To treat the more general case where we impose no restrictions on the nature of the nuclear wave functions, we can define an "effective neutron wave function" by

$$\zeta_{l'I'^{M'M}}(\mathbf{r}) = \int \Omega_{I'^{M'}}(\mathbf{x}, \mathbf{r})^* \Omega_{I^M}(\mathbf{x}) d\mathbf{x}, \quad (9)$$

where Ω's are the initial and final nuclear wave functions and $\mathbf{x} \equiv$ coordinates of all initial nuclear particles. This can be expanded into a series containing all the l values compatible with the nuclear spins and parities, and the m summation can be easily performed. The only important point (as is clear from references 1 and 2) is that there is no interference between different l's.

* Work performed under the auspices of the AEC.
[1] S. T. Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).
[2] Bhatia, Huang, Huby, and Newns, Phil. Mag. **43**, 485 (1952).

Half-Lives of Eu^{152}, Eu^{154}, and Sm^{151}

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THE half-lives of Eu^{152}, Eu^{154}, and Sm^{151} have been measured directly by mass spectrometric methods. In each case, the half-life was determined by the change with time of the isotopic constitution of samples containing an appreciable percentage of the nuclide under investigation. For Eu^{152} and Eu^{154} the sample used for the determination of the half-lives was a normal europium sample irradiated in a pile. Data on this sample have been used previously for an indirect determination of the half-lives of Eu^{152} and Eu^{154}.[1]

The half-life of Sm^{151} was determined by the change in isotopic abundance of Sm^{151} in a sample of purified fission-produced samarium, used for a previous indirect determination of the half-life by Inghram, Hayden, and Hess.[2]

In every case, isotopic analysis was made on a 12-inch radius of curvature 60°-deflection mass spectrometer.[3] The europium sample was purified from its daughters by elution with pH 3.06 ammonium citrate from an ion exchange column filled with Dowex 50 resin. No further purification was made on the samarium. The data pertinent to the calculations and the results are given in Table I.

The errors quoted for the half-lives consider only the mean deviation of the isotopic determinations.

The value for the half-life of Sm^{151} is in fair agreement with the 122-year value determined indirectly by Inghram, Hayden, and Hess, but disagrees markedly with the 10^3-year half-life obtained by Marinsky.[4]

The serious discrepancy between the half-lives determined for Eu^{152} and Eu^{154} and the half-lives obtained by Hayden, Reynolds, and Inghram may be caused by an experimental error in the determination of the absolute amount of the gadolinium present after bombardment. The presence of a short-lived isomer of Eu^{154} would otherwise be necessary to explain the error in half-life of Eu^{154}. No such isomer is known.

The values for the branching ratios of the 9.2-hour Eu^{152}, the 13-year Eu^{152}, and the proportion of Eu^{151} capture that goes to each of the two Eu^{152} isomers, all measured indirectly by Hayden, Reynolds, and Inghram, are almost certainly in error since they involve the above determined half-lives. No statement about the correct values can be made without a repetition of their experiment.

TABLE I. Decay data.

	% decay	Decay period (yr)	Half-life (yr)
Eu^{152}	16.7 ± 2.4	3.4	13 ± 2
Eu^{154}	13.9 ± 3.3	3.4	16 ± 4
Sm^{151}	3.6 ± 0.9	3.8	73^{+25}_{-14}

[1] Hayden, Reynolds, and Inghram, Phys. Rev. **75**, 1500 (1949).
[2] Inghram, Hayden, and Hess, Phys. Rev. **79**, 271 (1950).
[3] Inghram, Hess, and Hayden (to be published).
[4] Way, Fano, Scott, and Thew, *Nuclear Data*, National Bureau of Standards, Circular 499 (1950).

Fast Coincidences with Čerenkov Counters

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THE duration of the light flash from a Čerenkov radiator is expected to be much shorter than that from a scintillation crystal. This letter reports an experiment performed at the National Bureau of Standards to study the resolving time limitations of Čerenkov counters[1] in preparation for coincidence experiments with high energy particles. The light was produced in Lucite radiators of two different types (A and B of Fig. 1), by secondary

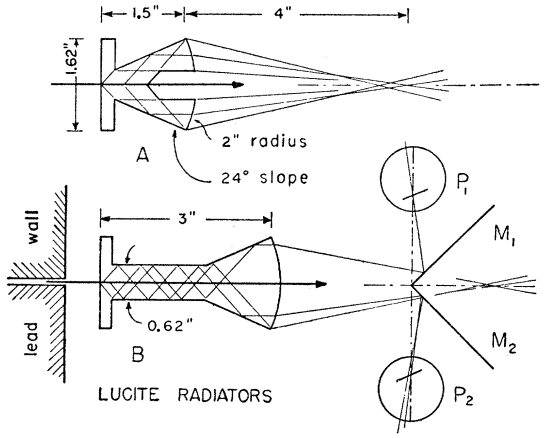

FIG. 1. Čerenkov radiator designs. Heavy arrow indicates direction of high energy electron. Thin lines show paths of optical radiation.

electrons in the x-ray beam of the 50-Mev betatron. The light was brought to an approximate focus by refraction at the spherical end surfaces of the radiators. At the focal point the duration of the light flash from radiator type B is expected to be about 1.5×10^{-10} second due to unequal light collection times. That from type A is expected to be much shorter as the optical path differences are just compensated by the transit time of the electron through the Lucite. However, imperfect focusing can produce path differences of about 3 millimeters and a pulse duration of about 10^{-11} second. The light beam is divided by the mirrors M_1 and M_2 so as to stimulate two 1P21 photomultipliers P_1 and P_2 in coincidence. One can expect to liberate about 6 photoelectrons from each photo-cathode per centimeter penetration of the electron.[2] The phototubes were operated at 1400 volts dc potential. The current pulses from the individual tubes were amplified by 200 megacycle band width distributed amplifiers (Hewlett Packard Model 460A) and brought out of the betatron room through 40 meters of *RG* 59/*U* cable. The coincidences vanish if a piece of black cloth is placed between the Lucite and the mirrors. Thus they are caused by optical radiation coming from the Lucite. The small solid angles (10^{-3} of 4π) subtended by the photo-cathodes inhibit detection of any weak isotropic radiation from the Lucite.

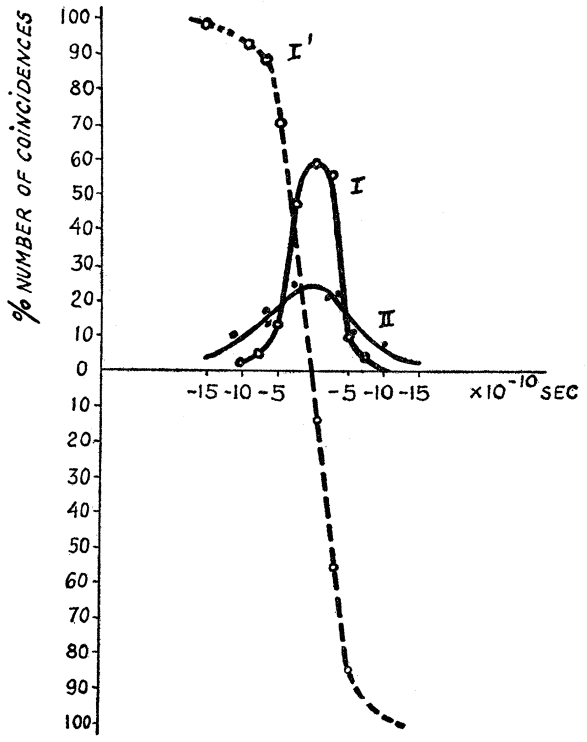

FIG. 2. Delayed coincidence curves obtained with Čerenkov counters. Curves I and I′ obtained with radiator type *B*. Curve II obtained with radiator type *A*.

To obtain short resolving times in spite of the prolongation of the pulses in the multipliers, amplifiers, and long cables, the differential coincidence circuit was used.[3] This gives positive outputs if the pulse from P_1 is earlier than that from P_2 (counting rate $D_+(T)$, T being the delay cable in one channel) and negative outputs if P_1 is later than P_2 [counting rate $D_-(T)$]. A separate diode bridge coincidence circuit[4] (resolving time 5×10^{-9} second) was used to count the total number of coincidence [counting rate $C(T)$], and to gate (10^{-6} second) the D_+ and D_- scalars. Plotting $R=(C_{\max}-D_+-D_-)/C_{\max}$ *versus* T, we obtain the normalized coincidence curves I and II in Fig. 2. It has been shown[5] that the area of such delay curves gives the resolving time (2τ) of the equipment independently of random time delays between the pulses from the two counters. The width of the delay curves ($2\tau'$=area divided by maximum value of R) measures a mean ($\bar{t}$) of the random time lags (t) which occur in the equipment including the counters. $\bar{t}$ for the separate channels is defined as follows:

$$\bar{t}=[(\tau'^2-\tau^2)/2]^{\frac{1}{2}}. \quad (1)$$

For Gaussian curves, which the data approximates, $\bar{t}$ and the root mean square time deviation, $\sigma_{\rm rms}$, have the connection

$$\sigma_{\rm rms}=(2/\pi)^{\frac{1}{2}}\bar{t}. \quad (2)$$

Curve I was taken with radiator type *B*. It gives $\tau=2.5\times10^{-10}$ second, $\tau'=4.4\times10^{-10}$ second, $\bar{t}=2.5\times10^{-10}$ second, and $\sigma_{\rm rms}=2.0\times10^{-10}$ second. Plotting, instead, $S=(D_+-D_-)/C_{\max}$ *versus* T we obtain the dotted curve I′, whose slope is 15 percent per 10^{-10} second. Curve II was taken with radiator type A. It gives $\tau=1.9\times10^{-10}$ second, $\tau'=7.5\times10^{-10}$ second, $\bar{t}=5.1\times10^{-10}$ second and $\sigma_{\rm rms}=4.0\times10^{-10}$ second.

The random time fluctuations ($\sigma_{\rm rms}$) for Čerenkov counters are shorter in spite of the smaller number of photoelectrons than those presently found for scintillation counters. Since the fluctuations in the circuitry are smaller than 10^{-10} second (checked by branched pulses from one tube), the fluctuations observed here must occur mainly in the first stages of the photomultiplier tubes. This view can be further supported by the difference between curves I and II. The light collection time for curve II is certainly negligible, yet $\bar{t}$ is about 2 times larger than for curve I. This is to be expected from the threefold reduction in the number of photoelectrons produced at the photocathodes. At the present time it is possible to measure time intervals to within an error of 10^{-11} second with these techniques,[6] provided one can limit statistical counting errors to one percent.

* These authors' work supported by the ONR and AEC.

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[6] Bay, Meijer, and Papp, Phys. Rev. **82**, 754 (1951); Z. Bay, Phys. Rev. **77**, 419 (1950).

The Absolute Determination of Resonant Energies for Radiative Capture of Protons by Beryllium in the Energy Range Below 520 kev

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THE electrostatic analyzer described previously[1] has been used to determine absolutely the proton energy for which resonances occur in the reaction $Be^9(p,\gamma)B^{10}$ in the energy range below 520 kev.

Thick target yield curves indicated that the yield below 200 kev was extremely small. The resonance postulated by Tangen[2] at about 150 kev therefore appears to be unlikely. The thick target curves could not be explained on the assumption of a single broad resonance at about 330 kev, since the yield continued to increase steeply up to 500 kev.

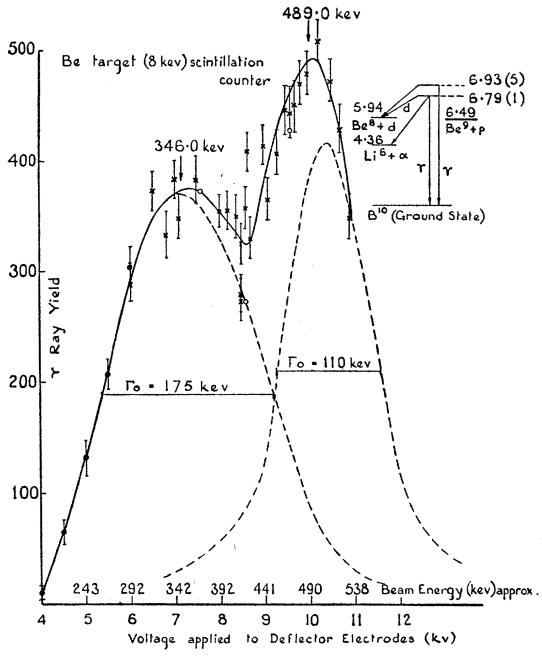

FIG. 1. Thin target (8-kev) yield curve for beryllium observed with a scintillation counter.