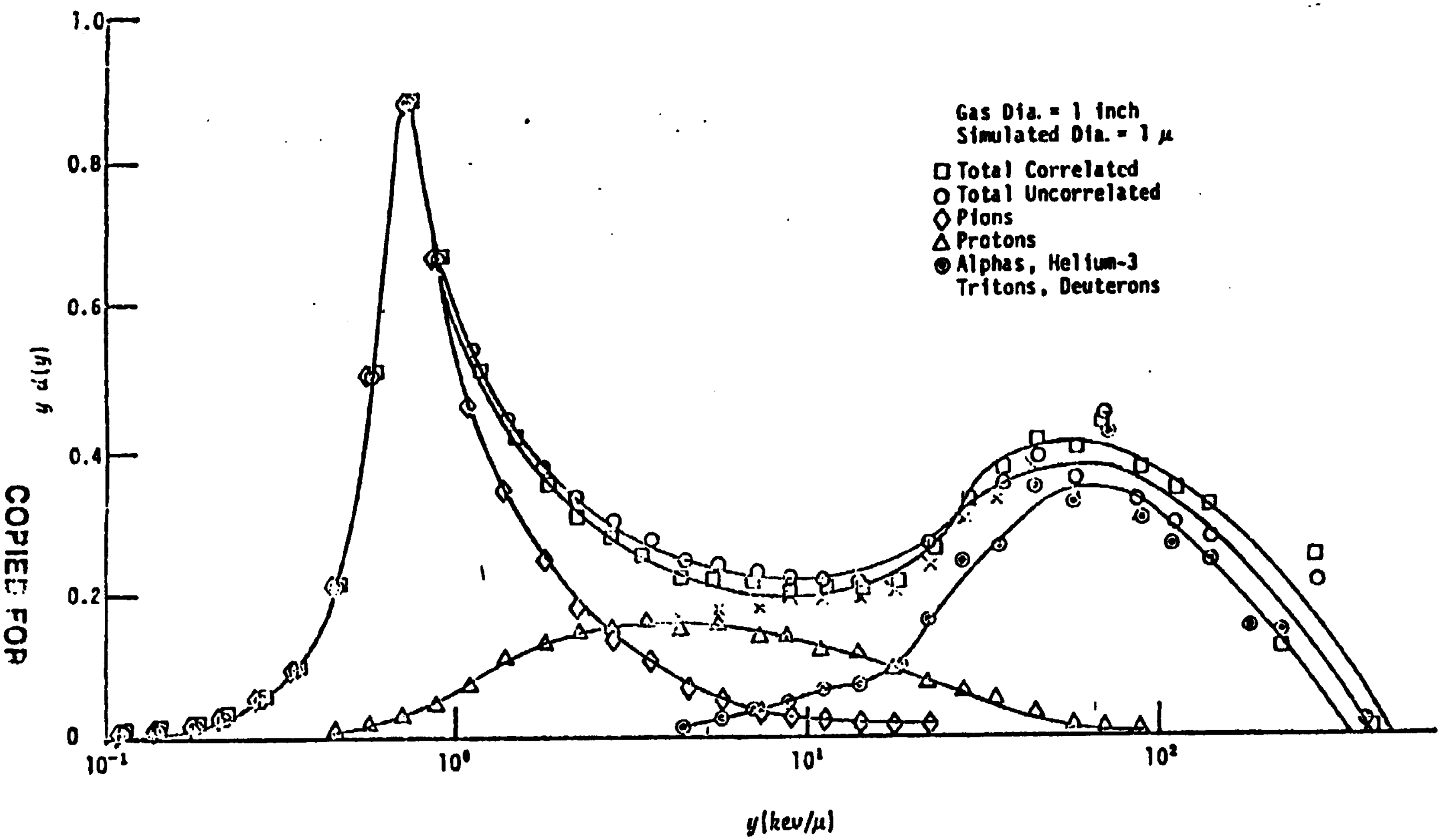


Figure 9. Computed Relative Dose per Unit Logarithmic Interval *y* vs. *y*.
(Armstrong and Chandlor, 1976)

use of LET distributions as a basis for characterizing radiation fields and in interpreting biological effects, it is still desirable to obtain LET spectra.

Figure 9 shows the dose distribution computed with and without the TE wall. (These results are normalized so that the areas under the two curves, i.e., the total dose, is the same.) Figure 9 shows that the TE wall has a substantial effect in the y range from $\tilde{-}$ 20 to 100 keV/μ; any effect for y > 100 keV/μ is masked by statistical fluctuations. (Better statistical precision could, of course, be obtained by simply requesting in the code input that a larger number of captures be treated.) The total absorbed dose in the gas is $\tilde{-}$ 8% higher with the TE wall than for a wall having the composition of "whole-body" tissue.

For purposes of comparison, recent data of Amols et al. (1975A) for $\pi^+$ and $\pi^-$ are shown in Figs. 10 and 11.

c. Background Radiation

It is necessary to know the background radiation for calculating whole body doses in regions not in the primary beam. Schillaci and Roeder (1973) have calculated neutron production from pion beams and have calculated the dose levels expected as a function of distance from the beam.

To date, the only experimental data available are data outside the primary beam, both in and adjacent to a water phantom, obtained at LAMPF with tissue-equivalent plastic proportional counters (Amols et al., 1975B) and with fission foils (Wilenzick et al, 1975). The neutron dose, at a distance of about 25 cm from the beam axis, for a beam approximately 3 x 5 x 7 cm, FWHM, is typically about 0.02% of the peak dose. The result of one measurement is shown in Fig. 12. The measurements with the proportional counter are particularly interesting because these data show a significant low lineal energy (or low LET) component in the background radiation. This component results from the halo of pions, muons, and electrons surrounding the primary beam and in some cases represents a larger fraction of the background radiation than do neutrons.

The present methods would be ideally suited for determining what the dose would be outside of the immediate treatment volume. In fact, in many cases, the data would be automatically available as part of the output data without modifications in the existing codes.

d. Silicon Detectors as Pion Dosimeters

Many calculations associated with the pion therapy program require a knowledge of the types of particles interacting, their initial energies, and their rate of energy loss. Some of this information is obtained by the use of gas proportional counters in order to obtain microdosimetric spectra. It has been shown (Richman, 1975) that complementary data can also be obtained with silicon detectors.

Silicon detectors have certain inherent characteristics which make them attractive dosimetric devices for pion dosimetry. They are small, have good linearity and fast response, and they have excellent particle discrimination. Silicon detectors have been used from the beginning in

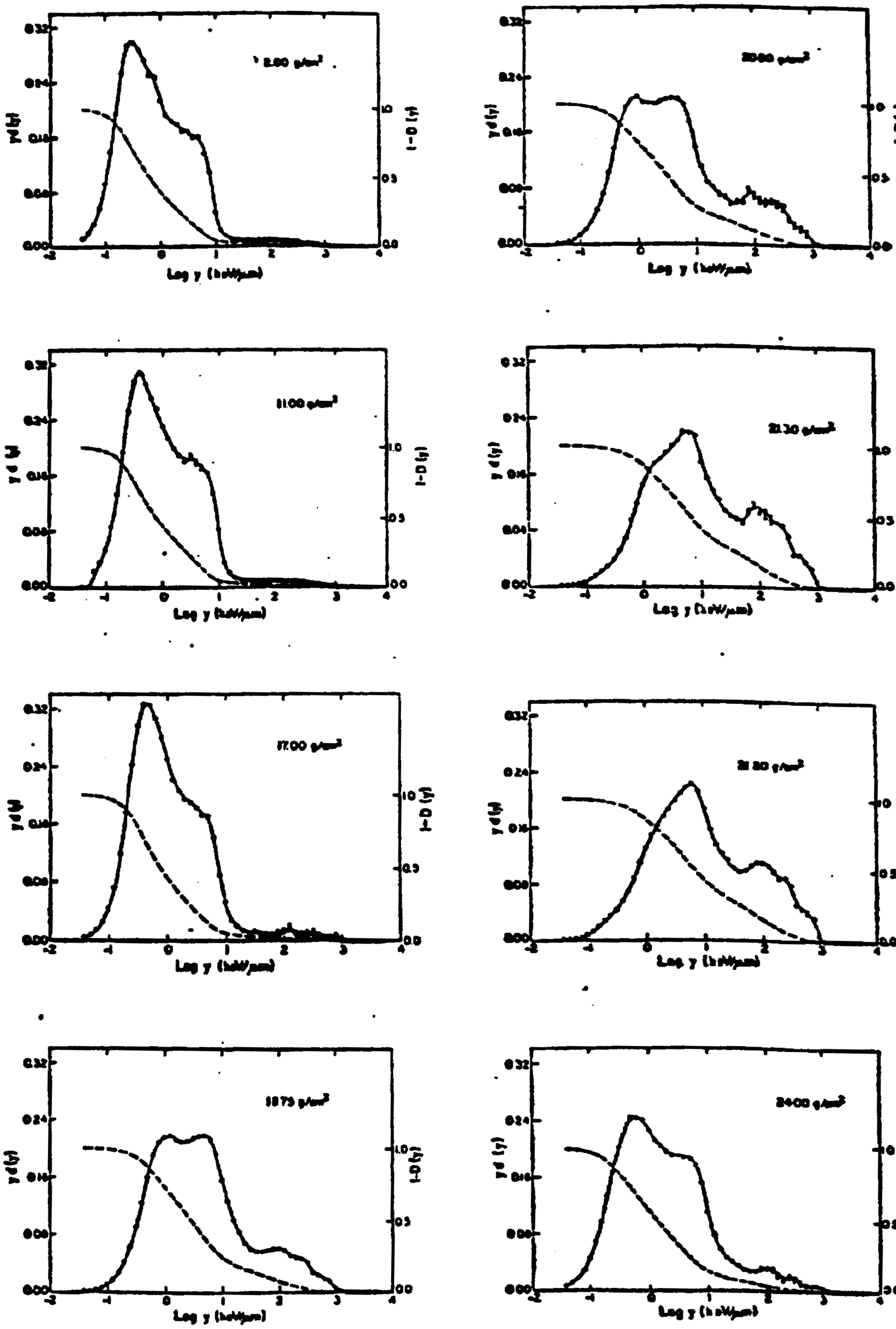

Fig. 10 The distributions in dose as a function of lineal energy for a 2-μm effective cavity diameter at eight different depths in a liquid phantom irradiated by $\pi^-$. Numbers in the upper right-hand corner of each panel indicate the areal density ($g/cm^2$) for each spectrum. Solid curves are differential dose distributions as a function of y. Dashed curves are integral dose distributions (Amols et al., 1975A).

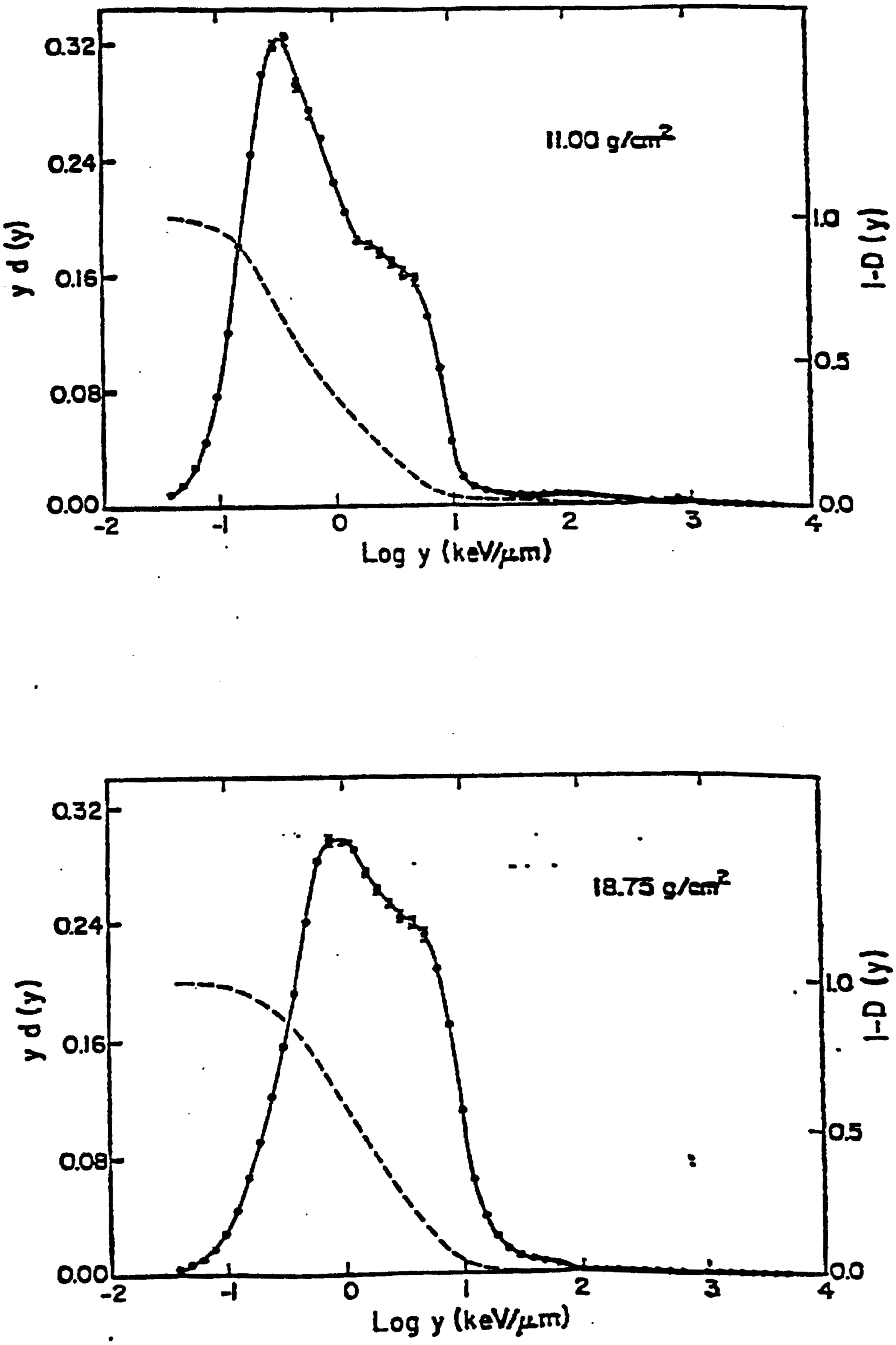


Fig. 11 The distributions in dose as a function of lineal energy for a 2-μm effective cavity diameter at 2 different depths in a liquid phantom irradiated by $\pi^+$. Solid curves are differential dose distributions as a function of y. Dashed curves are integral dose distributions (Amols et al., 1975A).

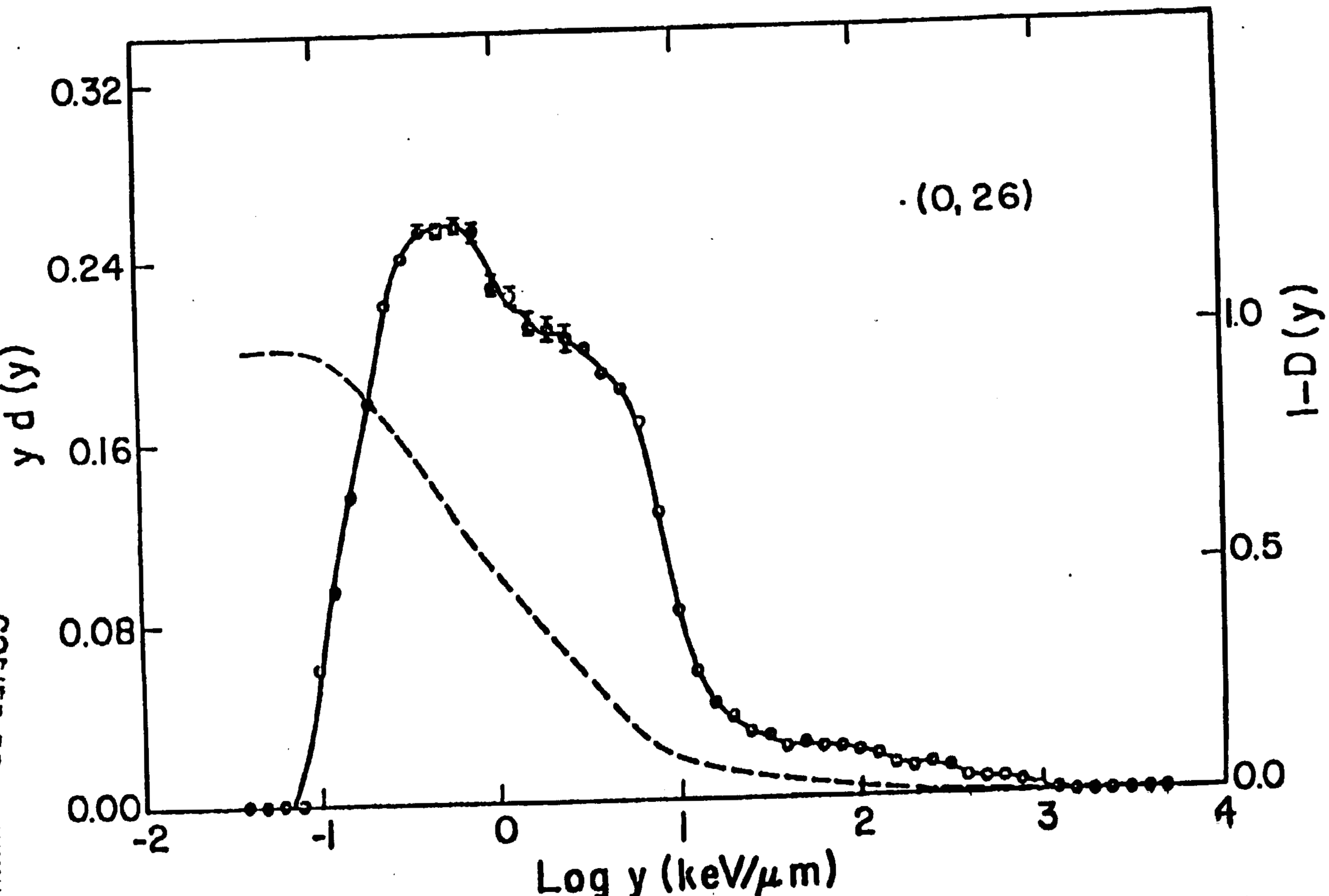




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Fig. 12 Dose per logarithmic interval of lineal energy vs lineal energy. The spectrum was taken in a water phantom at a position 26 cm outside of the stopping region in a plane perpendicular to the beam axis (Amols et al., 1975).

pion dosimetry work at Los Alamos. Richman (1976) has reported extensive work in this regard, and some of the results are shown in Fig. 13.

While silicon detectors have distinct advantages and complement other dosimetric methods (viz, gas proportional counters), silicon detectors do not yield directly a tissue-equivalent response. Mass stopping powers for tissue-like materials and silicon are substantially different and according to theoretical predictions (Armstrong and Chandler, 1974), the charged-particle energy production from $\pi^-$ captures in silicon is $\sim$ 25% less than in tissue. However, an essential point of the proposed work is that if thin ($\sim$ tens of microns) silicon detectors are used, then with the aid of calculations to unfold and modify the measured spectrum, the tissue-equivalent dose can be inferred.

Very limited calculations on the response of silicon detectors in the radiation field produced by stopping pions have been carried out (under NSF/RANN funding) by Armstrong and Chandler (1974A, 1976). In this work, the products from $\pi^-$ captures in tissue and silicon are determined using the theoretical nuclear model discussed previously. A Monte Carlo calculation is performed for each capture, and the energy deposition in the silicon by each charged particle product is determined using a code developed by Armstrong and Chandler (1973) for stopping powers and ranges. Thus, fluctuations in the particle production and correlations caused by more than one particle per capture contributing to the energy deposition (i.e., multiparticle events) are properly taken into account so that the analog of the measured pulse-height spectrum is obtained. The energy deposition in the tissue phantom with the silicon removed is also computed. Some of the results are shown in Fig. 14.

One of the main conclusions of these preliminary calculations is that if thin silicon detectors are used, then the contributions to the pulse height spectrum by various particle types are fairly well resolved. This means that the contributions to the measured spectrum by various particle types can, with the aid of calculations, be identified. Furthermore, the calculations show that the measured spectrum can be analyzed to infer the tissue-equivalent dose. Thus, in pion radiobiology, thick silicon detectors for practical reasons (Raju et al, 1971) may be advantageous in mapping the relative dose distributions and in determining the spatial distribution of stopping pions, whereas thin detectors offer the potential for estimating the tissue-equivalent dose and the contributions to the dose by various capture products.

Monte Carlo calculations are proposed as part of a coordinated effort on the application of silicon detectors in pion dosimetry. The calculations will provide quantitative information on the detector response that cannot be obtained, or would be extremely difficult to obtain, experimentally but which is needed in establishing the biological significance of the data for use in pion treatment planning. In particular, the calculations will be used to unfold the measured spectrum of energy depositions in silicon to infer the absorbed dose by various particle types in tissue-equivalent material. Monte Carlo calculations will also be carried out to study the effects of inhomogeneities (bone, lung, tissue, etc. on the dose distributions produced by $\pi^-$ beams. From these calculations,

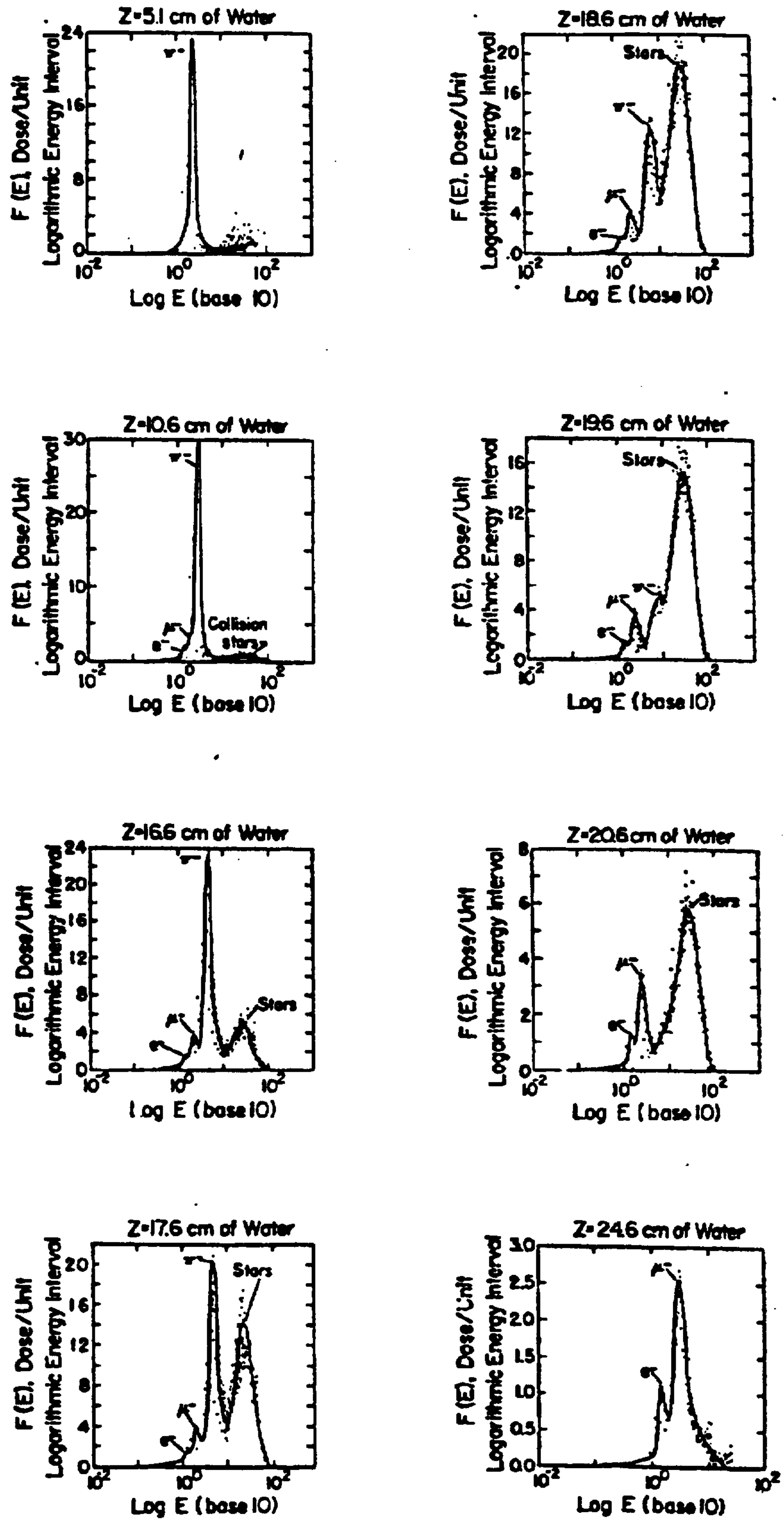




Fig. 13 The fractional energy deposited in a 5000-μm silicon detector per logarithmic interval of energy versus energy at various depths in a water phantom (Richman

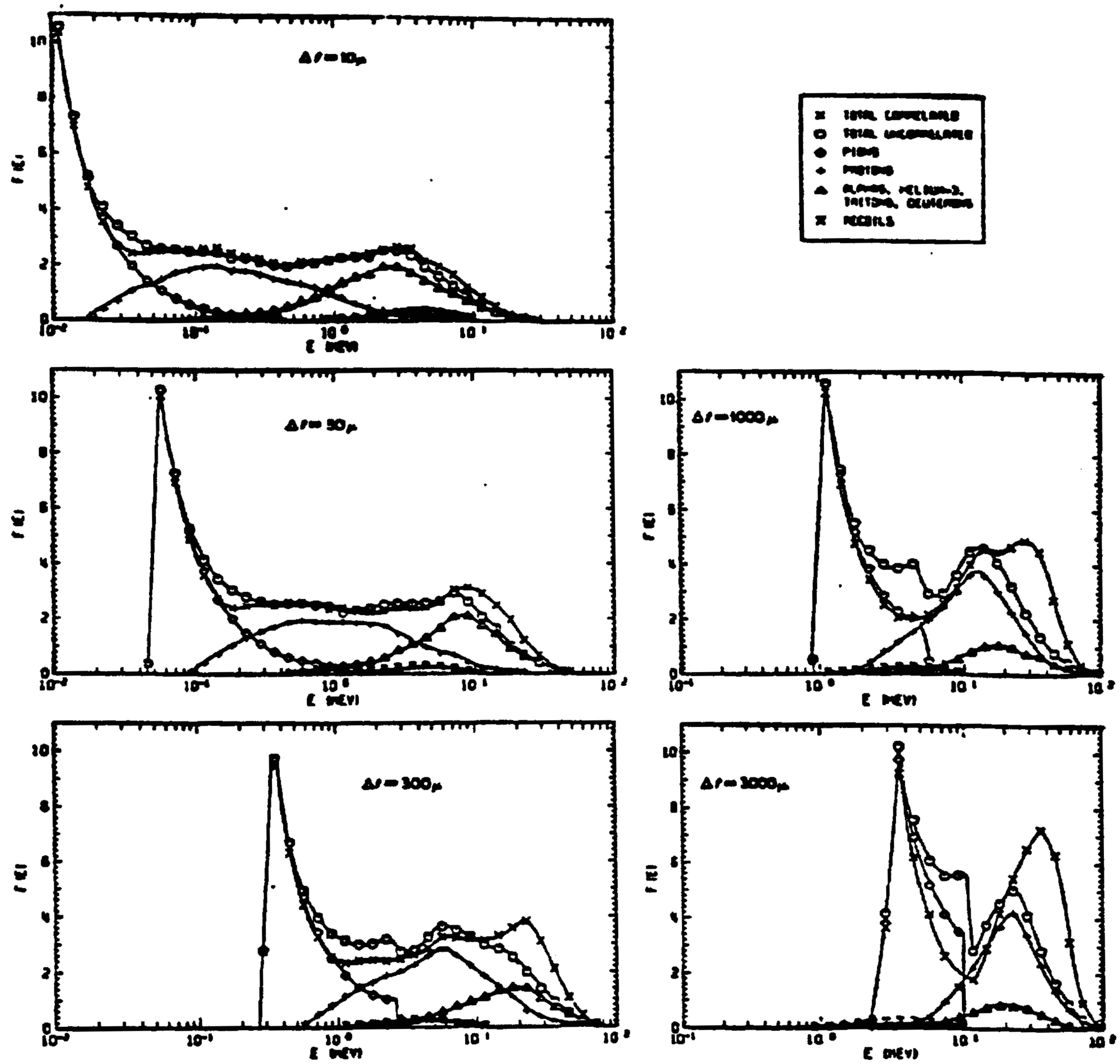


Fig. 14 Energy deposition spectra for silicon detectors of various thicknesses. F(E), defined in text, has units of $MeV \cdot g^{-1} \cdot cm^2 \cdot capture^{-1} \cdot (log_{10}$ energy interval$)^{-1}$ (Armstrong and Chandler, 1974B).

in the experiments so that the comparisons will be as definitive as possible. Emphasis will be placed on identifying and understanding any discrepancies between theory and experiment. If there should be important differences between the calculated and experimental results resulting from approximations in the calculations, work will be directed toward refining the calculational method to produce, insofar as possible, agreement with experimental results.

Also, the sensitivity of the computed results (absorbed dose, y spectra, RBE, and OER) to some of the assumptions and theoretical models employed in the calculations will be evaluated. For example, the preliminary calculations indicate that the difference in response of tissue vs. tissue-equivalent plastic and walled vs. wall-less detectors is due in large part to the higher α-particle production from $\pi^-$ captures (predominantly by carbon nuclei) in the tissue-equivalent plastic and from $\pi^-$ captures (predominantly by oxygen nuclei) in the tissue. In some of the calculations, the α-particle production is obtained by using by using a theoretical nuclear model: the intranuclear-cascade-evaporation model. Thus, it is important to know to what extent a specified change in the theoretically predicted α-particle production, say ± 15%, affects, for example, the predicted value of the RBE. Also, the code at present uses the Fermi-Teller Z-law (Fermi and Teller, 1947) to determine the type of nucleus that undergoes capture-i.e., the probability of final capture by a nucleus of charge Z (excluding hydrogen) is taken to be Z times the atom density of Z-type nuclei. Deviations from the Z-law (apparently due to molecular structure) have been observed (e.g., Gershtein et al, 1969), but to predict capture probabilities for complicated compositions such as tissue, with molecular effects taken into account, is not presently possible. Preliminary measurements of mu-mesic x-rays from tissue-like materials made recently at Los Alamos Scientific Laboratory suggest substantial deviations from the Z-law. However, the practical significance of these deviations as related to the dosimetry calculations proposed here is not clear because some of the largest deviations from the Z-law appear to occur for nuclei of low abundances. Therefore, a few calculations will be made using capture probabilities substantially different from those predicted by the Z-law in order to estimate an upper-limit for the influence of this uncertainty on the predicted detector response, RBE, and OER.

Several experiments are underway to measure the differential angular and energy cross sections for charged particle production from pion interactions. As such data become available, they will be incorporated into the codes. However, these experiments are difficult and demand large amounts of accelerator time, so that results will be slow in coming. It is probable that, in the foreseeable future, there will remain a significant dependence on theoretical models.

guidelines for inhomogeneity corrections can be obtained for utilization in pion treatment planning. For both the dosimetric and the inhomogeneity calculations, direct comparisons with experimental silicon dosimetry data will be made.

4. Biological Significance of Dosimetric Data

Calculations will be made to relate the physical data to radiation quality and biological effects. The calculational method proposed gives a rather complete picture of the physical processes that occur and can provide the detailed physical information needed to estimate biological effects. Available information would include not only the detector response in terms of y spectra but also the energy spectra for the fluence of all charged-particle types and the "directly-computed" LET spectrum, where applicable, (as opposed to the LET spectrum inferred from the y spectra). Thus, the calculations will provide the physics input needed to compare the cell survival, RBE, and OER predictions of various biological models. In particular, values will be obtained for the RBE and OER as predicted by the models of Kellerer and Rossi (1972), Katz et al. (1972), and, possibly, Chatterjee and Tobias (1974). Since the conceptual bases for these biological models are different, it is necessary to obtain a comparison of the numerical predictions of the RBE and OER for the same radiation field and detector configuration and to compare with experimental biological data.

Because of the large variation of radiation quality in a given pion beam, as well as from one beam to the next, it will be necessary to estimate the corresponding variation in biological effects. Ultimately, in treatment planning it will be necessary to calculate, not only isodose contours, but also isoeffect contours.

At this time, the accuracy of the various models is limited, especially in the range of therapeutic doses. It is proposed that the methods used to calculate biological effects will have to be improved as experimental data become available. That is, a semiempirical approach may have to be taken, where the models and theories are used to interpolate and extrapolate from available biological and clinical data, not only for pions but also for other high LET and conventional radiations.

It is not the intention of this proposal to develop treatment planning codes capable of searching for exceptable isoeffect contours appropriate for specific treatments, as will be needed in treatment planning codes. Rather it is our intent that the present codes be used for comparison with preclinical data in order to determine the basic reliability of the method. It is likely, however, that some of the present routines may be directly applicable, at least in part, to the corresponding problem in treatment planning.

5. Guidance of Experimental Work

It is the intention of this proposal that the calculations supplement the preclinical therapeutic program in order to reduce the total amount of costly experiments necessary to determine the applicability of negative pions to clinical therapy.

6. Verification of Calculational Method

A very important objective of the proposed work will be to obtain comparisons between calculated and experimental absorbed doses, y spectra, and LET spectra. The calculational method will be sufficiently general for the calculations to be made for the beam characteristics, detector configurations, and phantom compositions as used

## C. Methods of Procedure

While the general outline expected for the work is described in the following paragraphs, the priorities for further calculations and additional code development will be based to a large extent on the initial comparisons with experimental data.

Both codes will be available for routine calculations. In some cases, as mentioned previously, it may be desirable to perform the same calculation by both methods in order to determine the reliability of a method used. However, in general, this will not be the case. If applicable, PION-1 will be used because of its lower computer cost. For those calculations which cannot be done with PION-1, HETC will be used.

It is anticipated that some modifications of the codes will be needed over the period of the grant. PION-1 will be modified so that it is not necessary to use cylindrical symmetry. This is not anticipated to be a major modification.

The basic computer codes will be modified to include energy straggling and estimates of the W-value variation with particle type and energy, if necessary. While W-values are not well known for the tissue-equivalent gases of interest here, approximate, semi-empirical data are available (e.g. Dennis, 1971) and can be used to check the sensitivity of the y spectra, total dose, and RBE to W-value variations. (The recent work of Turner, et al (1975) suggests that, in terms of the total dose, W-value variations for radiation fields produced by pion beams will be small.)

The sensitivity of the computed results (absorbed dose, y spectra, RBE, and OER) to the theoretically predicted α-particle production and to the use of the Fermi-Teller Z-law in determining the $\pi^-$ capture probabilities will be checked. Initial comparisons with experimental data will be made for the $\pi^-$ capture region.

In order to obtain calculated responses for detectors located in the dose plateau region, some modification of the preliminary detector code will be required. This will not be a major effort since the needed input for nuclear interactions in the plateau region can be generated using the general nucleo-meson transport code HETC (Armstrong and Chandler, 1972A).

The calculational method will be extended to take into account the effects of δ-rays if necessary, in order to achieve overall agreement with initial measurements of y and LET spectra. This could be a major effort. The degree of detail with which it will be possible to treat δ-rays will require some study. The most detailed approach would be to extend the present Monte Carlo calculations of the heavy charged-particle trajectories to include the δ-ray production along each trajectory, and then to perform a Monte Carlo calculation to determine the δ-ray trajectories and energy losses, taking advantage of the work of Berger (1973). With this complete treatment, additional information on the effects of the detector walls on the event spectra and on the relation between the energy deposition in the gas and energy losses in biologically relevant volumes can be computed. A simpler approach, which should provide a realistic treatment of the energy deposition in the gas but which would not take into account the paths of individual δ-rays on the energy fluctuation, would be to employ some available analytical description (e.g., Katz, 1972; Chatterjee et al, 1973, and Fain et al, 1974) for the radial dependence of the average δ-ray energy deposition. This radial dependence (which is a function of the energy, charge, and mass of the heavy ion) could be applied in computing the energy deposited by individual heavy-ion trajectories that pass through or near the sensitive site.

A fundamental part of some of the calculational methods is the use of the intranuclear-cascade-evaporation model to obtain the energy and particle type of the products produced by $\pi^-$ capture. While calculations using this production model have been compared with experimental data for the absorbed dose (Armstrong and Chandler, 1972B) due to $\pi^-$ beams, and good agreement has been obtained, comparisons between calculated and measured detector responses would provide a different and somewhat more stringent test of the model. Should there be a major difference in the measured and calculated results attributable to the capture model, the work required to modify the model might require a major effort, depending, of course, on the nature and magnitude the differences. Included as part of the proposed work is the identification of any significant shortcomings of the model relevant to the present application. However, any major modification of the model is not part of the work proposed here. As experimental cross-sectional data become available, the dependency on this model will be reduced accordingly.

Initial comparisons with experimental data and code development as required will be performed during the first year of the program. Additional comparisons with measurements and code development to include the additional effects will be made during the second year. The third year will be devoted toward analysis of existing experimental data and patient treatments.

## D. Significance

The radiation field in the vicinity of the stopping pion beam is complex with a mixture of various high and low LET particles. For pion treatment planning it is important to know the absolute absorbed dose and the spatial distribution of the biological effects. This information will be obtained in part from pion dosimetry, radiological physics, and biology. A concerted theoretical effort concurrent with the experimental work is essential for the most beneficial and expedient use of the experimental data. The calculational work proposed here, together with measurements will contribute toward a detailed physical basis for:

a. Beam development, beam tuning, and beam shaping.

b. Precise and accurate dosimetry (where the term "dosimetry" refers to an adequate determination of beam characteristics so that careful and meaningful therapy can be accomplished) and biology.

c. Treatment planning.

## E. Facilities Available

The only unique facilities required are fast, large-memory computers with peripheral storage devices. Such computers are available at the Oak Ridge National Laboratory, the Los Alamos Scientific Laboratory, and subject to the National Cancer Institute's approval (at the request of the U.S. Energy Research and Development Administration) of Science Applications, Inc.'s use of the CDC 7600 computer located at the Lawrence Berkeley Laboratory, Berkeley, California. A data-link to this computer is conveniently located for use by Applied Research Institute personnel.

F. Collaborative Arrangements

The proposed work will be a collaborative effort involving members of the Los Alamos Scientific Laboratory, the Oak Ridge National Laboratory, Science Applications, Inc., and the Cancer Research and Treatment Center of the University of New Mexico. Because of previous work in the field performed by all members of this proposal, close communication has been maintained.

It is intended that this work benefit, not only the above institutions, but also all groups presently engaged in research with pions and other types of high LET radiations for therapeutic applications. Therefore, travel and consultant funds have been requested to allow approximately two one-day meetings per year for the purpose of discussing the progress and priorities of the calculational work and the status of the experimental programs, as well as to provide regular occasions for the exchange of ideas Invitations will be extended to other pion facilities and institutions engaged in preclinical investigations of other modalities.

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