MASTER

REMARKS PREPARED BY RICHARD MADEY FOR PRESENTATION ON
30 OCTOBER AT THE 1975 FALL MEETING OF THE DIVISION
OF NUCLEAR PHYSICS OF THE AMERICAN PHYSICAL SOCIETY,
AUSTIN, TEXAS, 1

THE RESPONSE OF NE-228A, NE-228,
NE-224, AND NE-102 SCINTILLATORS TO
PROTONS FROM 2.43 TO 19.55 MEV

BY

RICHARD MADEY, FRANK M. WATERMAN[†], AND ALAN R. BALDWIN
DEPARTMENT OF PHYSICS
KENT STATE UNIVERSITY
KENT, OHIO 44242

AND

J. D. CARLSON AND J. RAPAPORT
DEPARTMENT OF PHYSICS ✓
OHIO UNIVERSITY
ATHENS, OHIO 45701

NOTICE
This report was prepared as an account of work
sponsored by the United States Government. Neither
the United States nor the United States Energy
Research and Development Administration 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

[†]PRESENT ADDRESS: THE UNIVERSITY OF CHICAGO
CHICAGO, ILLINOIS 60637

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.

I. INTRODUCTION

TODAY, I WILL REPORT OUR MEASUREMENTS OF THE RESPONSE (RELATIVE TO ELECTRONS) OF FOUR SCINTILLATION COUNTER MATERIALS TO PROTONS WITH ENERGIES IN THE INTERVAL FROM ABOUT 2 TO 20 MEV. THE FOUR SCINTILLATORS WERE OBTAINED COMMERCIALY FROM NUCLEAR ENTERPRISES. ONE IS NE-102 PLASTIC; AND THREE ARE NE-224, NE-228, AND NE-228A LIQUIDS. THE NE-228A LIQUID WAS DEVELOPED BY NUCLEAR ENTERPRISES AT THE REQUEST OF THE USERS GROUP FROM KENT STATE UNIVERSITY FOR A SCINTILLATOR WITH THE SAME HIGH HYDROGEN CONTENT OF NE-228 BUT WITH A HIGHER LIGHT OUTPUT. THE RESPONSE MEASUREMENTS ON THE FOUR SCINTILLATORS WERE CARRIED OUT AT THE OHIO UNIVERSITY TANDEM VAN DE GRAAF ACCELERATOR IN COLLABORATION WITH DAVE CARLSON AND JACK RAPAPORT FROM OHIO UNIVERSITY.

2. EXPERIMENTAL ARRANGEMENT (SLIDE 1)

THE EXPERIMENTAL ARRANGEMENT APPEARS IN THE FIRST SLIDE. MONOENERGETIC NEUTRONS ARE PRODUCED BY BOMBARDING A HIGH-PRESSURE TRITIUM-GAS TARGET WITH 4.4 AND 9.0 MeV DEUTERONS. SINCE THE $T(D, N) \alpha$ REACTION HAS A Q-VALUE OF 17.6 MeV, THE ENERGY OF THE NEUTRONS PRODUCED AT 0° TO THE DIRECTION OF THE DEUTERON BEAM IS NOMINALLY 21 MeV FOR 4.4 MeV DEUTERONS AND 26 MeV FOR 9.0 MeV DEUTERONS. THE SCINTILLATOR TO BE CALIBRATED IS DESIGNATED AS D1 IN THIS SLIDE. [IT IS LOCATED ONE METER DOWNSTREAM FROM THE CENTER OF THE TRITIUM GAS TARGET AT AN ANGLE OF ZERO DEGREES.] WE ARE INTERESTED IN THE NEUTRON-PROTON ELASTIC SCATTERING PROCESSES THAT TAKE PLACE IN THE D1 SCINTILLATOR; ACCORDINGLY, WE MEASURE THE PULSE-HEIGHT OF A RECOIL PROTON IN THE FIRST

SCINTILLATOR WHENEVER ONE OF THE SECOND SCINTILLATORS
REGISTERS A SCATTERED NEUTRON. THE RECOIL PROTON
ENERGY IS DETERMINED KINEMATICALLY FROM THE INCIDENT
NEUTRON ENERGY AND THE NEUTRON SCATTERING ANGLE.

WE SELECTED FOUR RECOIL PROTON ENERGIES FOR EACH
INCIDENT NEUTRON ENERGY BY CHOOSING FOUR NEUTRON
SCATTERING ANGLES; FOR EXAMPLE, FOR 20.8 MeV INCIDENT
NEUTRONS, NEUTRON SCATTERING ANGLES OF 20° , 30° , 45° ,
AND 60° CORRESPOND KINEMATICALLY TO RECOIL PROTON
ENERGIES OF 2.4, 5.2, 10.4, AND 15.6 MeV, RESPECTIVELY.
THE FOUR NEUTRON SCATTERING ANGLES WERE DEFINED BY
THE POSITIONS OF THE FOUR D2 SCINTILLATOR COUNTERS
DESIGNATED AS D2A, D2B, D2C, AND D2D IN THIS SLIDE.
THE PULSE-HEIGHT OF EACH EVENT IN THE D1 SCINTILLATOR
WAS RECORDED ON A MULTICHANNEL ANALYZER ONLY WHEN A
COINCIDENCE EXISTED BETWEEN AN EVENT IN THE

D1 DETECTOR AND AN EVENT IN ONE OF THE FOUR D2 DETECTORS. TO PRODUCE A COINCIDENCE, THE D2 EVENT HAD TO OCCUR WITHIN A PRESELECTED TIME INTERVAL FOLLOWING THE EVENT IN THE D1 DETECTOR. THIS TIME INTERVAL WAS SELECTED TO CORRESPOND TO THE EXPECTED FLIGHT-TIME OF AN ELASTICALLY SCATTERED NEUTRON.

THE DESIGN AND CONSTRUCTION OF THE PULSE-HEIGHT MEASURING SYSTEM USED FOR THIS EXPERIMENT WAS THE RESPONSIBILITY OF ALAN BALDWIN. THE ELECTRONIC SYSTEM IS CAPABLE OF MEASURING RECOIL-PROTON PULSE-HEIGHTS OVER A DYNAMIC RANGE OF 200 TO 1. A PHOTOMULTIPLIER BASE, A HIGH-SPEED (100 MHz) FANOUT, AND A LINEAR GATE AND STRETCHER HAVE BEEN DESIGNED AND CONSTRUCTED TO PROVIDE A LINEAR RESPONSE FOR ANODE PULSES UP TO 10 VOLTS. THE DETAILS OF THE CIRCUITS WILL APPEAR SOON IN NUCLEAR INSTRUMENTS AND METHODS.¹

3. CALIBRATION WITH COMPTON ELECTRONS

IN ORDER TO PROVIDE CALIBRATION POINTS FOR DETERMINING THE LIGHT OUTPUT OF RECOIL PROTONS RELATIVE TO THAT OF ELECTRONS, WE GENERATED IN THE D1 SCINTILLATOR COMPTON ELECTRON SPECTRA OF KNOWN GAMMA-RAYS FROM CESIUM-137, MANGANESE-54, SODIUM-22, AND THORIUM-228. TO DETERMINE THE RESPONSE OF A SCINTILLATOR TO ELECTRONS, WE NEED TO KNOW THE ENERGY OF SOME FEATURE OF THE COMPTON ELECTRON SPECTRUM. PREVIOUSLY, KNOX AND MILLER² REPORTED THAT THE PEAK OF THE COMPTON ELECTRON SPECTRUM IS LESS SENSITIVE THAN THE HALF-HEIGHT TO THE PULSE-HEIGHT RESOLUTION OF A SCINTILLATION COUNTER. KNOX AND MILLER FOUND THAT THE PEAK OF THE COMPTON SPECTRUM IS ABOUT 5 PERCENT LOWER AND THE HALF-MAXIMUM FALLS ABOUT 12 PERCENT HIGHER THAN THE KINEMATIC MAXIMUM ELECTRON

ENERGY. IN OUR EXPERIMENT WE ASSOCIATED THE PEAK CHANNEL OF A COMPTON SPECTRUM WITH AN ELECTRON ENERGY EQUAL TO NINETY-FIVE PERCENT OF THE KINEMATIC MAXIMUM COMPTON ELECTRON ENERGY. THE LIGHT OUTPUT OF ELECTRONS IN ORGANIC SCINTILLATORS IS KNOWN TO BE A LINEAR FUNCTION OF ENERGY FOR ELECTRONS ABOVE APPROXIMATELY 100 KEV; HENCE, THERE IS A LINEAR RELATIONSHIP BETWEEN THE COMPTON ELECTRON ENERGIES AND THE ASSOCIATED CHANNEL NUMBERS OF THE COMPTON PULSE-HEIGHT SPECTRA. SINCE WE CALIBRATE THE CHANNEL NUMBERS OF THE PULSE-HEIGHT SPECTRA IN UNITS OF ELECTRON ENERGY, WE ASSOCIATE AN EQUIVALENT-ELECTRON ENERGY WITH THE PULSE-HEIGHT PEAK OF EACH RECOIL-PROTON SPECTRUM.

4. ILLUSTRATIVE RECOIL PROTON SPECTRUM (SLIDE 2)

THE SECOND SLIDE IS AN ILLUSTRATIVE EXAMPLE OF A PULSE-HEIGHT SPECTRUM FROM MONOENERGETIC RECOIL PROTONS IN NE-224; MORE SPECIFICALLY, THIS SPECTRUM WAS PRODUCED BY 20.8 MeV NEUTRONS THAT SCATTERED ELASTICALLY FROM PROTONS IN NE-224 THROUGH AN ANGLE OF 45° , THE PEAK CHANNEL NUMBER 2384 ± 6 CORRESPONDS KINEMATICALLY TO A RECOIL PROTON ENERGY OF 10.4 MeV. THE LEVEL OF BACKGROUND FROM CHANCE OR ACCIDENTAL COINCIDENCES CAN BE SEEN ON EITHER SIDE OF THE RECOIL PROTON PEAK. THE LEVEL OF BACKGROUND FROM ACCIDENTAL COINCIDENCES WAS SMALL AT A NEUTRON ENERGY OF 20.8 MeV; HOWEVER, AT 26 MeV, THE BACKGROUND FROM ACCIDENTAL COINCIDENCES WAS SO LARGE THAT THE RECOIL PROTON PEAKS AT 20° AND 30° WERE GENERALLY OBSCURED. THE ACCIDENTAL COINCIDENCES AT 26 MeV INCREASED AS A

RESULT OF THE LARGE NUMBER OF LOW-ENERGY NEUTRONS
PRODUCED IN THE $T(D,2n)^3\text{He}$ REACTION.

5. RESULTS (SLIDE 3)

THE NEXT SLIDE (NO. 3) IS A PLOT OF THE MEASURED
RESPONSE OF NE-102. THE DOTS WITH ERROR BARS REPRESENT
OUR MEASUREMENTS FROM 2.4 MeV UP TO 19.6 MeV. THE ERROR
BARS REFLECT THE UNCERTAINTY IN THE ELECTRON ENERGY.
THE UNCERTAINTY IN THE RECOIL PROTON ENERGY IS SMALL.
THE TRIANGLES DESIGNATE PRIOR MEASUREMENTS BY WATERMAN
AND ME FOR 3.5, 5.8, AND 10.5 MeV PROTON. THE OPEN
CIRCLES ARE PREVIOUS MEASUREMENTS BY CZIRR, NYGREN, AND
ZAFIRATOS AT LOWER PROTON ENERGIES OF 0.5, 1.0, AND 2.0
MeV. THESE VALUES JOIN SMOOTHLY WITH OUR MEASUREMENTS.
THE DASHED LINE IN THIS SLIDE IS THE CURVE USED BY KURZ
AND ALSO BY STANTON TO CALCULATE THE RESPONSE OF PROTONS
(IN UNITS OF EQUIVALENT-ELECTRON-ENERGY) IN POPULAR
PROGRAMS TO COMPUTE THE NEUTRON DETECTION EFFICIENCY.

OUR RESULTS INDICATE THAT THE MEASURED RESPONSE OF PROTONS IN THE REGION FROM 5 TO 20 MeV IS ABOUT 10 PERCENT HIGHER THAN THAT USED IN THE KURZ AND STANTON COMPUTER PROGRAMS. FOR PROTON ENERGIES BELOW 5 MeV, OUR RESULTS AGREE WITH THE ELECTRON-PROTON RESPONSE FUNCTION USED IN THESE PROGRAMS. OUR RESULTS INDICATE THAT BOTH THE KURZ AND STANTON COMPUTER PROGRAMS UNDERESTIMATE THE NEUTRON DETECTION EFFICIENCY NEAR THRESHOLD WHEN THE THRESHOLD IS SET IN THE REGION FROM 5 TO 20 MeV PROTON ENERGY.

ILLUSTRATIONS

SLIDE

TITLE

- 1 EXPERIMENT ARRANGEMENT
- 2 RECOIL-PROTON PULSE-HEIGHT SPECTRUM IN
NE-224 SCINTILLATOR FROM 20.76 MEV NEUTRONS
THAT SCATTERED THROUGH AN ANGLE OF 45° .
- 3 RESPONSE OF NE-102 PLASTIC SCINTILLATOR TO
PROTONS. SHOWN ALSO ARE THE PREVIOUS
MEASUREMENTS OF MADEY AND WATERMAN⁵⁾ AND
CZIRR, NYGREN, AND ZAFIRATOS⁷⁾. THE
DASHED CURVE IS THE RESPONSE OF NE-102
TO PROTONS USED IN THE COMPUTER CODES OF
KURZ⁸⁾ AND STANTON⁹⁾.
- 4 RESPONSE OF NE-228A LIQUID SCINTILLATOR TO
PROTONS.

SLIDE

TITLE

- 5 RESPONSE OF NE-228 LIQUID SCINTILLATOR TO
PROTONS. SHOWN ALSO ARE THE PREVIOUS
MEASUREMENTS OF MADEY AND WATERMAN⁵⁾.
- 6 RESPONSE OF NE-224 LIQUID SCINTILLATOR
TO PROTONS. SHOWN ALSO ARE THE PREVIOUS
MEASUREMENTS OF CZIRR, NYGREN, AND
ZAFIRATOS⁷⁾.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6