Cross-section measurements using a nuclear explosion – An overview

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Ref: Dr. Nicola Colonna, Introductory Lecture: Measurements of neutron-induced fission for fundamental Nuclear Physics and Nuclear Technology

Fission cross-section measurements

Methods of cross-section measurements

- Reactors
- Accelerators – p, e-, heavy ions, surrogate reactions
- Radioactive sources
- Nuclear explosion

Features & requirement

- One neutron pulse compared to conventional repetitive pulsed neutron sources.
- Even a small underground explosion produces 10^{24} neutrons in > 10^{-7} sec.
- Pulse intensity ≈ 10^{10} pulses of the best high resolution e- linacs.
- Method – ToF to get energy of neutrons.
- Energy spectrum of neutrons tailored by moderators, depending on the need.
- Measure signal current vs neutron time of flight rather than individual pulses.
- Need - A large dynamic and fast range for recording signal levels.

Principle - Reaction rate is too high that individual fission event is not observed.

✓ Enormous number/microsecond of fission fragments striking the detector ⇒ produces a current from the detector, proportional to product of fission cross section & neutron intensity.

✓ At any given time, neutrons of only one energy are striking the sample - Already sorted out by ToF (moderators & collimators).

✓ Current as a function of time, measures the cross-section as a function of energy.

Reference article

PHYSICAL REVIEW C VOLUME 3, NUMBER 4 APRIL 1971

Analysis of the Fission and Capture Cross Sections of the Curium Isotopes*

M. S. Moore and G. A. Keyworth
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87544
(Received 24 December 1970)

Using a nuclear explosion as a neutron source, measurements were made of the fission cross sections of ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, and ^{248}Cm between 20 eV and 3 MeV. Radiative-capture cross sections were measured at the same time for a sample of mixed Cm isotopes, consisting primarily of ^{244}Cm and ^{246}Cm. Resonance analysis was carried out for ^{244}Cm between 20 eV and 1 keV, for ^{246}Cm and ^{248}Cm between 20 and 400 eV, and for the odd isotopes between 20 and 60 eV. The results of the analysis show evidence of intermediate structure in the sub-barrier fission of ^{244}Cm.

I. INTRODUCTION

The neutron cross sections of curium isotopes are of interest for two reasons. The first reason has to do with fission systematics. The existence of pronounced structure in the sub-barrier fission of even-even targets of uranium and plutonium is as analysis of resonances in the even targets below 200 eV.

Fullwood[7] has reported fission cross-section measurements of ^{244}Cm from the Persimmon nuclear explosion. Fullwood noted that the data obtained were suggestive of intermediate structure, but since complementary capture or total cross

PHYSICS 8 event

LA-4566

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LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Fission and Capture Cross Sections
of Some Curium Isotopes from
the Physics 8 Nuclear Explosion

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

177 pages, with point cross-sections

Experiment - large effort

- **Sample fabrication by many groups**
- **Shipping & assembly of equipments**
- **Innumerable dry runs (everything is tested except device itself) – <u>Only one shot</u>**
- **Only one pulse – Everything must work perfectly & automatically during the pulse.**

M.S.Moore & G.A. Keyworth, Phys. Rev. C 3 (1971) 1656.

History

1960's – Use of nuclear explosion as a neutron source for generating nuclear data was developed at Los Alamos Scientific Lab, series of Physics shot were done.

Physics 1	**Inconclusive**
Physics 2	**Inconclusive**
Physics 3* (1964)	**Feasibility - I**
Physics 4' (1964)	**Feasibility - II**
Physics 5 (1965)	Fission -^{240}Pu, ^{241}Pu, ^{241}Am, ^{242}Am (n,γ) – ^{240}Pu
Physics 6 (1967)	Fission -^{238}Pu, ^{244}Cm, (n,γ) – ^{238}Pu
Physics 7 (1968)	Fission -^{233}Pa, ^{232}U, ^{234}U, ^{236}U, ^{237}U, ^{237}Np, ^{243}Am, ^{243}Cm, (n,γ) – ^{233}Pa
Physics 8 (1969)	**Last**

event code - *Pipefish
'Parrot
Petrel

1,2,3 – For demonstrating the signal capability

Fission fragment from 235U were detected by a p-n Si detector, signals amplified and recorded by plate cameras.

Radiative capture cross-sections with Moxon-rae detector , total c.s. is difficult to measure total c.s. with only one pulse, data was not published (instrumentation issues).

New data on transactinium isotopes.

Just with 1μg sample of ^{239}Pu – demonstrated requirement of limited quantity of material.

Collimated beam of neutron was used but sample ruptured – no data, noise problems

Review Paper No. B3 LA-UR-75-1747

STATUS OF NEUTRON CROSS SECTIONS OF TRANSACTINIUM
ISOTOPES IN THE RESONANCE AND FAST ENERGY REGIONS —
UNDERGROUND NUCLEAR EXPLOSION MEASUREMENTS

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ABSTRACT

The nuclear explosion technique as a means of obtaining neutron cross-section data of actinide isotopes with half-lives of the order of days or longer is reviewed. The status of measurements previously made in this region (except for ^{232}Th, ^{233}U, ^{235}U, ^{238}U, and ^{239}Pu) is discussed. Some suggested corrections which may be in order for previously published data are described, and recommendations are made for possible future work by this technique.

1. INTRODUCTION

The measurement of neutron cross sections by time of flight with a nuclear explosion as a neutron source is ideally suited for samples which

*M.S.Moore, LA-UR-75-1747, 'Status of n-c.s. of transactinium isotopes in the resonance and fast energy regions – underground nuclear explosion measurements'

Underground nuclear explosion - Experiment (1)

Physics 8 event – 5 beams – one was for physics experiments.

30 m high tower – first floor a stack of targets

(^{243}Cm, ^{244}Cm, ^{246}Cm, ^{248}Cm, ^{238}U, Blank, ^{6}Li, ^{235}U, ^{245}Cm, ^{247}Cm, ^{242}Pu, ^{244}Pu, ^{237}Np, ^{243}Am, ^{10}B)

- **Targets - few μg – mg, deposited on stainless steel backing of 0.35 mm thickness.**

- **Beam – Collimated several meters below the first sample (dia ~ 1.94 cm)**

- **Detectors - Must respond quickly & accurately**

Si p-n junction detector – been successfully used for number of years for nuclear explosion experiment & gives linear response to high intensity signal.

Moxon-Rae detector – For detecting γ-radiations, radiative capture measurements.

Each foil was viewed by two p-n Si detectors, at 55 & 90 deg to the beam.

- **Signal recording**

(i) Photographically on moving film (mostly for Cm)

(ii) Magnetically on a moving magnetic disk.

- **Data retrieval - After the shot – exposed films is recovered, developed, copied, & digitized (automatically/manually) then these x-y data sets are edited to give signal in mV vs time in μsec.**

- **Detector efficiency and calibration –^{197}Au(n,γ)^{198}Au**

- **Neutron flux – Different monitors used in the stack.**

M.S.Moore & G.A. Keyworth, Phys. Rev. C 3 (1971) 1656.

Underground nuclear explosion – Experiment (2)

Building

• 30 m high tower – stack of samples at first floor – after passing through the stack and undisturbed upto 6th & 7th floor, and then polarized by transmission, analyzed and dumped in to air.

• At 6th floor, beam further collimated & passed through a ribbon of ^{197}Au & ^{238}Uspinning on a drum – for absolute calibration for capture measurements.

Plan

✓ Relating current to a cross-section – requires one to know detector response as a function of neutron energy.
✓ Fission cross section for number of elements.
✓ Capture c.s. by Moxon-Rae detectors.
✓ Dynamic range for recording signal levels (0.5 mV-1.5 V) – Amplifier whose output is linear below 1mV, & logarithmic above that.

Reading the signal

✓Output of the amplifiers fed to vertical deflection plates of a high speed oscilloscope.

✓ Deflection was recorded on moving film, and film motion serves the time base.

✓ ToF estimated with different resolution cameras & hence to neutron energy.

Data analysis

✓ Data was digitized by professional film readers
✓ Reduction by computer codes,
(i) Converting raw reading of oscilloscope deflection readings (x-y) to a voltage signal vs n-ToF.
(ii) Signals from flux monitors & background signals combined to get cross-section as a function of En.
(iii) Cross section analyzed and resonance parameters extracted.
✓Pulse height spectrum from Si detector – energy deposited per fission calculated.

M.S.Moore & G.A. Keyworth, Phys. Rev. C 3 (1971) 1656.

Nuclear explosion measurements

Advantages

- Uniqueness – To handle small, short lived highly radioactive sources.
- The duration of experiment is only a few seconds.
- Economical if a large number of experiments are done simultaneously.
- Measurements relatively easy for heavy elements.
- Avoid problem of scattering, accelerator structure.
- Low sample mass requirements.

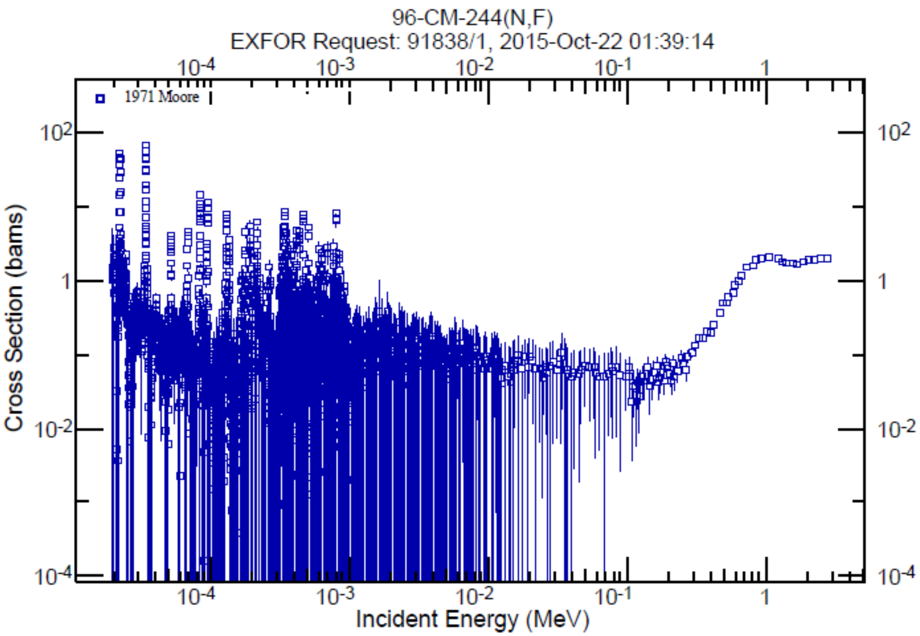
Not possible to do such experiments anymore – Check for alternatives.

Disadvantages

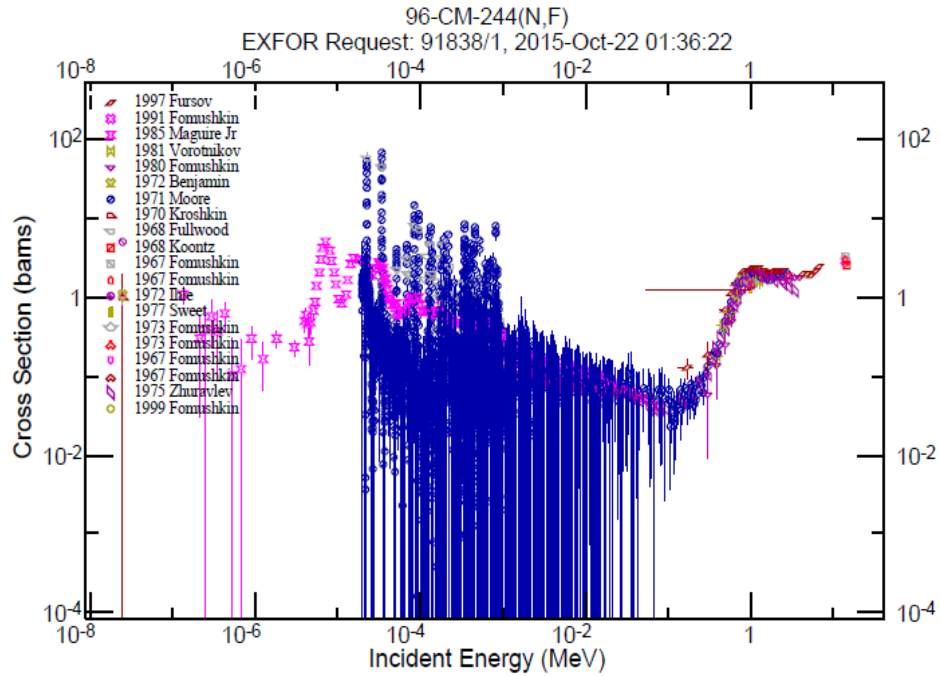
- Difficult to repeated & verify.
- Cost of making single measurement is too high, can be associated with a test series.

Results example

Cm cross-sections – (i) To understand fission systematics &
(ii) Cm isotopes are integral part of production chain of ^{252}Cf – need to know all fission & capture cross section for any reactor applications.



<u>Moore (1971)</u> – looks the most comprehensive measurement ever did.



Present status of $^{244}Cm(n,f)$

Nuclear explosion in space - other experiments (1)

PHYSICAL REVIEW VOLUME 142, NUMBER 3 FEBRUARY

U^{233} Fission Cross Section Measured Using a Nuclear Explosion in Space*

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(Received 26 August 1965)

A high-altitude nuclear explosion in 1962 was used as a neutron source in an experiment to measure the fission cross section of U^{233} relative to U^{235} in the 30-eV to 5-MeV energy region. Fission data were telemetered to the ground station at Kauai, Hawaii from sounding rockets carrying the fission counters which were near their apogee at the time the nuclear explosion occurred over Johnston Island. The flight path for the neutron time-of-flight experiment was 1280 km. The U^{233} fission-cross-section results indicated average values about 20% lower in the 2-MeV energy region and about 30–40% higher in the 30–500-eV energy region than the average of previously obtained values. The results also fill the gap in U^{233} fission-cross-section data which existed between previous high-energy Van de Graaff and low-energy time-of-flight measurements in the 1–20-keV region.

I. INTRODUCTION

IN 1962 the U. S. Atomic Energy Commission and Department of Defense conducted a series of high-altitude nuclear explosions over Johnston Island. The intensity of neutrons emitted during one of these events was enough to make neutron-cross-section measurements[1,2] at a distance of 1280 km from the explosion. The detectors (two fission counters and a BF_3 counter) were mounted in payloads which were launched from Kauai, Hawaii, by means of Nike-Apache sounding rockets. The rockets were near their apogee (about 150 km) at the time of the nuclear explosion.

from the explosion. Data which were obtained fo
23 sec (duration of the experiment was limited
length of recording tape used for signal pla
covered the energy region from 30 eV to 8 MeV
The U^{233} fission cross section was selected for i
gation in this experiment for the following reaso

(1) Knowledge of the U^{233} fission cross sec
fundamental to the economies of reactor tech
based on the Th^{232}-U^{233} breeding chain. The ec
feasibility of a thorium breeder reactor is of co
able importance since the total energy availabl

High altitude nuclear explosion (1962)

To measure fission c.s. of ^{233}U relative to ^{235}U in 30eV to 5 MeV.

Fission data telemetered to ground
Station at Kauai, Hawaii from sounding
Rocket carrying the fission counters ,
Nuclear explosion occurred at Johnston Island.

Flight path for neutron was 1280 km.

Richard D. Albert, Phys. Rev. 142 (1965) 778.

Other experiments (2)

XA04N0905

USE OF NUCLEAR EXPLOSIVES IN MEASUREMENT OF NUCLEAR PROPERTIES OF FISSILE MATERIALS

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Nuclear explosives have been used as sources of neutrons for measurement of the several cross sections for interaction of neutrons with fissionable materials.[1,2] Because most of the very heavy nuclides are highly radioactive and short-lived, the intense single burst of neutrons is ideal for such measurements. Over two dozen of these nuclides have been investigated with this technique.

Those heavy materials that are thermally fissionable are frequently available only in very small quantities because they are "burned out" by fission in the reactors used to produce them. Fortunately, the large numbers of neutrons from a nuclear explosion make possible the measurement of a fission cross section with only a few micrograms of material. Frequently the available sample is not only small but also short-lived. For example, on the Pommard experiment we measured the fission cross section of ^{237}U (one week half-life) with an 18-microgram sample. This measurement extended in neutron energy from 40 electron volts to a few million electron volts. This example serves to demonstrate several useful features of nuclear explosion sources that we wish to exploit. First, the high intensity of neutrons in the beam allows us to produce nuclear reactions at such a high rate in the sample material that backgrounds produced in nuclear reaction detectors by sample radioactivity are trivial in comparison to signals from the reactions being studied. Highly radioactive materials are therefore appropriate subjects for study with bomb neutrons. The second advantage of the explosion source over

Physics 8 event –
Discussing details of neutron scattering Experiment

$^{3}He(n,\alpha)T$
High pressure He gas used
α particles & tritons detected with Solid state & gas chambers.

Thank you for your attention !

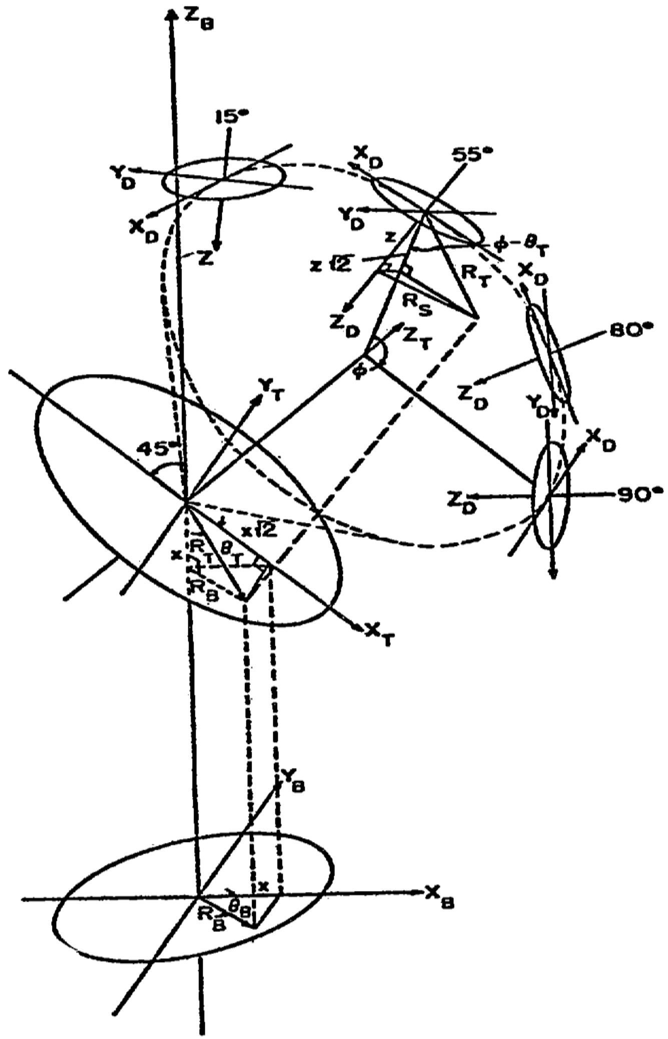

Fig. 1. Beam-target-detector geometry. Each detector axis in inclined at 45° to the target plane, forming a cone with axis Z_T and apex angle 90°. The target plane is inclined at 45° to the beam axis Z_B.