ADDENDUM TO PROCEEDINGS OF THE
10 MAY 1989 ANTIPROTON TECHNOLOGY
WORKSHOP

A compilation of presentation materials from the workshop
held at Brookhaven National Laboratory, jointly sponsored
in accordance with the AL/DoE Memorandum of Agreement
for Applied Research in Energy Storage support from
Brookhaven National Laboratory

August 1989

Editor: Gerald D. Nordley

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Prepared for the
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FOREWORD

This special report comprises the presentations provided by speakers at the Antiproton Technology Workshop held at Brookhaven National Laboratory (BNL) 10 May 1989 jointly sponsored under the Astronautics Laboratory (AFSC) / Department of Energy-BNL Memorandum of Agreement for support of Applied Research In Energy Storage (ARIES). This special report has been reviewed and approved in accordance with the distribution statement on the cover an on the DD form 1473.

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FOR THE DIRECTOR

ROBERT C. CORLEY
Chief, Astronautical Sciences Division
This workshop, held at Brookhaven National Laboratory, 10 May 1989, was a follow-on to the Antiproton Science and Technology Workshops held at the RAND Corporation in Santa Monica through October 1987 following the Air Force Project Forecast II initiative in Antiproton Technology. The workshop was attended by about 50 researchers from a wide variety of disciplines, including medicine, particle physics, and the aerospace industry. New, more efficient technology for a variety of scientific, medical, and industrial uses could result from antiproton experiments proposed by workshop participants. Antiprotons are particles of antimatter which release highly penetrating radiation when they are stopped in normal matter. According to presentations at the Antiproton Technology Workshop this radiation can be used, in very small quantities, to image objects and determine their composition and density. In larger amounts, the radiation could be used to kill cancer tumors or produce highly localized heating and shock waves. DOE plans are contingent on potential user support.
Block 16.

Storage support from Brookhaven National Laboratory.
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* Copies of viewgraphs were unavailable at the time of compilation (17 May 1989). They may be inserted if received later.

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STOPPING POWER OF MeV PROTON 
AND ANTIPROTON BEAMS

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PRESENTED AT THE ANTIPROTON TECHNOLOGY WORKSHOP
HELD AT BROOKHAVEN NATIONAL LABORATORY
10 MAY 1989
Stopping Power of MeV Proton and Antiproton Beams

R.A. Lewis, R. Kauzleiter, C. A. Smith
W.S. Toothacker, M. G. Willis
Penn State University

Antiproton Technology Workshop
May 10, 1989
BNL
\[\Delta P_e = F \alpha t\]
\[\Delta E_e = \frac{2Z^2e^2y}{m_e v^2} \cdot \frac{1}{b^2}\]
\[\frac{dE}{dx} = 4\pi n_e \frac{Z^2e^2y}{m_e v^2} \int \frac{db}{b}\]
Impact Parameters

$2\,\text{MeV}\,\alpha$

$\Delta E = 43\,\text{eV}$

$\omega = \sqrt{b}$

distance of closest approach

de Broglie $\lambda$

$\alpha = \frac{1}{b}$

$W = \int \vec{F} \cdot \vec{v}\,dt$

$b_{\text{max}} = 0.27\,\text{Å}$

$b_{\text{min}} = 1.5\,\text{Å}$

$0.05\,\text{Å}$

$0.12\,\text{Å}$
Barkas Effect

\[ \Delta y = \frac{3\pi}{2} \frac{e^2 \omega}{m v^3} = B \]

adiabatic

\[ \frac{dE}{dx} \times (1 \pm B) \]
$Z^3$ effects important for media with large $\omega$, projectiles with small $V^3$:

- Antiproton trapping
- Ion surface science
- $\bar{p}$ ICF
- Stopping ions
- Plasmas
- (Z^3 effects)

Agreement with Lindhard may be fortuitous

- Jackson, McCarthy version
- Quantum mechanical $Z^3$ effects
Fig. 2

L. H. Andersen et al.,
CERN EP/89-14
Phys. Rev. Letters

Fig. 2
Sensitivity

Energy loss difference 13 m Silicon
0.055 - 0.054 mV

Quadrature sum

0.012 mV

Energy resolution at 2 MeV
0.003 MeV

Time of flight resolution (Silicon)
0.015 MeV

Electronic loss fluctuation (CF)
0.028 mV

Nuclear scattering in target
0.023 MeV

Product: 3 events/hour below 2.5 MeV

Event Rate

p beam intensity @ 46 MeV
500/5000

Sensitivity

Calculation

Yield

Solid angle efficiency at target 0.29

MCP efficiency 0.95

MCP degrader thickness 250/100

3 s.d. Barker effect

0.004 MeV

0.037 MeV
Fig. 1. Apparatus for secondary electron detection.

Fig. 7. Average number $\bar{n}$ of secondary electrons (left scales) emitted from one foil as a function of ion energy. Solid lines: Differential energy loss according to Northcliffe and Schilling\textsuperscript{12}) (right scales). The normalization is different for different ions: $dE/dx = 1 \text{ MeV/mg cm}^{-2}$ corresponds to the following average numbers of secondary electrons: 7.4 (\textsuperscript{4}He), 5.0 (\textsuperscript{16}O), 4.2 (\textsuperscript{32}S), 3.8 (\textsuperscript{127}I).
Warm Fusion Shell

\[ \bar{p} \rightarrow \]

Fusion occurs here,
not here
Carbun Target

proton energy loss

$\Delta E, \text{MeV}$

X - proton, P difference

0.01

0

0.1

0.1

$\delta$ - uncertainty

Incident Energy, Mev
ΔE, MeV

0.01

0 2 4 6 8 10

Incident energy, MeV

Uranium target

X - proton, ̅p difference

ajor energy loss

0 - uncertainty
Summary

1-5% dE/dx measurements for 1-10 MeV p, p̅ at BNL
Sensitive to 5-50% Barkas effect

6 targets @ 30 hours, p̅ beam
10 hours, p beam
\frac{180}{180} hour
\frac{60}{60} hour
\frac{240}{240} hour

Carbon, silicon, iron, copper, silver, uranium
Sensitive to W/L^3 dependence
Energy Loss by Particle Beams

Bibliography

Theory of Ionization

1. N. Bohr, Philos. Mag. 25,10 (1913)
2. Bethe, Bloch
5. R.M. Sternheimer, Phys. Rev. 88, 851 (1952)
   Phys. Rev. 91, 256 (1953)
   (density effect)
   (heavy ions)

Hot plasma
10. G. S. Fraley et al., The Physics of Fluids 17,474 (1974)
12. S. Karashima et al., Laser & Particle Beams 5, 525 (1987)

Z**3 and Z**4 effects

Measurements in Hot Plasma

   (333 MeV uranium ions in hydrogen at 2.2 eV)

   (1 MeV deuterons in aluminum at 15 eV)

Measurement of Surface Effects

22. H. G. Clerc et al., Nucl. Inst. & Meth. 113, 325 (1973)
   (electron emission with slow ions)

   (transition radiation)

Measurement of $Z^3$ and $Z^4$ Effects

   (0.7 MeV protons in high Z media)

   (proton-antiproton differences)
ANTIPROTON INDUCED FUSION REACTION

W. S. TOOTHACKER

LABORATORY FOR ELEMENTARY PARTICLE SCIENCE
THE PENNSYLVANIA STATE UNIVERSITY
UNIVERSITY PARK, PA

PRESENTED AT THE ANTIPROTON TECHNOLOGY WORKSHOP
HELD AT BROOKHAVEN NATIONAL LABORATORY
10 MAY 1989
Antiproton Induced Fusion Reaction

by

R. A. Lewis, G. A. Smith, and W. S. Toothacker

Laboratory for Elementary Particle Science
PENN STATE UNIV

Supported by JPL (NASA)
Antiprotons which stop in Uranium cause fission 100% of the time.

Ref

1) Angelopolus et. al.  
   Phy Lett, 1988

2) Armstrong et. al.  
   Zeit für Phys A, 1988

3) Armstrong et. al  
   Zeit für Phys A, in press
Applications?

- Ability to deposit large amounts of energy in a very small volume
- Ability to create very large pressure and temp
- Ability to induce fusion in a DT pellet
Monte Carlo Code

- Track $\bar{p}$ through U until stop
- Model fission
- Track fission fragment through U
- Track fission fragment through DT
- Track suprathermals through DT
- Calculate & model fusions
- Track alphas through DT
Figure 2

Pbar X Stopping Point in microns
Figure 3

Pbar Y Stopping Point in microns
Figure 8

\[ \text{mean} = 92 \text{ MeV} \]
Figure 9

mean = 62 MeV
Fission Fragment Stopping Point in 10 keV DT

X Stopping point in mm

Y Stopping point in mm
Energy of Suprathermal Deuterons in 10 keV DT

111 Suprathermals per pbar

keV

Mean = 58 keV
2 mm

100 µm

Deuterium (Tritium; filling)

Fission Fragment

V shell 16.5 µm

2 MeV

\( \frac{P}{F} \)
Assume: 2 mm dia DT pellet with 16.5 μm U shell

$3.3 \times 10^{15}$ p/ns for 30 ns

Results: 1) Gain $\geq$ 300 ($\sim 1100$ fusions)

2) Too slow

Lawson's criteria

$N \geq 0.05$ (100% burn)

$\Rightarrow I = 360$ ns

but we estimate ablation time $\geq 10$ ns

- Thermal fusions
- Fission fragments
- Suprathermal fusions
Need more help from supra thermals.

Try adding a moderator like Li or look at reactions involving heavier atoms:

- Better energy transfer
- Increased stopping

Preliminary look at Li filled pellet:

- Frag stop in < 0.25 mm
  (< 2 mm in DT)
- Suprathermal Li have mean energy ≈ 90 keV
  (58 keV in DT)
Warm Fusion Shell

uranium shell

O, T, Li, ...

$C \approx 150$

fusions occur here, in shell

not inside

$\nu \rightarrow \alpha \nu$

J.C. Solem