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SCIENTIFIC APPLICATIONS

THE PRESENT STATUS OF SCIENTIFIC APPLICATIONS OF NUCLEAR EXPLOSIONS*

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This is the fourth in a series of symposia which started in 1957 at Livermore with the purpose of examining the peaceful uses of nuclear explosives.[1] Although principal emphasis has been placed on technological applications, the discussions have, from the outset, included the fascinating question of scientific uses. Of the possible scientific applications which were mentioned at the 1957 meeting, the proposals which attracted most attention involved uses of nuclear explosions for research in seismology. It is interesting to note that since then a very large and stimulating body of data in the field of seismology has been collected from nuclear tests. Since a parallel session of this conference is devoted to seismology, it will not be discussed further in this session.

Ideas for scientific applications of nuclear explosions go back considerably further than 1957. During the war days Otto Frisch at Los Alamos suggested that a fission bomb would provide an excellent source of fast neutrons which could be led down a vacuum pipe and used for experiments in a relatively unscattered state.[2] This idea, reinvented, modified, and elaborated upon in the ensuing twenty-five years, provides the basis for much of the research discussed in this morning's program.

In 1952 a somewhat different property of nuclear explosions, their ability to produce intense neutron exposures on internal targets and to synthesize large quantities of multiple neutron capture products, was dramatically brought to our attention by analysis of debris from the first large thermonuclear explosion (Mike) in which the elements einsteinium and fermium were observed for the first time.[3] Most of the remainder of this morning's program will be devoted to reports on experiments whose origin can be traced back to this observation.

The reports of the next two Plowshare symposia in 1959 and 1964[4,5] help record the fascinating development of the scientific uses of neutrons in nuclear explosions. Starting with two "wheel" experiments in 1958 to measure symmetry of fission in ^{235}U resonances, the use of external beams of energy-resolved neutrons was expanded on the "Gnome" experiment in 1961 to include the measurement of neutron capture excitation functions for ^{238}U, ^{232}Th, ^{197}Au, and ^{180}Hf by M. Lindner at Livermore. The list of experiments grew longer in 1964 with the addition of several fission cross-section measurements, marking the beginning of the physics cross-section measurement program at Los Alamos. Since then four more nuclear tests with energy-resolved neutron beams have been used for physics and nuclear chemistry experiments, one each in 1965, 1967, 1968, and 1969. The major developments during this period include successive

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large increases in numbers of measurements on each new test, a steady improvement in our ability to prepare and to measure the neutron cross sections of very small samples and very radioactive samples, an expansion in the capacity to record and analyze enormous numbers of data points, and a better understanding of the techniques for shaping the neutron spectrum to best satisfy the varying demands of a large number of experimentalists.[6-20] By 1969 the number of experiments on a single test had grown to thirty-two (Table I) accommodated in a five-story tower mounted on rails so that all equipment could be removed from the immediate area of the explosion before ground collapse.

TABLE I

Measurements Performed on Physics Experiment, NTS, Summer, 1969

Fission	Capture	Scattering	Transmission
Am-243	Au-197	Yt-89	Pu-239
Bk-249	Th-232	Ta-181	
Cf-249, 252	U-238	Pu-239	
Cm-243, 4, 5, 6, 7, 8	Cm-244, 6		
Es-253	Pu-239		
Np-237			
Pu-239, 242, 4			
U-232, 4, 6, 8			

Other:

Further investigation of the symmetry of fission at resonances in ^{235}U

Ratio of neutron capture cross sections for production of isomers of ^{134}Cs at resonances

Neutron polarization by transmission through LMN polarized proton crystal at 1° K

A particularly striking illustration of the improvement in energy resolution and collimation of the neutron beam in "wheel" experiments is available from comparison of autoradiographs of exposed ^{235}U in the 1958 "Quay" experiment, the 1961 "Gnome" experiment, and in the recent 1969 experiment (Figs. 1, 2, and 3).

The external neutron beam is uniquely suitable for the measurement of cross sections of small, frequently highly radioactive nuclides and its application to such measurements will continue to increase. A number of such measurements have been done but a large number remain.

Fission cross sections of twenty-eight nuclides have been measured using nuclear explosion sources. Some of these experiments could have been performed in the laboratory but others are impossible using laboratory techniques. Nearly as many remain with lifetimes suitable for nuclear explosion work. As might be expected, the remaining nuclides present formidable problems of sample preparation; the fact that very small samples are usable with our intense sources is in many cases the deciding factor in determination of practicability of the measurement.

Capture cross-section measurements have been made on several nuclides including some such as ^{147}Pm, ^{152}Eu, and ^{154}Eu that are extremely radioactive.

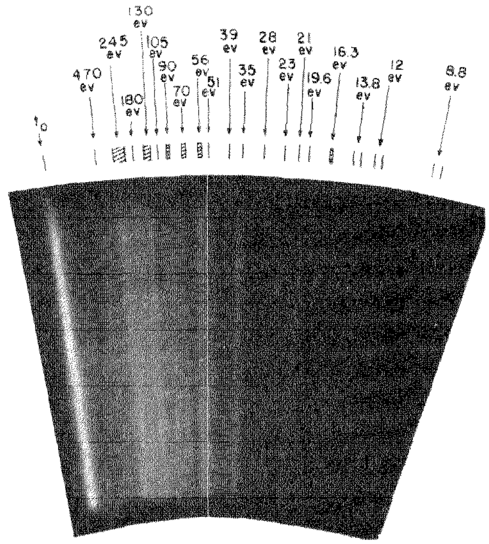

Fig. 1. Autoradiograph of ^{235}U wheel, 1958 experiment.

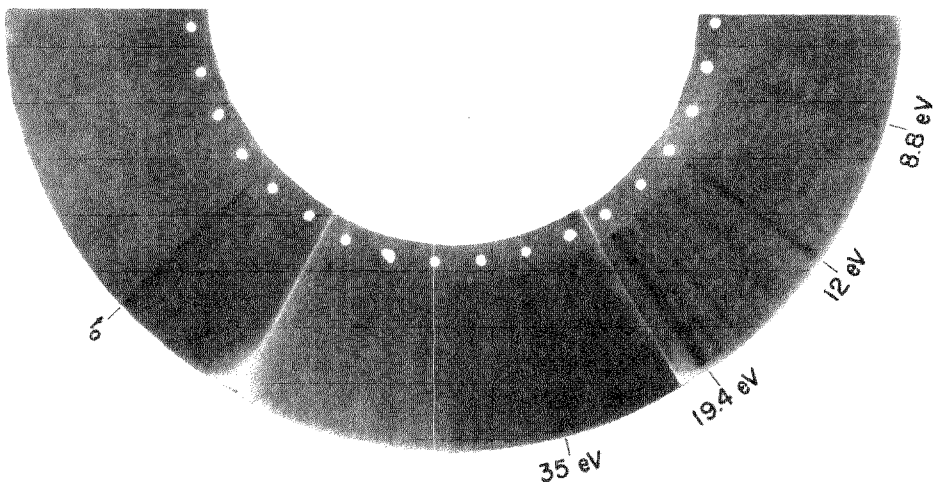

Fig. 2. Autoradiograph of ^{235}U wheel, 1961 experiment.

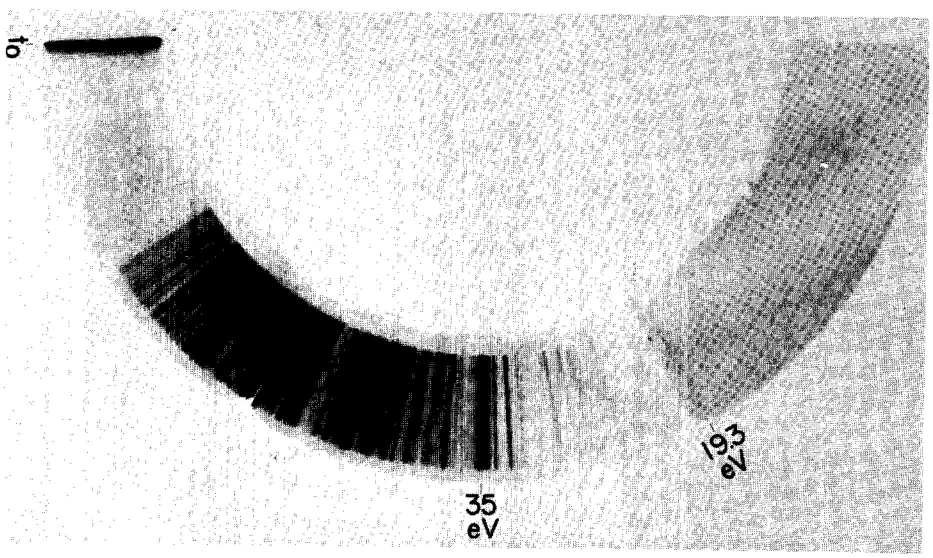

Fig. 3. Autoradiograph of ^{235}U wheel, 1969 experiment.

Both the fission products and the heavy elements provide many examples of radioactive materials whose neutron capture cross section is needed for practical purposes but whose radioactivity precludes the measurement except with the intense beam of neutrons from an explosion source.

Measurements of neutrons resonantly scattered from nuclei have been plagued with intensity problems. We shall hear later in the program of the elegant experiments that can be performed when lack of intensity in the neutron beam poses no difficulty.

Finally, it was demonstrated in the 1969 experiment that the neutron beam from a nuclear explosion can be polarized and this has opened up an entirely new set of experiments for us to consider. Polarization experiments have always been famous for their low counting rates. The combination of our intense beams of neutrons and an efficient method for polarization of those neutrons is certain to result in many very interesting research efforts on future shots.

Like the external beam experiments, the multiple neutron capture experiments have established an impressive record of development and improvement. The principal advance in the experimental technique has been in the neutron source. A figure of merit in these experiments is the size of the term $\int nvdt$, the time-integrated neutron flux or exposure of the target expressed in neutrons per cm^2 or per barn. In a review of this subject in early 1967[21] we plotted the highest exposure achieved by the end of each year for the years 1963-1966 and extrapolated this curve through 1967. However, no new devices were tested until the "Hutch" event conducted by Livermore last summer. Nevertheless, the 1967 extrapolation nearly fits on our actual experience curve from which we might draw the conclusion that designs with computers evolve and improve with time independently of the frequency of actual tests (Fig. 4).

Another figure of merit in these experiments is the total amount of ^{257}Fm made in recent devices, a figure which has increased dramatically between 1964 and 1969 (Fig. 5). Despite this enormous increase, no nuclides heavier than ^{257}Fm have been identified in the "Hutch" debris. Accordingly, we now hypothesize that there are short-lived spontaneous fissioning species (half-lives of less than one day) in every mass chain through mass 265 which lead to the disappearance of these chains before the debris is recovered and chemistry is completed. This explanation is supported by empirical extrapolations of the known spontaneous fission half-lives to this mass region but, unfortunately, we still have no certain guidance as to what may occur in even heavier regions.

There is some reason to believe that a mere repetition of the "Hutch" experiment with the addition of a prompt sample recovery system would lead to the identification of new short-lived heavy nuclides. It can also be argued, somewhat more optimistically, that a new device should be tested at the limit of the present state-of-the-art in the hope that a region of greater stability would be reached. However, the highest mass number made in such an advanced experiment might be 275 or 280. Consequently, it would be rash to predict that the capture chain in such an experiment would pass through the short-lived region above mass 257 and reach a predicted island of stability which is presently thought to exist in the neighborhood of mass 298.

Perhaps a more promising prospect for achieving the kind of experimental information we need to guide our further efforts lies in the direction of large-scale recovery and extraction of products from a "Hutch" type device. For the first time in "Hutch" it has been demonstrated that macroscopic quantities of ^{257}Fm can be made. Other uniquely heavy and neutron-rich products include ^{250}Cm and ^{254}Cf. The ^{257}Fm can be used to determine the properties of its immediate neighbors ^{258}Fm, ^{259}Fm, ^{259}Md, ^{259}No, ^{260}No, and ^{257}Es. By heavy ion bombardments, neutron evaporation products can be obtained from each of the

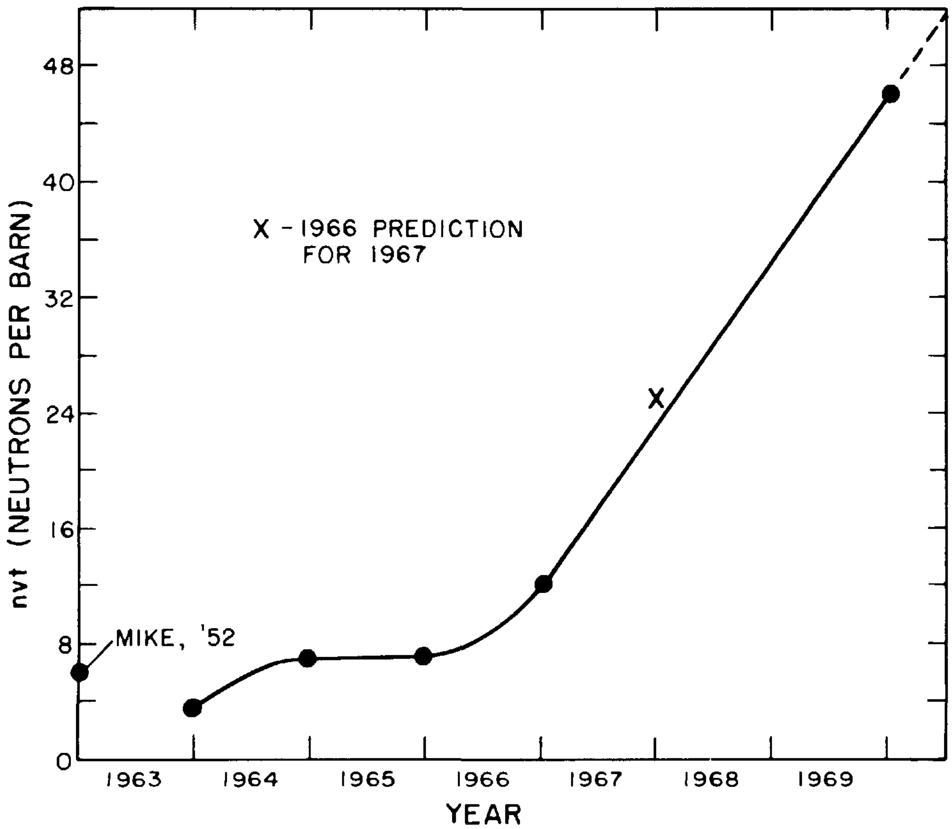

Fig. 4. Improvement in neutron exposure since 1963.

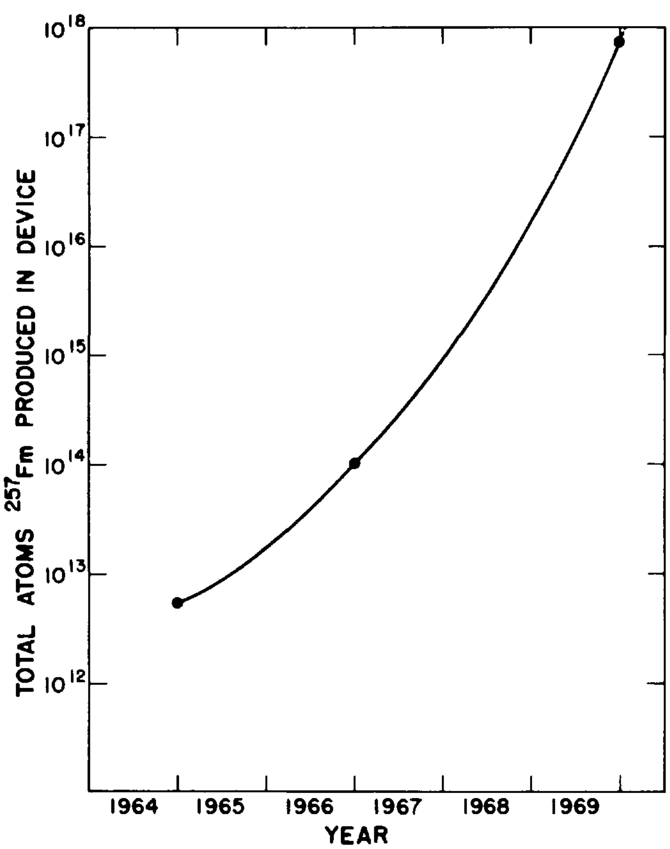

Fig. 5. Increase in ^{257}Fm produced in multiple neutron capture experiments since 1964.

very neutron-rich targets which will be closer to the line of beta-stability and presumably longer-lived than can be produced from presently available heavy plutonium and curium isotopes. Presumably the same general result should be obtained from more exotic reactions which may occur in heavy ion bombardment such as ${}^{18}Ar^{40} + {}^{96}Cm^{250} \rightarrow {}^{10}Ne^{20} + 104^{270}$. The status of efforts to recover these valuable materials from the "Hutch" debris will be described later in this program.

Succeeding presentations in this session will cover the subject matter in more detail than has been attempted here. The points of principal emphasis in this summary are that a considerable effort has been devoted over the past several years to the further development and enrichment of scientific research with nuclear explosions, that new and highly useful nuclear data have resulted from such investigations, and that the outlook for the future should be at least as bright as the realizations of the immediate past.

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