Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное образовательное учреждение
высшего образования

**«НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»**

Направление подготовки/профиль: 14.06.01 Ядерная, тепловая и возобновляемая энергия и связанные с ними технологии**,** 2.4.9. Ядерные энергетические установки, топливный цикл, радиационная безопасность (на английском языке)
Школа: Инженерная школа ядерных технологий
Отделение:Научно-образовательный центр международного ядерного образования и карьерного сопровождения иностранных студентов

Научно-квалификационная работа

Тема научно-квалификационной работы
Исследование режимов работы энергетического ядерного реактора со спектральным регулированием для повышения глубины выгорания топлива

УДК __________

Аспирант

Группа	ФИО	Подпись	Дата
А9-43И	Элзаят Тарек Тауфик Хассан		

Руководителя профиля подготовки

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Директор ИЯТШ	Долматов О.Ю.	к.т.н., доцент		

Руководитель отделения

Должность	ФИО	Ученая степень, звание	Подпись	Дата
И.о. зав. каф. – руководитель НОЦ ЦМЯО на правах кафедры	Верхотурова В.В.	к.ист.н.		

Научный руководитель

Должность	ФИО	Ученая степень, звание	Подпись	Дата
	Чертков Ю.Б.	к.т.н., доцент		

Томск – 2023 г.

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Field of training (specialty): 14.06.01 Nuclear, Thermal and Renewable Energy and Related Technologies, 2.4.9. Nuclear Power Facilities, Nuclear Fuel Cycle, Radiation Safety (in English)
School: Nuclear Science & Engineering
Division: Research and Training Centre for International Nuclear Education and Career

Scientific qualification work

Title
Study of operating modes of a power nuclear reactor with spectral shift control methods to increase fuel burnup

UDC ___________

PhD student

Group	Full name	Signature	Date
А9-43и	Elzayat Tarek Tawfik Hassan		

Programme Director

Job position	Full name	Academic degree, academic rank	Signature	Date
Director of Nuclear Science & Engineering School	Oleg Yu. Dolmatov	Candidate of Science, associate professor		

Research and Training Centre for International Nuclear Education and Career

Job position	Full name	Academic degree, academic rank	Signature	Date
Head of Research and Training Centre for International Nuclear Education and Career	Vera V. Verkhoturova	Candidate of Science, associate professor		

Scientific supervisor

Job position	Full name	Academic degree, academic rank	Signature	Date
	Chertkov Yury Borisovich	Candidate of Science, associate professor		

Tomsk– 2023.

Abstract

In view of the anticipated oncoming decrease/increase in the projected supply/demand in nuclear fuel market due to finite nuclear fuel resources, the low efficiency of fuel utilization in current LWRs and the small scale of deployment fast breeder reactors, the conventual LWRs design will require significant improvements that should be retrofitted for a near-term deployment. These required improvements imply evolving from the current LWRs design to more advanced nuclear reactor designs which has high fuel burnup levels (high energy extracted per fuel cycle thereby prolog fuel cycle length) and high conversion ratio values (high accumulation of the secondary fuel, Pu content) along with retaining the same safety features as in conventual LWRs. This study proposes an innovative design for LWRs that has the potential to extending fuel burnup and enhance the conversion ratio value simultaneously with retaining the same safety features as in standard LWRs. Accordingly, we applied alternative method to compensate for fuel excess reactivity through shifting the neutron energy spectrum over fuel operating cycle, the so-called the spectral shift-controlled reactor (SSCR). The SSCR can improve utilization of nuclear fuel through eliminating, or at least significantly reducing the traditional poison-controlled methods (control rods, soluble and burnable absorbers) during the operating cycle. In the SSCR, long-term reactivity control is carried out through productive absorption of excess neutrons via resonance radiative capture (n,γ) in fertile fuel isotopes rather than parasitic absorption in neutron absorbing poisons methods (control rods, soluble and burnable absorbers). In such a way that at the beginning of cycle (BOC) with a high initial excess reactivity, the neutron spectrum is hardened with high neutron density in the resonance energy range wherein resonance escape probability has lowest values. Subsequently, towards the end of fuel cycle (EOC), the spectrum is softened, shifted downward to thermal energy range, with highest resonance escape probability values. This allows excess neutrons at BOC to be captured primarily in ^{238}U or ^{232}Th and hence breeding more ^{239}Pu and ^{241}Pu or ^{233}U for uranium or thorium-based fuel cycles, respectively. At the same time, providing the same amount of negative reactivity worth that standard soluble and burnable poisons would have to compensate the initial excess reactivity of the fresh fuel at BOC. Research subject included study of

operating modes of a power nuclear reactor with spectral shift control (SSC) methods to increase fuel burnup. The investigation included implement the SSC concept chemically (D_2O/H_2O) and mechanically (V_M/V_F) for the OECD/NEA computational benchmark model of VVER-1000 with low enriched uranium (LEU) fuel assembly. Among various neutronic characteristics, focus herein is put mainly on the variation of fuel reactivity of the SSC methods and the associated void coefficient values throughout fuel cycle. Since the former is a determinant for fuel assembly neutron economics and the latter is influential in its safety characteristics. The obtained results showed that SSC design have achieved the three main aims simultaneously over the traditional poison reactivity control method which included: suppressing the excess reactivity of fresh fuel with, even having, a higher negative reactivity worth than H_3BO_3 and Gd_2O_3, improving reactor conversion ratio, and enhancing discharge burnup during one batch fuel cycle scheme. As a result, longer fuel cycle length with a few number of batches scheme can be realized with the mechanical NU-SSCRs design for reducing the downtime for refueling thereby raising the capacity factor. While for poison reactivity control methods, the same approach would be required increase of poisons content which will lead to reducing the conversion ratio, cycle length and further increase in fuel enrichment requirements.