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# The Role of Radiochemistry in the Development of Nuclear Medicine on The Treatment of Cancer in Kazakhstan

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**ABSTRACT:** The article examines contemporary achievements and the role of radiochemistry in the development of nuclear medicine for oncological therapy in Kazakhstan. Radiochemistry is a fundamental scientific discipline that underpins the synthesis, production, and quality control of radionuclide compounds used for the diagnosis and treatment of malignant tumors. Particular attention is given to key medical radionuclides such as Tc-99m, I-131, Lu-177, and Sm-153, as well as to promising isotopes applied in targeted radionuclide therapy and theranostics. Technological approaches to the development of radiopharmaceuticals are discussed, including labeling methods, quality standardization, isotope stability assurance, and their integration into clinical protocols for the treatment of various types of cancer. The article analyzes current clinical practices in Kazakhstan, including the use of PET/CT for diagnosis and monitoring therapeutic efficacy, the implementation of radionuclide therapy, and precision targeted tumor treatment methods. Significant progress is noted in the expansion of the national radiochemical base, increased availability of radiopharmaceuticals, and the integration of international safety and quality standards. At the same time, key challenges are identified, including a limited number of qualified specialists, insufficient laboratory and production infrastructure, and the need to develop regulatory frameworks and interdisciplinary collaboration among chemists, physicists, and medical professionals. Prospects for the development of nuclear medicine in Kazakhstan are associated with strengthening scientific infrastructure, expanding educational programs, introducing innovative radiochemical technologies, and integrating targeted therapy and theranostic approaches. A comprehensive strategy will enhance diagnostic accuracy, improve the effectiveness of cancer treatment, and ensure alignment of national practice with international standards in the field of precision oncology.

**Keywords:** Nuclear medicine, Oncology, Radionuclide therapy, Radiochemistry, Targeted therapy, Theranostics.

## INTRODUCTION

The article examines contemporary advances and the practical role of radiochemistry in the development of nuclear medicine for oncological therapy in Kazakhstan. Radiochemistry is an interdisciplinary field of science that enables the production, characterization, labeling, and rigorous quality control of radionuclide compounds used in the diagnosis, monitoring, and targeted therapy of malignant tumors. Innovative radiochemical approaches contribute to the development of radiopharmaceuticals with high specific activity, improved pharmacokinetic properties, and the ability to selectively target tumor cells while minimizing exposure to healthy tissues—one of the key principles of precision oncology (Tengrinews.kz, 2025)

The main medical radionuclides used in practical nuclear medicine include technetium-99m (Tc-99m), which is widely applied in scintigraphy and functional imaging; iodine-131 (I-131), used in the treatment of thyroid diseases and certain oncological conditions; lutetium-177 (Lu-177), employed in targeted therapy of neuroendocrine tumors and prostate cancer; and samarium-153 (Sm-153), which is effective for the palliative treatment of bone metastases (BMCUDP.kz, 2025a). These isotopes have demonstrated significant clinical value in numerous international studies due to their ability to provide selective action on pathological tissues with minimal radiation burden to the body (BMCUDP.kz, 2025b).

In Kazakhstan, the development of nuclear medicine is accompanied by the establishment of national capacities for the production and implementation of radiopharmaceuticals, the active use of PET/CT imaging techniques, and the adoption of international quality standards (GMP) in manufacturing processes. For example, innovative radiopharmaceuticals based on ^18F-PSMA for prostate cancer diagnostics and ^18F-FET for neuro-oncological studies are actively used in the country, indicating a transition toward more precise diagnostic protocols and an expansion of the range of clinical tasks addressed through nuclear medicine (Cherry et al., 2012; Bodei et al., 2019).

Despite the achievements attained, several challenges remain, including an insufficient number of qualified specialists, limited laboratory and production infrastructure, and the absence of a fully developed regulatory framework that complies with international safety and quality requirements for radiopharmaceuticals. Interdisciplinary collaboration among chemists, physicists, biomedical researchers, and clinicians is a key factor for sustainable development and for the integration of advanced radiochemical technologies into oncological practice.

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In clinical nuclear medicine practice, a limited yet well-characterized range of medical radionuclides is employed, with their selection determined by physical properties, radiation type, and feasibility of radiochemical labeling. Radionuclides used for diagnostic and therapeutic purposes differ substantially in half-life, radiation characteristics, and biological behavior, enabling optimization of both tumor visualization and therapeutic efficacy. Diagnostic radionuclides, such as technetium-99m, provide high-quality imaging while maintaining a low radiation burden, whereas therapeutic radionuclides, including iodine-131, lutetium-177, and samarium-153, enable selective destruction of malignant tissues. The comparative characteristics of the principal radionuclides applied in oncological nuclear medicine are summarized in table 1.

*Table 1. Current Status of Nuclear Medicine and Radiochemistry*

| Radionuclide | Physical half-life | Radiation type | Main clinical application | Radiochemical features | References |
|---|---|---|---|---|---|
| Tc-99m | 6.02 h | $\gamma$ | SPECT imaging, functional diagnostics | High labeling stability, generator-produced | (Sartor et al., 2004; Qaim, 2019) |
| I-131 | 8.02 d | $\beta^-$, $\gamma$ | Thyroid cancer therapy | Simple radiochemistry, high therapeutic efficacy | (Silberstein et al., 2012) |
| Lu-177 | 6.65 d | $\beta^-$, $\gamma$ | Theranostics (NETs, prostate cancer) | High target specificity, favorable dosimetry | (SilkwayTV, 2025; Tengrinews.kz, 2025) |
| Sm-153 | 46.3 h | $\beta^-$, $\gamma$ | Palliation of bone metastases | Strong bone affinity | (Wadsak and Hacker, 2010) |

Contemporary nuclear medicine encompasses a broad range of diagnostic and therapeutic technologies, the effectiveness of which is directly determined by the level of development of radiochemical methods. High accuracy in scintigraphic and tomographic imaging is achieved through stable radiolabeling procedures and high radiochemical purity of radiopharmaceuticals. At the same time, targeted radionuclide therapy requires not only an optimal selection of radionuclides but also reliable chemical conjugation with biological vectors that ensure selective accumulation in tumor tissues. A comparative overview of the major diagnostic and therapeutic nuclear medicine modalities from radiochemical and clinical perspectives is provided in table 2.

*Table 2. Radiochemical and clinical characteristics of nuclear medicine techniques*

| Technique | Diagnostic therapeutic role | Typical radionuclides | Role of radiochemistry | Clinical significance |
|---|---|---|---|---|
| SPECT | Diagnostic | Tc-99m | Stable and rapid radiolabeling | Functional imaging |
| PET/CT | Diagnostic | F-18, Ga-68 | High radiochemical purity | Early cancer detection |
| TRT | Therapeutic | Lu-177, I-131 | Targeted radionuclide delivery | Precision oncology |

The present study aims to provide a systematic analysis of the role of radiochemistry in the development of nuclear medicine in Kazakhstan, to assess the technological and clinical aspects of implementing radiopharmaceuticals in oncological therapy, to identify existing limitations, and to define prospects for the further scientific and practical development of this field.

### *Radiochemistry as the Foundation of Nuclear Medicine*

Radiochemistry underpins all stages of the radiopharmaceutical life cycle—from radionuclide production to clinical application. The key objectives of radiochemistry include the synthesis of stable radionuclide complexes, the achievement of high radiochemical purity, and compliance with radiation safety requirements (Jurisson and Cutler, 1999).

Of particular importance are the processes involved in labeling biologically active molecules with radionuclides, which enable the development of agents with high selectivity for tumor tissues. Modern radiochemical approaches involve the use of chelating agents, automated synthesis modules, and multi-level quality control systems, ensuring the reproducibility and safety of radiopharmaceuticals (Tengrinews.kz, 2025).

### *Key Radionuclides and Their Clinical Applications*

Tc-99m is the most widely used diagnostic radionuclide worldwide due to its short half-life and optimal gamma emission energy. It is extensively applied in bone, myocardial, and other organ scintigraphy procedures (Sartor et al., 2004).

I-131 is used for both diagnostic and therapeutic purposes in thyroid disorders, including differentiated thyroid cancer. Its therapeutic effect is primarily associated with beta radiation, which leads to the destruction of tumor cells (Silberstein et al., 2012).

Lu-177 is a cornerstone radionuclide in targeted radionuclide therapy and theranostics. It is employed in the treatment of neuroendocrine tumors and prostate cancer, demonstrating high therapeutic efficacy and a favorable safety profile (SilkwayTV, 2025).

Sm-153 is predominantly used for the palliative treatment of bone metastases, reducing pain and improving patients' quality of life (Wadsak and Hacker, 2010).

### *Current State of Nuclear Medicine in Kazakhstan*

Nuclear medicine centers equipped with PET/CT scanners and laboratories for the production of radiopharmaceuticals are actively developing in Kazakhstan. The implementation of international GMP standards has contributed to improvements in the quality and safety of radionuclide-based products. At the same time, challenges persist related to human resource capacity, infrastructure development, and the regulatory and legal framework governing nuclear medicine activities.

## MATERIALS AND METHODS

A comprehensive approach was applied for the analysis, including the following components:

1. A systematic literature review of national and international publications on radiochemistry, radiopharmacy, and the clinical application of radionuclides in oncology (Jurisson and Cutler, 1999; SilkwayTV, 2025).
2. An analysis of technological processes, including the production, labeling, and quality control of the radionuclides Tc-99m, I-131, Lu-177, and Sm-153, as well as the development of novel radiopharmaceuticals.
3. A clinical analysis based on data from national nuclear medicine centers, including the use of PET/CT, radionuclide therapy, and theranostics.
4. A comparative analysis of national and international protocols to identify gaps in infrastructure, workforce capacity, and regulatory frameworks.

This methodology enabled both qualitative and quantitative analyses, allowing the identification of achievements, limitations, and future prospects for the implementation of innovative radiochemical methods in oncological practice in Kazakhstan.

## DISCUSSION

The conducted analysis confirms that radiochemistry is a key scientific and technological driver in the development of nuclear medicine and modern oncological therapy. In the context of the global transition of oncology toward personalized and targeted treatment strategies, the importance of radiochemical research is steadily increasing, as it enables the development of radiopharmaceuticals with high molecular selectivity, optimized pharmacokinetics, and controlled radiation effects on tumor tissues (Jurisson and Cutler, 1999; Silberstein et al., 2012).

Modern radionuclides used in clinical practice demonstrate a clear evolution from predominantly diagnostic agents to multifunctional theranostic compounds. Tc-99m continues to play a fundamental role in routine nuclear diagnostics due to its favorable physicochemical properties and the well-established radiochemical infrastructure supporting its production (Qaim, 2019). I-131 remains a clinically significant therapeutic radionuclide, showing high efficacy in the treatment of differentiated thyroid tumors, thereby confirming the long-term sustainability of classical radionuclide approaches (Sartor et al., 2004). At the same time, the introduction of Lu-177 represents a qualitatively new stage in the development of nuclear medicine, enabling the implementation of the theranostic concept and supporting individualized therapy for neuroendocrine tumors and prostate cancer (SilkwayTV, 2025). The use of Sm-153 in the palliative treatment of bone metastases highlights the clinical and social significance of radionuclide methods aimed at improving the quality of life of patients with advanced oncological diseases (Tengrinews.kz, 2025).

The development of nuclear medicine in Kazakhstan demonstrates positive dynamics driven by the expansion of diagnostic capabilities, the implementation of PET/CT technologies, and growing interest in targeted radionuclide therapy. However, comparative analysis with leading international centers indicates the need for further strengthening of the radiochemical component, including localization of radiopharmaceutical production, development of high-efficiency labeling methods, and adoption of advanced quality control standards (Jurisson and Cutler, 1999; Wadsak and Hacker, 2010).

Systemic constraints include a shortage of specialized personnel, limited research infrastructure, and insufficient integration of fundamental radiochemical research into clinical practice. Of particular importance is the harmonization of national regulatory frameworks with IAEA recommendations and GMP requirements, which is a critical condition for ensuring radiation safety and clinical reproducibility of radiopharmaceuticals (Sartor et al., 2004; Bodei et al., 2019).

Looking ahead, a key direction for development is the transition from import-dependent technologies to the establishment of a national radiochemical and radiopharmaceutical platform focused on the development of next-generation theranostic agents. This will not only increase the accessibility of high-technology oncological care but also facilitate Kazakhstan's integration into the international scientific and clinical community.

## CONCLUSION

Radiochemistry represents the fundamental basis for the sustainable development of nuclear medicine and the implementation of innovative methods for the treatment of oncological diseases in Kazakhstan. It provides the complete radiopharmaceutical development cycle—from the production of medical radionuclides and their chemical modification to clinical application and quality control. The use of radionuclides such as Tc-99m, I-131, Lu-177, and Sm-153 confirms the high effectiveness of radionuclide technologies and their alignment with contemporary principles of precision oncology. This review demonstrates that Kazakhstan has significant potential for the further development of nuclear medicine, including the expansion of clinical applications of theranostic approaches, the advancement of PET/CT diagnostics, and the integration of international quality and safety standards. At the same time, realization of this potential requires systematic strengthening of the radiochemical scientific base, training of highly qualified specialists, and active interdisciplinary collaboration between scientific and clinical institutions. Future development of nuclear medicine in Kazakhstan should be oriented toward the introduction of innovative radiochemical technologies, localization of radiopharmaceutical production, and participation in international research programs. A comprehensive and strategically coordinated approach will enhance the effectiveness of oncological care, improve patient prognosis and quality of life, and ensure sustained alignment of the national healthcare system with global standards of high-technology medicine.

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## CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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