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PRODUCTION OF ^{99m}Tc ON A MEDICAL CYCLOTRON: A FEASIBILITY STUDY

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Direct production of Curie quantities of ^{99m}Tc using an isotopically enriched target of ^{100}Mo is possible with any of the commercially available compact cyclotrons. Simultaneous production of 100-mCi quantities of ^{99}Mo is also possible with the higher energy models of the compact cyclotrons. Experimental data indicate that yields of 15 Ci/hr of ^{99m}Tc and 500 mCi/hr of ^{99}Mo are possible with 22-MeV protons at a target power level of 10 kW (estimated maximum power level of currently available target systems). Production of significant quantities of these radionuclides (normally reactor produced) increases the usefulness of the medical cyclotron and adds strength to the justification for its installation in a metropolitan medical center.

EXPERIMENTAL

Thirteen molybdenum foils of normal isotopic abundance, each 0.935 in. in diam and 0.003 in. thick (79 mg/cm^2), were bombarded with a 0.0061 μA-hr integrated beam current of 22-MeV protons in the 86-in. cyclotron (*1*). The foil stack was placed in a water-cooled target probe and inserted in the beam pipe at the "T" position (*1*) using a $^3/_{16}$-in. collimator for the bombardment. A 0.935 $\times$ 0.001-in. (16 mg/cm^2) copper foil was inserted between the molybdenum foils at an energy below the threshold for ^{99m}Tc and ^{99}Mo production as a proton beam current monitor. After bombardment the foils were separated, and the quantity of ^{99m}Tc produced in each foil was determined using a 60-cc Ge(Li) detector coupled with a multichannel analyzer. After many shorter-lived activities had decayed, the ^{99}Mo induced in each foil was determined using a 3 x 3-in. NaI(T1) detector coupled with a multichannel analyzer. From these data excitation functions for the ^{100}Mo(p,2n)^{99m}Tc reaction and ^{100}Mo(p,2p)^{99}Nb $\xrightarrow{decay}$ ^{99}Mo-^{100}Mo(p,pn)^{99}Mo reactions were derived.

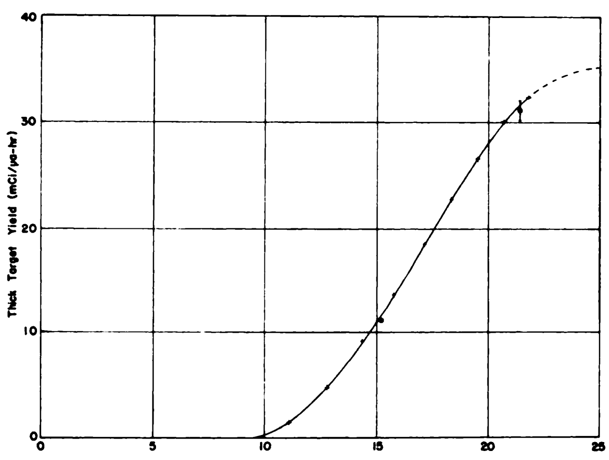

FIG. 1. Technetium-99m thick target yield as a function of proton energy. Solid line represents measured yield data from natural molybdenum foils normalized to 97.42% ^{100}Mo. Circled points represent yields from enriched ^{100}Mo targets. The dashed portion of the curve represents an extrapolation of the yield data to 25 MeV.

To substantiate the yields from the foil-stack data and investigate impurity levels experimentally, 600 mg of 97.42% isotopically enriched ^{100}Mo was sealed in a 0.935-in.-diam aluminum cup with a 0.362-in.-diam recess, 0.2 in. deep (900 mg/cm^2-thick) and bombarded at incident proton energies of 21.4, 20.2, and 15.2 MeV and integrated beam currents of 0.00046, 0.0296, and 0.00068 μA-hr, respectively. Radioassays of ^{99m}Tc for the 21.4- and 15.2-MeV enriched target bombardment were obtained. A radioassay for ^{99}Mo and repeated examinations for radionuclidic purity were performed for 4 weeks following the 20.2-MeV bombardment.

The beam current for the foil-stack bombardment was determined by comparing both the ^{63}Zn and ^{65}Zn radioactivities produced in the copper foil with pub-

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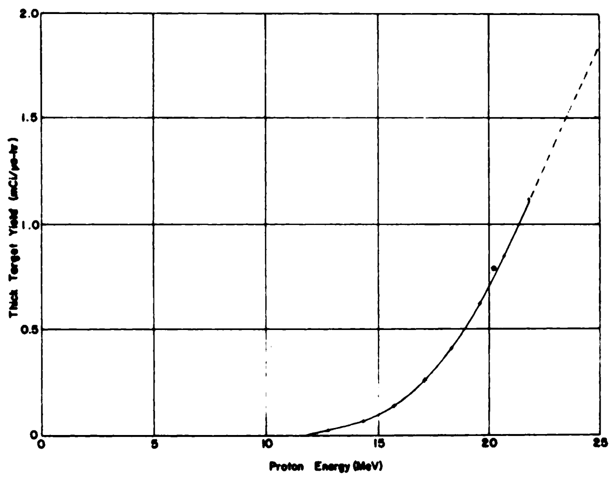

FIG. 2. Molybdenum-99 thick target yield as a function of proton energy. Solid line represents measured yield data from natural molybdenum foils normalized to 97.42% ^{100}Mo. Circled point represents the yield from an enriched ^{100}Mo target. The dashed portion of the curve represents an extrapolation of the yield data to 25 MeV.

lished excitation functions (*2*). The measured beam current was used to calibrate an electronic current integrator for the beam current monitoring of the subsequent irradiations. This method implies that all yield data are relative to the published cross section for $^{63}Cu(p,n)^{63}Zn$ and $^{65}Cu(p,n)^{65}Zn$ reactions.

RESULTS AND DISCUSSION

The curve shown in Fig. 1 represents the thick target yield of ^{99m}Tc from the $^{100}Mo(p,2n)^{99m}Tc$ reaction as a function of energy. The marks defining the solid curve were obtained by summing the ^{99m}Tc activity of the individual foils corrected from 9.63% (the abundance of ^{100}Mo in naturally occurring molybdenum) to 97.42% (the ^{100}Mo abundance in the isotopically enriched target). The thickness of the foils were converted to MeV units from range-energy data (*3*). The circled points are the thick target yields obtained from the isotopically enriched target bombardments. The bar on one of the circled points indicates an uncertainty in its value arising from differences in beam current monitoring. An extrapolation of the excitation function to 25 MeV was made, and the estimated thick target yield from 22 to 25 MeV is shown by the broken portion of the curve.

The curve shown in Fig. 2 represents the thick target yield of ^{99}Mo from the appropriate nuclear reactions as a function of energy. It was similarly obtained by summing the ^{99}Mo activity of the individual foils corrected from 9.63% to 97.42% ^{100}Mo abundance. The circled point is the thick target yield of ^{99}Mo obtained from the isotopically enriched ^{100}Mo bombardment. The broken portion of the curve is an estimation of the thick target yield to 25 MeV based on extrapolations of the excitation functions.

From these data it is anticipated that an internal cyclotron bombardment of 97.42% isotopically enriched ^{100}Mo at 22 MeV and 455 μA will produce 15 Ci/hr of ^{99m}Tc and 500 mCi/hr of ^{99}Mo. From extrapolated data, an internal bombardment at 25 MeV and 400 μA should produce 14 Ci/hr of ^{99m}Tc and 750 mCi/hr of ^{99}Mo. On internal cyclotron

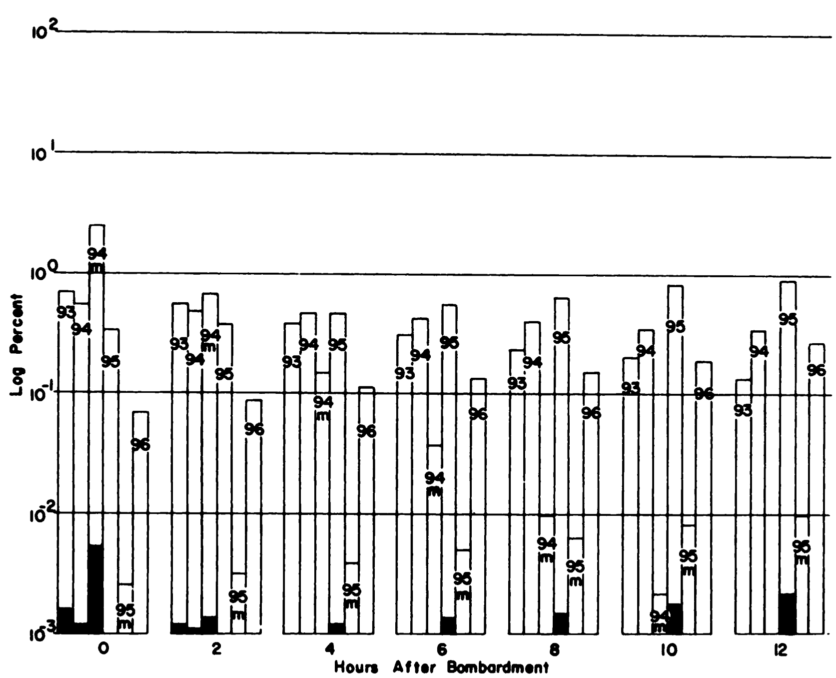

FIG. 3. Percent of technetium impurities in ^{99m}Tc produced by direct production method. Open bars represent percent impurities measured from 97.42% ^{100}Mo target material, shaded bars represent percent impurities estimated from 99.99% ^{100}Mo target material.

targets, the limiting factor is usually the quantity of heat or thermal power which can be dissipated from the target. Thermal power is a function of the energy of the incident particle and the beam current. If the incident particle energy is increased (i.e. from 22 to 25 MeV), the beam current must be decreased to maintain constant thermal power. From constant thermal power yield curves, the optimum proton energy for ^{99m}Tc production in an internal target is 22–23 MeV. The optimum proton energy for ^{99}Mo production is somewhat above 25 MeV.

If an internal target system is not available on the particular cyclotron being used, an external target bombarded with 25-MeV protons at a nominal beam current of 65 μA should produce about 2.2 Ci/hr of ^{99m}Tc and 120 mCi/hr of ^{99}Mo. The radionuclidic purity of the ^{99m}Tc produced directly in the isotopically enriched ^{100}Mo target is shown in Fig. 3. The open bars represent the percent of other technetium radionuclides related to a constant level of ^{99m}Tc content at the times indicated. Even through all the impurities are below 1% of the ^{99m}Tc content between 2 and 12 hr after bombardment, a higher purity product may be desirable. The Isotopes Division at the Oak Ridge National Laboratory has indicated that an enrichment of 99.99% ^{100}Mo can be achieved. The shaded bars in Fig. 3 show the impurities which might be expected from a bombardment of this material. Note that all the impurities are below 0.002% between 2 and 12 hr after bombardment. If the ^{99m}Tc is obtained from the ^{99}Mo production method, the technetium radioimpurities will be removed by the first target processing and will not be present in subsequent elutions. In this case, the 97.42% enriched ^{100}Mo target material would be acceptable.

SUMMARY

The compact medical cyclotron can be used to produce a sufficient quantity of ^{99m}Tc by a direct nuclear reaction to supply the daily needs of a metropolitan community. Assuming an operating cost of \$100/hr, ^{99m}Tc could be produced for about 1.5¢/mCi. If the machine is operated on a cost-sharing basis, the revenues thus generated will contribute to the cyclotron operating budget and reduce the cost of producing other important short-lived radionuclides. A 99.99% isotopically enriched ^{100}Mo target may be required to minimize the radionuclidic impurities. The 22-MeV cyclotron model is capable of producing a sufficient quantity of ^{99}Mo simultaneous with the direct ^{99m}Tc production to serve as a reserve generator should the daily cyclotron operating schedule be interrupted.

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REFERENCES

1. Pinajian JJ, Butler TA: ORNL 86-in.-cyclotron facility for isotope production. *Isotope and Radiation Technology* 1: 137–143, Winter 1963–64

2. Hansen I.F, Albert RD: Statistical theory predictions for 5- to 11-MeV (p,n) and (p,p′) nuclear reactions ^{51}V, ^{59}Co, ^{63}Cu, ^{65}Cu, and ^{103}Ru. *Phys Rev* 128: 291, 1962

3. Hill CW, Ritchie WB, Simpson KM: Data compilation and evaluation of space shielding problems, range and stopping power data. *Lockheed-Georgia Co. Report NP-15697*, 56, 1965