Particle Fluxes and Energy Deposition in Infinite Homogeneous Air Due to Protons of Energy 1-, 5-, 10-, and 20-GeV

T. A. Gabriel
B. L. Bishop
J. D. Amburgey
J. Barish

MASTER

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$3.00

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, contractors, subcontractors, or their employees, makes any warranty, express or implied, nor assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report, nor represents that its use by such third party would not infringe privately owned rights.

Contract No. W-7405-eng-26

Neutron Physics Division

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

**PARTICLE FLUXES AND ENERGY DEPOSITION
IN INFINITE HOMOGENEOUS AIR
DUE TO PROTONS OF ENERGY
1-, 5-, 10-, and 20-GeV**

T. A. Gabriel
B. L. Bishop[†]
J. D. Amburgey[†]
J. Barish[†]

Date Published - December 1977

[†]Computer Sciences Division.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

NOTICE This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
FOR THE
DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *fy*

PARTICLE FLUXES AND ENERGY DEPOSITION
IN INFINITE HOMOGENEOUS AIR DUE TO
PROTONS OF ENERGY 1-, 5-, 10-, and 20-GeV

T. A. Gabriel
B. L. Bishop
J. D. Amburgey
J. Barish

Abstract

Calculations have been carried out to determine the spatial dependence of the energy deposition and the spatial and energy dependence of particle fluxes in infinite homogeneous air without hydrogen due to protons of energy 5-, 10-, and 20-GeV. The fluxes are broken down into nine particle types. The energy deposition is divided among seven categories. The spatial dependence of the energy deposition is also presented for 1- and 10-GeV protons incident on infinite homogeneous air with hydrogen. The spatially integrated production of various residual nuclei is included.

Discussion and Results

HETC¹ plus CALOR² has been used to determine the spatial dependence of the energy deposition and the spatial and energy dependence of particle fluxes in infinite homogeneous air without hydrogen due to protons of energy 5-, 10-, and 20-GeV. The particle fluxes have been broken down into nine categories including protons, neutrons ($E \geq 10$ MeV), charged-pions, -muons, leptons^{*}, and gammas^{*}. The energy deposition is divided among seven categories including primary protons; secondary-protons; charged-pions, and -muons; heavy ($A > 1$) charged particles; low-energy neutrons⁺ ($E < 10$ MeV); and electromagnetic⁺.

The spatial dependence of the energy deposition is also presented for 1- and 10-GeV protons incident on infinite homogeneous air with hydrogen.

The compositions of the air used in the calculation are given in Table 1.

Table I
Composition of Air

Element	Number %	
N	78.067	77.093
O	20.990	20.728
A	0.943	0.932
H	--	1.247
$\rho = 1.205 \times 10^{-3} \text{ g/cm}^3$		

* Only leptons and gammas that result from the electromagnetic cascade produced by the decay of muons and π^0 's are included.

⁺ See ORNL/TM-4803 for approximations dealing with low-energy neutrons and residual excitation energy.

The laterally integrated energy deposition as a function of depth in air with no hydrogen due to protons of energy 5-, 10-, and 20-GeV is given in Fig. 1*. The laterally integrated energy deposition in air with hydrogen due to protons of energy 1- and 10-GeV is presented in Fig. 2*. The points in Fig. 2 represent the 10-GeV case in which no hydrogen is present. The spatial dependent energy deposition for 1- and 10-GeV protons incident on air with hydrogen is given in Tables 2 and 3. In these tables the incident protons are started at $x = y = 0$ and $z = 2.5 \times 10^5$ cm. The numbers given under the energy deposition represent the statistical error in %.

Shown in Fig. 3 are particle fluxes due to incident 20-GeV protons in air with no hydrogen. These fluxes are averaged over the spatial coordinates of $z = 2.857 \times 10^5$ to 3.571×10^5 cm and $r = 0$ to 6.000×10^3 cm. Note in the figure where the incident protons are started. The spatially integrated production of various residual nuclei are given in Table 4 for 1- and 10-GeV protons incident on air with hydrogen. No production by neutrons with energy < 10 MeV is included.

The remainder of the data for the no-hydrogen cases are given on microfiche and are included with this report. The following should be noted when using this data.

- 1) The particle fluxes are not divided by the ΔE of the energy interval.
- 2) The energy points given are the upper energy points for the energy bins.

*The position where the zero width, zero angular spread beam of protons are allowed to start is zero.

Fig. 1. Laterally Integrated Energy Deposition in Air (no hydrogen) Due to Protons of Energy 5-, 10-, and 20-GeV.

Fig. 2. Laterally Integrated Energy Deposition in Air (with hydrogen) Due to Protons of Energy 1- and 10-GeV. The points represent the 10-GeV case in which no hydrogen is present.

1

•

[illegible]

[illegible]

TABLE 3 (CONT'D)
ENERGY DEPOSITION IN AIR DUE TO 10-GEV PROTONS (MEV/INCIDENT PROTON)

DEPTH(CM)	5120.0	10240.0	20480.0	40960.0	81920.0	163840.0	327680.0	655360.0	1310720.0
0.500E 05	0.0	0.0	0.0	0.0	0.2983E-02	0.6939E-01	0.1099E 00	0.3172E 00	0.6737E-01
	0.0	0.0	0.0	0.0	263.6	157.8	74.9	137.9	222.1
0.100E 06	0.0	0.0	0.0	0.0	0.6778E-01	0.2657E 00	0.5662E 00	0.5985E 00	0.4435E-01
	0.0	0.0	0.0	0.0	143.7	193.5	33.3	126.6	150.8
0.150E 06	0.4732E-02	0.1140E-01	0.6634E-01	0.2425E 00	0.1153E 01	0.2448E 01	0.1242E 01	0.2971E 00	0.1033E-02
	293.7	195.6	245.0	92.0	60.6	43.0	67.0	113.3	300.0
0.200E 06	0.2410E-01	0.2223E-01	0.6971E 00	0.1424E 01	0.4537E 01	0.6564E 01	0.2218E 01	0.3033E 00	0.0
	290.9	244.0	112.8	64.3	39.6	18.8	42.4	128.6	0.0
0.250E 06	0.1352E 01	0.3569E 01	0.7737E 01	0.1242E 02	0.1638E 02	0.1122E 02	0.2845E 01	0.2529E 00	0.0
	36.1	36.9	17.3	28.4	17.1	22.4	44.3	165.4	0.0
0.260E 06	0.3579E 01	0.4163E 01	0.5663E 01	0.6546E 01	0.5296E 01	0.2305E 01	0.6184E 00	0.3394E-01	0.0
	25.2	25.7	13.9	18.5	16.6	38.5	76.3	298.8	0.0
0.270E 06	0.8181E 01	0.6039E 01	0.6490E 01	0.6591E 01	0.5592E 01	0.2477E 01	0.1019E 01	0.3448E-01	0.9987E-02
	24.5	17.6	18.8	26.2	24.1	41.6	68.0	137.5	300.0
0.280E 06	0.1424E 02	0.1204E 02	0.9369E 01	0.7985E 01	0.6457E 01	0.3422E 01	0.7777E 00	0.2454E-01	0.1684E-02
	24.4	16.7	19.5	23.0	18.1	26.5	43.7	192.1	300.0
0.290E 06	0.1836E 02	0.2067E 02	0.1370E 02	0.9790E 02	0.6415E 01	0.3753E 01	0.7104E 00	0.1019E 00	0.1032E-01
	9.6	17.5	17.5	27.2	27.1	29.5	54.4	99.0	300.0
0.300E 06	0.2050E 02	0.2702E 02	0.2248E 02	0.1280E 02	0.7397E 01	0.3365E 01	0.9311E 00	0.3485E-01	0.0
	22.4	13.0	14.9	27.1	19.9	32.3	53.0	156.6	0.0
0.350E 06	0.1103E 03	0.1751E 03	0.2021E 03	0.1396E 03	0.6157E 02	0.2272E 02	0.4378E 01	0.4838E 00	0.9440E-03
	6.5	12.4	10.1	10.4	15.4	16.5	37.6	46.8	300.0
0.400E 06	0.9441E 02	0.1731E 03	0.2592E 03	0.2553E 03	0.1300E 03	0.3761E 02	0.7653E 01	0.4947E 00	0.0
	9.0	7.6	11.7	8.0	10.9	10.7	25.0	99.0	0.0
0.450E 06	0.6794E 02	0.1471E 03	0.2334E 03	0.2480E 03	0.1857E 03	0.5714E 02	0.1081E 02	0.1352E 01	0.0
	5.7	9.4	7.7	5.2	6.8	12.4	19.0	76.1	0.0
0.500E 06	0.4581E 02	0.1004E 03	0.1920E 03	0.2655E 03	0.1998E 03	0.6964E 02	0.1422E 02	0.1540E 01	0.0
	18.2	7.3	6.9	7.6	11.3	11.3	21.1	41.8	0.0
0.550E 06	0.2758E 02	0.6479E 02	0.1365E 03	0.2111E 03	0.1920E 03	0.8092E 02	0.1512E 02	0.1505E 01	0.0
	25.4	15.6	13.5	7.9	8.5	10.9	11.7	36.3	0.0
0.600E 06	0.1617E 02	0.4510E 02	0.9928E 02	0.1627E 03	0.1634E 03	0.8721E 02	0.1706E 02	0.1458E 01	0.6450E-01
	20.2	19.7	9.9	8.7	11.6	13.5	13.1	73.2	300.0
0.650E 06	0.1022E 02	0.2603E 02	0.6613E 02	0.1182E 03	0.1274E 03	0.7329E 02	0.1671E 02	0.1665E 01	0.7871E-02
	25.5	27.9	10.1	11.9	12.6	7.6	15.5	45.5	300.0
0.700E 06	0.4571E 01	0.1581E 02	0.4278E 02	0.8403E 02	0.1043E 03	0.5980E 02	0.1531E 02	0.1496E 01	0.0
	30.4	20.3	17.1	14.4	10.8	13.4	24.6	47.2	0.0
0.750E 06	0.2750E 01	0.8822E 01	0.2680E 02	0.5891E 02	0.7690E 02	0.4760E 02	0.1356E 02	0.1719E 01	0.0
	42.4	30.8	30.6	20.7	11.7	13.9	27.9	53.6	0.0
0.800E 06	0.1334E 01	0.4967E 01	0.1911E 02	0.4283E 02	0.5595E 02	0.3943E 02	0.1251E 02	0.7978E 00	0.0
	37.2	44.2	22.3	20.1	8.2	9.0	18.6	15.8	0.0
0.850E 06	0.1173E 01	0.2610E 01	0.1184E 02	0.2872E 02	0.4017E 02	0.3017E 02	0.9929E 01	0.1263E 01	0.0
	110.3	36.5	10.7	14.5	7.6	14.2	26.5	81.2	0.0
0.900E 06	0.7557E 00	0.2154E 01	0.5722E 01	0.1935E 02	0.2791E 02	0.2355E 02	0.7418E 01	0.1240E 01	0.0
	121.4	60.4	49.3	15.8	13.6	13.8	39.8	80.5	0.0
0.950E 06	0.5076E 00	0.1436E 01	0.4112E 01	0.1344E 02	0.2061E 02	0.1672E 02	0.4872E 01	0.1177E 01	0.0
	193.1	89.1	74.4	14.5	14.1	21.2	47.8	45.0	0.0
0.100E 07	0.4351E 00	0.8095E 00	0.3175E 01	0.9687E 01	0.1409E 02	0.1190E 02	0.4590E 01	0.4675E 00	0.3970E-01
	143.2	136.9	50.3	26.4	22.4	23.4	34.6	96.1	300.0
0.110E 07	0.3925E-01	0.9267E 00	0.2991E 01	0.1344E 02	0.2048E 02	0.1643E 02	0.5094E 01	0.9330E 00	0.7289E-02
	178.6	165.9	73.3	39.5	22.6	24.3	45.7	61.1	300.0
0.120E 07	0.9961E-02	0.2444E 00	0.1235E 01	0.6109E 01	0.1420E 02	0.1057E 02	0.3363E 01	0.4448E 00	0.0
	197.3	221.0	70.4	32.3	33.5	30.1	50.5	192.4	0.0
0.130E 07	0.3029E-01	0.1633E 00	0.6740E 00	0.3577E 01	0.8089E 01	0.6561E 01	0.2037E 01	0.1405E 00	0.0
	296.4	260.1	104.3	39.3	59.9	29.1	43.3	127.3	0.0
0.140E 07	0.9396E-05	0.2161E-02	0.4157E 00	0.1661E 01	0.4623E 01	0.4344E 01	0.2079E 01	0.1187E 00	0.0
	300.0	202.6	234.8	90.3	59.6	42.5	66.4	177.0	0.0
0.150E 07	0.0	0.1574E-06	0.3475E 00	0.6168E 00	0.2976E 01	0.2161E 01	0.7985E 00	0.4798E-01	0.0
	0.0	300.0	275.1	128.8	42.9	61.3	76.2	263.2	0.0
0.175E 07	0.9519E-04	0.3694E-03	0.6370E 00	0.9337E 00	0.3326E 01	0.3553E 01	0.6840E 00	0.5735E-01	0.0
	300.0	290.5	299.8	150.0	64.1	49.7	104.8	201.7	0.0
0.200E 07	0.0	0.0	0.3884E 00	0.5205E 00	0.1685E 00	0.2023E 01	0.2268E 00	0.0	0.0
	0.0	0.0	299.9	204.8	107.1	92.9	269.9	0.0	0.0
0.250E 07	0.9521E-03	0.6427E-02	0.1984E 00	0.4174E 00	0.1006E-01	0.7097E 00	0.1777E 00	0.0	0.0
	300.0	296.9	299.0	298.7	293.3	209.5	292.0	0.0	0.0

Fig. 3. Particle Fluxes in Air Downstream From a 20-GeV Proton Beam.

Table IV

Production of Various Residual Nuclei
in Air by 1- and 10-GeV Incident Protons

	Nuclei/Incident Proton	
	1-GeV	10-GeV
C ¹⁴	0.296 ± 7.4%	1.65 ± 3.7%
C ¹¹	0.0866 ± 8.0%	0.446 ± 11%
Be ⁷	0.0110 ± 24%	0.0610 ± 34%
H ³	0.0446 ± 13%	0.254 ± 18%
O ¹⁴	0.0181 ± 20%	0.105 ± 24%

3) The lowest energy limits for the particles are

$$E_{\min} (p, \pi^+, \pi^-, \mu^+, \mu^-, \gamma) = 0,$$

$$E_{\min} (\text{neutrons}) = 10 \text{ MeV},$$

$$E_{\min} (e^+, e^-) \sim 2.6 \text{ MeV}.$$

4) The r and z coordinate points given are the upper coordinate points. $r_{\min} = z_{\min} = 0$.

5) The spatial energy deposition is not divided by the spatial volume.

6) The incident protons are started at $x = y = 0$ and $z = 2.14286 \times 10^5 \text{ cm}$ with direction of cosines $\alpha = \beta = 0$, and $\gamma = 1$.

7) Statistical fluctuations of the data may necessitate averaging over wider radial and depth intervals. (This also applies to the data given in Tables 2 and 3.)

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

References

1. K. C. Chandler and T. W. Armstrong, "Operating Instructions for the High-Energy Nucleon-Meson Transport Code HETC, ORNL-4744, Oak Ridge National Laboratory (1972).
2. T. A. Gabriel and J. D. Amburgey, "CALOR: A Monte Carlo Program Package for the Design and Analysis of Calorimeter Systems," ORNL/TM-5619 (1977).

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Internal Distribution

1-2.	L. S. Abbott	42.	C. R. Weisbin
3.	F. S. Alsmiller	43.	G. E. Whitesides
4.	R. G. Alsmiller	44.	A. Zucker
5-6.	J. D. Amburgey	45.	P. Greebler (Consultant)
7.	J. Barish	46.	W. W. Havens, Jr. (Consultant)
8.	H. W. Bertini	47.	A. F. Henry (Consultant)
9-19.	B. L. Bishop	48.	R. E. Uhrig (Consultant)
20-33.	T. A. Gabriel	49-50.	Central Research Library
34.	H. Goldstein (Consultant)	51.	ORNL Y-12 Technical Library,
Document Reference Section
35.	F. C. Maienschein	52.	Laboratory Records Department
36.	F. R. Mynatt	53.	Laboratory Records, ORNL R.C.
37.	E. M. Oblow	54.	ORNL Patent Office
38.	R. W. Roussin		
39.	RSIC		
40.	R. T. Santoro		
41.	M. L. Tobias		

External Distribution

55. E. D. Bloom, Stanford Linear Accelerator Center, P. O. Box 4349, Stanford, CA 94305.
56. R. Eisenstein, University of Illinois, Urbana, IL 61801.
57. C. Fabjan, CERN, Geneva 23, Switzerland.
58. G. Feldman, Stanford Linear Accelerator Center, P. O. Box 4349, Stanford, CA 94305.
59. W. T. Ford, Fermi National Accelerator Laboratory, P. O. Box 500, Batavia, IL 60510.
60. D. Hitlin, Stanford Linear Accelerator Center, P. O. Box 4349, Stanford, CA 94305.
61. T. Jensen, Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627.
62. J. Kirkby, Stanford Linear Accelerator Center, P. O. Box 4349, Stanford, CA 94305.
63. L. Litt, Department of Physics, Michigan State University, East Lansing, MI 48823.
64. W. Schmidt, Institute of Experimental Nuclear Physics, University of Karlsruhe, 75 Karlsruhe, Germany.
65. A. L. Sessoms, Department of Physics, Harvard University, Cambridge, MA 02138.
66. L. R. Sulak, 252 Jefferson Laboratory, Harvard University, Cambridge, MA 02138.
67. W. J. Willis, CERN, Geneva 23, Switzerland.
- 68-94. Technical Information Center (TIC).
95. Department of Energy, Research and Technical Support Division, P. O. Box E, Oak Ridge, TN 37830: Director.
- 96-126. Given High-Energy Accelerator Shielding distribution.

ORNL/TM-6107

PARTICLE FLUXES AND ENERGY DEPOSITION
IN INFINITE HOMOGENEOUS AIR
DUE TO PROTONS OF ENERGY
1-, 5-, 10-, and 20-GeV

T. A. Gabriel J. D. Amburgey
B. L. Bishop J. Barish

MICROFICHE ENCLOSED

KAROLTON KLASP®
NO. 35 5 x 7 1/2
KAROLTON ENVELOPE
WEST CARROLLTON, OHIO