

RADIATION HAZARDS FROM ^{241}Am SOURCES USED IN THYROID STUDIES

G. Venkataraman and S. Jayaraman

Bhabha Atomic Research Center, Trombay, Bombay, India

The neutron and gamma photon doses corresponding to the neck and eye level from an $^{241}\text{AmO}_2$ source used in thyroid studies have been theoretically estimated. The radiation hazard to the patient is found to be not significant.

Americium-241 sources with activities of a few curies are used for x-ray fluorescent scanning of the thyroid gland (1). The 59.6-keV gamma photons emitted by ^{241}Am are used to excite the characteristic x-ray emission of iodine atoms in the thyroid. A typical source for these studies is a pellet compressed from $^{241}\text{AmO}_2$ and aluminum powder; the powdered aluminum acts as a binder. In such a matrix alpha particles from ^{241}Am can cause a neutron flux through (α, n) reactions with the aluminum and oxygen atoms of the source complex. This neutron flux (2) is of some concern from the viewpoint of radiation protection. Robinson et al (2) measured the neutron flux with a neutron "rem counter." The rem counter is too large (about 9 in. in diameter) for making measurements at the short distances from the source corresponding to the neck and eye regions. As a check, we thought it worthwhile to calculate the neutron dose theoretically from the known (α, n) cross sections of aluminum and oxygen.

METHOD OF CALCULATION

The neutron yields and spectra resulting from the interaction of alpha particles with aluminum and oxygen were calculated separately and then added together to get the overall neutron yield and spectrum. Among the natural oxygen isotopes, ^{18}O is the chief contributor to neutron yield from the $^{241}\text{AmO}_2$ source. Oxygen-16, although overwhelmingly abundant (99.759%), has a threshold of 15.2 MeV for the (α, n) reaction. Since the abundance and the (α, n) cross section of ^{17}O are only about 15% and 10%, respectively, of those of the ^{18}O isotope, neutron contributions from ^{17}O can also be disregarded.

The calculations were done for the type of source described by Robinson et al (2). The activity of ^{241}Am was 5 Ci, and the source was shaped as a cylinder whose active area was 1.75 in. in diameter and 0.75 in. thick. Since no information was given on the ratio of Am to Al atoms, it was taken to be 1:20 since the Am:Be ratio in Am-Be neutron sources is known to vary between 13 and 30. From these data the number of Am, O, and Al atoms per cubic centimeter of source were calculated.

The neutron yield per alpha particle from the source is given by

$$Y = N \int_{E_t}^{E_{\max}} \frac{\sigma_{\alpha, n}(E) dE}{\left[\frac{dE}{d\chi} \right]}, \quad (1)$$

where N is the number of target nuclei (aluminum or oxygen) per cubic centimeter; $\sigma_{\alpha, n}(E)$ is the neutron-production cross section of the target material, in barns per atom; E is the energy of the alpha particle; $dE/d\chi$ is the stopping power of the source material (the AmO_2 -Al mixture) for an alpha particle of energy E ; E_t is the threshold alpha energy for neutron production; and E_{\max} is the maximum energy of the emitted alpha particles.

The neutron spectrum (3) is given by

$$\phi(E_n) = N \int_{E_t}^{E_{\max}} \frac{p(E_n, E) \sigma_{\alpha, n}(E) dE}{\left[\frac{dE}{d\chi} \right]}, \quad (2)$$

where $p(E_n, E)$ is the probability that a neutron of energy E_n per unit energy interval is produced when an alpha particle of energy E interacts with the target medium. These probabilities were calculated assuming that the neutron is emitted isotropically in the

Received Aug. 19, 1975; revision accepted Nov. 20, 1975.

For reprints contact: G. Venkataraman, Div. of Radiological Protection, Bhabha Atomic Research Center, Trombay, Bombay 400 085, India.

center of mass system. The stopping power of the source material, in erg/cm, is given by

$$\frac{2.97 \times 10^{-4}}{E} (\ln E - 26.26), \quad (3)$$

where E is in MeV. The number of oxygen and aluminum nuclei per cubic centimeter were found to be 2.61×10^{20} and 2.61×10^{21} , respectively.

The $^{27}\text{Al}(\alpha, n)^{30}\text{P}$ reaction. The threshold alpha energy for neutron production is 3.00 MeV and the reaction has a negative Q value of 2.7 MeV. The emitted neutrons have a maximum energy of only 2.4 MeV. We used the cross-section data of Williamson, Katman, and Burton (4). The neutron yield for a 5-Ci source was calculated to be 1.04×10^4 neutrons per second. The neutron spectrum produced in this reaction is shown by the continuous line of Fig. 1. The average kerma per unit neutron flux, maximum permissible flux density, average quality factor, and modifying factor for the eye lens calculated for this spectrum are, respectively, 2.40×10^{-9} rad, 25.6 neutrons/cm²-sec, 10.3, and 1.1. The basic data needed for the averaging process were the kerma values of Ritz et al (5), the maximum permissible fluxes and quality factors from the NCRP (6), and the modifying factors given by the ICRP (7).

The $^{18}\text{O}(\alpha, n)^{21}\text{Ne}$ reaction. The yield due to this reaction was calculated from the figure for neutron yields of $^{238}\text{PuO}_2$ sources given by Taherzadeh (8): 2.24×10^{-8} neutrons per alpha. The number of oxygen nuclei per cubic centimeter in PuO_2 is 5.04×10^{22} . Its stopping power, in erg/cm, is

$$\frac{1.68 \times 10^{-2}}{E} (\ln E - 27.34). \quad (4)$$

Thus, the neutron yield for the 5-Ci AmO_2 -Al source from the $^{18}\text{O}(\alpha, n)^{21}\text{Ne}$ reaction was 1.23×10^3 neutrons/sec, which is quite low compared with the yield of the aluminum reaction. The neutron spectrum for the $^{18}\text{O}(\alpha, n)^{21}\text{Ne}$ reaction is taken to be the same as that measured for a PuO_2 source by Neff et al (9). The $^{18}\text{O}(\alpha, n)$ reaction simply adds a high-energy tail to the $^{27}\text{Al}(\alpha, n)$ neutron spectrum, and the combined spectrum for the two reactions is shown by the dashed line in Fig. 1. The kerma and other parameters for the combined spectrum are the same as for the $^{27}\text{Al}(\alpha, n)$ spectrum.

RESULTS AND DISCUSSION

The total neutron output for the 5-Ci source comes out to be 1.16×10^4 neutrons/sec, which is low compared to the measured yield of 3.22×10^4 neutrons/sec (10). The theoretical yield does not increase very much if the aluminum content is increased. Even when the Al:Am ratio is increased

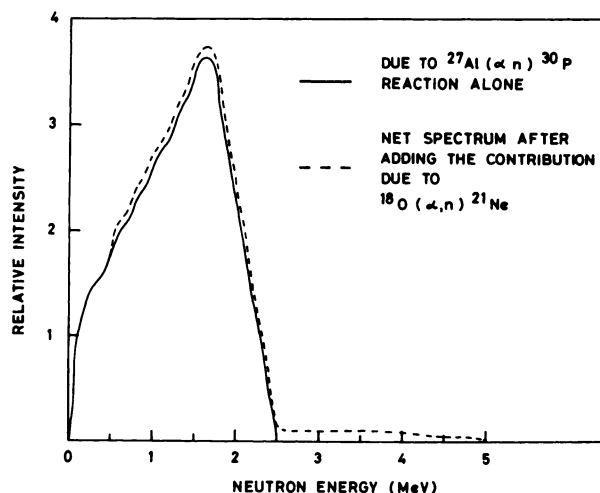


FIG. 1. Neutron spectrum of AmO_2 -Al source.

from 20 to 1000, the yield goes up by only 40%. Even though the number of aluminum nuclei per cubic centimeter increases, the stopping power of the medium also increases, and the neutron yield is a function of both, as shown by Equation 1. The higher measured yield could be due to impurities of low atomic number in the source.

The neutron dose equivalent at a distance of 2.5 in. along the axis of the source (corresponding to the surface of the neck) is calculated to be 2.1 mrem/hr. No measured data corresponding to this point are available. At 6 in. the calculated neutron dose is 0.4 mrem/hr, whereas the measured dose is ~ 1.2 mrem/hr. This difference is consistent since the measured neutron yield is greater by a factor of 3 than our theoretical yield. At a point corresponding to the eye (0.5 in. along the source axis and 6 in. from the axis), the calculated dose equivalent comes out to be 0.33 mrem/hr. Even if a 15-Ci source is used and one accepts the measured values, the dose equivalents at the neck and eye regions amount to about 20 and 3 mrem/hr, respectively.

The only significant radiation, in terms of the dose to humans, is gamma radiation. Robinson et al (2) pointed out the origins of the various photons observed in the gamma spectrum of the source. However, the relative yields of gamma photons are such that only the 59.6-keV gammas emitted by ^{241}Am (these are used to excite the thyroidal iodine) contribute significantly to the dose. The gamma photon dose at a distance of 2.5 in. along the axis (corresponding to the neck region) is 3.5 rad/hr for the 5-Ci source, allowing for the self-shielding and attenuation in the stainless-steel outer covering of the source but without taking into account any collimator that may be used. The gamma dose to the eye in the absence of a collimator may be as high as

500 mrad/hr. Since the average scan will take a maximum of 30 min, the dose to the neck amounts to about 1.8 rad.

Since the patient will probably not be subjected to this type of examination repeatedly, one need not be unduly worried about this localized dose to the patient. If a collimator is used, the dose is bound to be lower. On the other hand, the technical staff must take proper precautions since they will handle the source more often. Clearly, the source must be kept in a properly shielded container when not in use.

REFERENCES

1. HOFFER PB: Fluorescent thyroid scanning. *Am J Roentgenol Radium Ther Nucl Med* 105: 721-727, 1969
2. ROBINSON EL, HANNAH BO, BASS WB, et al: Neutron and photon flux from x-ray fluorescent thyroid scanners. *Health Phys* 26: 301-306, 1974
3. HESS WN: Neutrons from (α ,n) sources. *Ann Phys* 6: 115-133, 1959
4. WILLIAMSON RM, KATMAN T, BURTON BS: F^{19} , Na^{23} , and $Al^{27}(\alpha,n)$ reactions. *Phys Rev* 117: 1325-1329, 1960
5. RITTS JJ, SOLOMITO M, STEVENS PN: *The Calculation of Neutron Induced Physical Doses in Human Beings*, ORNL-TM-2991, Oak Ridge National Laboratories, 1970
6. National Committee on Radiation Protection: *Protection Against Neutron Radiation*, National Bureau of Standards, NCRP Report No. 38, 1971
7. ICRP: *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 4, London, Pergamon, 1964, p 38
8. TAHERZADEH M: Neutron yield from the (α ,n) reaction in the isotope oxygen-18. *Nucl Sci Eng* 44: 190-193, 1971
9. NEFF RA, ANDERSON ME, CAMPBELL AR, et al: Some neutron and gamma radiation characteristics of a plutonium cermet fuel for isotopic power sources. In *Symposium on Natural and Man-Made Radiation in Space, Las Vegas*, NASA-TM-X-2440, 1972, pp 853-858
10. ROBINSON EL, BAIR JK, DUGAN JL: Absolute neutron yield of a fluorescent thyroid scanner source. *Health Phys* 28: 205-207, 1975

1st ANNUAL WESTERN REGIONAL MEETING THE SOCIETY OF NUCLEAR MEDICINE

October 1-3, 1976

Fairmont Hotel

San Francisco, Calif.

ANNOUNCEMENT AND CALL FOR ABSTRACTS FOR SCIENTIFIC PROGRAM

The Scientific Program Committee welcomes the submission of abstracts of original contributions in nuclear medicine from members and nonmembers of the Society of Nuclear Medicine for the 1st Annual Western Regional Meeting. Abstracts for the scientific program will be printed in the program booklet and will be available to all registrants at the meeting.

Guidelines for Submitting Abstracts

This year abstracts will be printed from camera-ready copy provided by the authors. Therefore, only abstracts prepared on the official abstract form will be considered. These abstract forms are available from Jean Lynch, Executive Secretary, Northern California Chapter SNM, P.O. Box 40279, San Francisco, Calif. 94140. Abstract forms will only be sent to the Pacific Northwest, Southern California, Northern California, and Hawaii Chapters in a regular mailing. All other requests will be sent on an individual basis.

Send the original abstract form, supporting data, and six copies to:

Michael Goris, M.D., Ph.D.
Scientific Program Chairman
Department of Nuclear Medicine
Stanford University Medical Center
Stanford, Calif. 94305

Deadline for abstract submission: June 30, 1976

The 1st Annual Western Regional Meeting will have commercial exhibits and all interested companies are invited. Please contact Robert Hattner, M.D., Exhibits Chairman, Division of Nuclear Medicine, UCSF, 3rd and Parnassus Aves., San Francisco, Calif. 94143.