In summary, it may be said that from this work Mo^{90} appears to have (1) a half-life of 5.7 ± 0.2 hours; (2) a disintegration scheme involving predominantly three gamma-rays, with energies of approximately 1.1, 0.24–0.26, 0.10–0.13 Mev, of which the second gamma-ray is electron converted to a small extent, and the third to a much larger degree; (3) positrons of roughly 1.4-Mev maximum energy (or of an energy slightly greater than the maximum energy of those from Nb^{90}), and a greater amount of electron capture relative to positron emission than is the case with Nb^{90}.

I wish to state my gratitude to Dr. J. Meadows and Mr. R. Wharton of the Harvard Cyclotron Group for their invaluable help with the bombardments, and to Mr. Rodman Sharp of this laboratory for his assistance with counting.

[1] This preliminary work was performed at the University of California Radiation Laboratory, and the author desires to express his thanks for the guidance and interest of Professor G. T. Seaborg.
[2] R. B. Duffield and J. D. Knight, Phys. Rev. **76**, 573 (1949).
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[5] L. Jacobson and R. Overstreet, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Paper No. 91, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, Div. IV.

Systematic Calculations of Gamma-Ray Penetration*

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A NUMBER of methods[1] of varying degrees of rigor have been proposed for finding the intensity and spectrum of Compton-scattered photons arising in the penetration of gamma-rays through a medium. Recently, Spencer and Fano[2] have indicated a seminumerical technique of solving the Boltzmann transport equation for an infinite medium, which is well adapted for use with high speed automatic calculators. In essence the procedure reduces the original transport equation to a set of integral equations for the spatial moments of the gamma-ray flux. These equations now involve only one independent variable, the energy, and are so interlinked that any given number of spatial moments can be found by the numerical integration of a *finite* number of the equations, without any need for analytical approximations. The required flux distribution function can be approximated in various ways from a knowledge of a finite number of its moments, one of the most suitable being an expansion in terms of an appropriate system of polynomials.

Study of the rate of convergence in the polynomial expansion and comparison of the results with experiment[3] indicated that the method could provide answers of adequate accuracy for a wide range of problems of interest.[4] Accordingly, with the support and encouragement of the U. S. Atomic Energy Commission, especially the Oak Ridge National Laboratory, an extensive calculational program has been undertaken to exploit the method, making use of the SEAC, the National Bureau of Standards calculating machine. The materials investigated have covered the complete periodic table, including pure Compton-scattering medium, H_2O, Al, Fe, Sn, W, Pb, and U. For most of these substances calculations have been made for both point isotropic and plane monodirectional sources. In addition, for Pb, Fe, and pure Compton scatterer (which are the most important materials in practice), calculations have been made for infinite plane source geometries in which the photons leave the source with angular distributions corresponding to the Legendre polynomials $P_n(\cos\theta)$, $n=1, 2, 3$.[5] It is hoped that any source angular distribution with symmetry about the normal that does not vary too rapidly can be approximated well enough out of the first four Legendre polynomials. The range of initial energies considered, 0.5 to 10 Mev, was chosen so as to cover the problems of interest in the shielding of reactors. The calculations reported here include the range of penetrations from 1 to 20 mean free paths from the source. For deep penetrations, greater than 15–20 mean free paths, it is not practical to calculate enough terms to obtain adequate convergence.[6]

In the computations it has been assumed that the only scattering process is incoherent Compton scattering of unpolarized gamma-rays. For the energies involved coherent scattering is so nearly forward as to be no collision at all, and it has therefore been omitted from both the total cross section and the scattering kernel. The only other processes considered have been pair production and photoelectric effect, both of which have been treated as completely absorptive. All cross-sectional data were taken from the National Bureau of Standards compilation.[7]

At the present time all machine work has been completed, and final computations are now in progress. Full details of the calculations will be issued later this year.[8] Complete tables of build-up factors and differential spectra will be included in the report, along with examples of angular distributions. These results will not exhaust the calculations which can be made with the raw output from the SEAC. To make these more generally available it is intended to place annotated microfilm copies of the output tapes at each of the U. S. Atomic Energy Commission Depositary Libraries.

We should like to acknowledge the assistance of the Mathematics Division of the National Bureau of Standards, which did the actual coding of the problem and operating of the SEAC, and of the Computing Section of Nuclear Development Associates, which is calculating the finished results from the machine computations.

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[1] See, for example, Hirschfelder, Magee, and Hull, Phys. Rev. **73**, 852 (1948); Bethe, Fano, and Karr, Phys. Rev. **76**, 538 (1949); L. L. Foldy, Phys. Rev. **81**, 395 (1951); G. H. Peebles and M. S. Plesset, Phys. Rev. **81**, 430 (1951).
[2] L. V. Spencer and U. Fano, Phys. Rev. **81**, 464 (1951) and J. Research Natl. Bur. Standards **46**, 446 (1951). Also see L. V. Spencer and Fannie Stinson, Phys. Rev. **85**, 662 (1952).
[3] G. R. White, Phys. Rev. **80**, 154 (1950); E. Hayward, Phys. Rev. **86**, 493 (1952); Elliot, Farrar, Myers, and Ravilious, Phys. Rev. **85**, 1048 (1952).
[4] Examples of the results that can be provided by the moments methods will be found in references 2 and 3.
[5] The P_0 case (plane isotropic) can be determined directly from the point isotropic solution.
[6] Semi-asymptotic techniques have been developed which overlap with the moments method and carry the solution out as far as desired. See L. V. Spencer, Phys. Rev. **88**, 793 (1952).
[7] G. R. White, National Bureau of Standards Report No. 1003, 1952 (unpublished).
[8] U. S. Atomic Energy Commission Report, NYO-3075 (to be published).

Heavy Isotopes of Magnesium and Silicon

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IN bombardments of chlorine (as sodium chloride) with 340-Mev protons from the Berkeley 184-inch cyclotron, a magnesium chemical fraction contained a 21-hour activity of high radiochemical purity. The radiations present were beta-particles of about 0.4 Mev and of about 3 Mev, in addition to gamma-rays of less than 100 kev and of about 1.7 Mev. The hard radiations were shown by chemical separation to be due to a 2.3-minute Al^{28} daughter, so that the 21-hour activity must be Mg^{28}.

A silicon fraction was removed from the same target and was found to contain the 160-minute Si^{31} in high abundance. If another activity attributable to the unknown isotope Si^{32} were formed in yield comparable to that of Si^{31}, its half-life would have to be either equal to or less than that of Si^{31}, or greater than several hundred years.

The study of the radiations of Mg^{28} and the search for a silicon isotope attributable to Si^{32} are being continued, and the results will be reported at a later date.