論文の内容の要旨

論文題目　Parametric analyses in electron linac production of ^{99}Mo/^{99m}Tc
（電子リニアックを用いた ^{99}Mo/^{99m}Tc 製造におけるパラメータ解析）

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Technetium-99m (^{99m}Tc), the daughter radionuclide of molybdenum-99 (^{99}Mo), plays an indispensable role in diagnosing various diseases such as myocardial ischemia and bone metastasis. Recent interruptions of ^{99}Mo production reactors have prompted research into accelerator production of ^{99}Mo/^{99m}Tc, among which ^{99}Mo production using an electron linear accelerator (linac) and the ^{100}Mo(γ,n)^{99}Mo reaction is considered a promising alternative.

The key to realizing electron linac production of ^{99}Mo/^{99m}Tc lies in increasing the yield of ^{99}Mo and the radioactive concentration of ^{99m}Tc, both of which are determined by parameter choices. Therefore, identifying the parameters of importance and understanding their appropriate ranges can justify the design parameters of a newly constructed ^{99}Mo electron linac, and can make an existing electron linac available for ^{99}Mo production. Through parametric analyses, this dissertation attempts to provide a comprehensive understanding of beam and targetry parameters.

To solve simulation problems for wide ranges of parameter values, we developed three computer programs. We then carried out parametric analyses using the programs, and validated some

of the results through experiments. Subsequently, we conducted modeling studies and defined a figure of merit that can quantify the influence of ^{100}Mo enrichment level on ^{99}Mo/^{99m}Tc yields. Also, we parameterized the ^{99m}Tc radioactive concentration such that it takes into account the issue of low specific activity ^{99}Mo.

In addition to the parametric analyses, we conducted small-animal biodistribution studies to test the radiopharmaceutical quality of linac-derived ^{99m}Tc. The tests showed that linac-derived ^{99m}Tc can be comparable to the conventional reactor-derived ^{99m}Tc.

The main goal of this dissertation is to provide reasonable parameter values in electron linac production of ^{99}Mo/^{99m}Tc, based on multivariate parametric analyses. The analyses consist of (i) identification of important parameters, (ii) understanding the influences of the parameters on the overall ^{99}Mo/^{99m}Tc production system, (iii) developing tools and methods for solving the identified parametric problems, (iv) and analyzing the numerical results. Based on the analyses, we suggest acceptable ranges of the identified parameters.

Chapter 1 explains the background and purpose of the dissertation. The problems of fission production of ^{99}Mo are introduced, and the need for parametric analyses is explained.

Chapter 2 introduces the three programs developed for parametric analyses: `phitar`, `enrimo`, and `actdyn`. The algorithms and characteristic features of the programs are explained.

Chapter 3 analyzes linac and beam parameters using the programs `phitar` and `actdyn`. To be specific, the following parameters are addressed: (i) the operating frequency of a ^{99}Mo production linac, (ii) accelerating structure, (iii) beam energy, (iv) beam current, (v) beam size, and (vi) beam emittance.

Chapter 4 explains targetry parametric analysis. Quantitative and comparative analysis was carried out to determine the suitable converter material and the suitable targetry configuration. The program `phitar` described in Chapter 2 was used for the analysis.

Chapter 5 addresses the topic of optimal converter thicknesses, which is part of the targetry parametric analysis (Chapter 4). Converter thicknesses that can increase ^{99}Mo yields were analyzed and experimentally validated. The calculation and experimental results were in agreement. Analysis of the results showed that the yields and specific yields of ^{99}Mo can be improved by adjusting converter thicknesses.

Chapter 6 describes the definition and use of a figure of merit called density change coefficient (DCC). DCCs can be used to calculate the changes of ^{100}Mo reaction yields and the changes of $^{92,94–98}$Mo reaction yields with respect to ^{100}Mo enrichment levels. The program `enrimo` introduced in Chapter 2 was developed for calculating DCCs. Using the DCCs of $^{92,94–98,100}$Mo calculated by `enrimo`, quantitative analysis was carried out on ^{100}Mo yield increases and $^{92,94–98}$Mo yield decreases for various enriched ^{100}Mo products. The results showed that not only the ^{100}Mo enrichment level, but also the depletion levels of $^{92,94–98}$Mo should be considered in selecting the ^{100}Mo enrichment level.

Chapter 7 addresses the problem of low specific activity (LSA) ^{99}Mo, which is one of the most challenging issues in the linac production of ^{99}Mo/^{99m}Tc. To enable calculation of ^{99m}Tc radioactive concentration (RAC) with the LSA issue considered, we parameterized the RAC of conventional alumina ^{99m}Tc generators and pre-elution ^{99m}Tc concentrators. Experimental verification was performed on activated carbon chromatography, which is a pre-elution ^{99m}Tc concentrator.

Chapter 8 describes preclinical testing of linac-derived ^{99m}Tc. Through biodistribution studies on laboratory mice, ^{99m}Tc obtained from an electron linac and activated carbon chromatography is compared to conventional reactor-derived ^{99m}Tc. The results showed the linac-derived ^{99m}Tc exhibit similar pharmacokinetics with reactor-derived ^{99m}Tc, corroborating that electron linacs can become an alternative source of ^{99}Mo/^{99m}Tc.

Chapter 9 summarizes the dissertation and addresses future research topics.

This dissertation identified and analyzed several important parameters involved in the linac production of ^{99}Mo/^{99m}Tc, and found reasonable ranges of the parameter values. The characteristic approach of this dissertation was the writing and use of dedicated analysis programs, which enabled us to conduct a wide spectrum of parametric studies. In addition, new parameters such as the DCC and parameterized RAC were defined to improve ^{99}Mo/^{99m}Tc production processes and efficiencies. We expect that by using the parameter values and the computational approaches of the dissertation, the yields of ^{99}Mo/^{99m}Tc and the RAC of ^{99m}Tccan be significantly improved, which in turn can contribute to the realization of linac production of ^{99}Mo/^{99m}Tc.